Oifig na nOibreacha Poiblí
The Office of Public Works

Lower Lee (Cork City) Flood Relief Scheme
(Drainage Scheme)

Supplementary Report
Option of Tidal Barrier

230436-00
December 2017

ARUP

Office of Public Works

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Contents

References

Tables

Figures

Appendices

Executive Summary

The Lower Lee Flood Relief Scheme (LLFRS) was commissioned by the Office of Public Works (OPW) with the objective of delivering a flood relief scheme for Cork City and environs to provide protection against the 1 in 100 year fluvial/1 in 200 year tidal flood events.

The project followed on from the pilot Lee Catchment Flood Risk Assessment and Management Study (CFRAMS) which identified the preferred scheme as being a combination of a flood forecasting and warning system, optimised dam operating procedures to reduce and control flows passed down into the Lower Lee catchment and raised waterside defences.

Following extensive study and assessment, a proposed scheme has been developed which consists of a modified version of the above measures together with a flow control structure on the south channel to rebalance flows between the north and south channels.

The proposed scheme was subsequently brought to Statutory Exhibition stage through the Arterial Drainage Act (as amended) in late 2016/early 2017.

During the exhibition stage, members of the public were invited and encouraged to submit their views in relation to the exhibited Scheme. As part of the process, a significant number of submissions were received querying whether a tidal barrier in Cork harbour offered a viable alternative to the proposed scheme, and in particular as a longer term solution in the face of climate change.

The option of a tidal barrier was considered both as part of the Lee CFRAMS and the Lower Lee FRS and was screened out as not being viable. It scored worse than the other alternatives considered in terms of technical, environmental and economic criteria. It had an extremely negative benefit cost ratio (BCR).

However, as a result of the number of submissions received, it became clear that it would be in the public interest to provide further detail and explanation as to why a tidal barrier had been screened out and was not currently a viable alternative.

This report provides this further information by setting out the key requirements for any potential barrier, potential locations, key constraints and considerations, likely impacts, likely costs, and comparison against the proposed scheme. It addresses, at an appropriate level of detail, the queries raised at exhibition, by considering at an outline (concept) level, all of the key requirements and constraints for a tidal barrier in Cork.

The findings of the report are considered to be robust, in terms of short to medium term decision making with respect to the best solution to alleviate flood risk in Cork.

Four locations for a tidal barrier were considered as follows:

- Jack Lynch Tunnel
- Downstream of Lough Mahon at Little Island (as put forward by a stakeholder group)

- Either side of Great Island at Monkstown and Marlogue
- Roche's Point.

The Jack Lynch Tunnel can be ruled out as technically unviable as it has insufficient storage upstream even in the current scenario, a situation which would worsen with climate change.

The Roche's Point location would require a barrier significantly deeper than any barrier in the world in a deep harbour in an area of high velocities. It could cost up to twice that of a barrier either side of Great Island. Whilst it would be imprudent to rule it out as a possible future solution for Cork, it is probable that it would be a solution of last resort, only in the scenario where climate change impacts were such that a barrier at Great Island became technically unviable.

A suitably designed tidal barrier at the Little Island location, with larger gates than proposed by the stakeholder group, may be technically viable in the current scenario. However this solution has limited storage and thus would have a shorter lifespan than the Great Island barrier in the face of climate change.

Whilst potentially technically viable at present, the Little Island site has many challenges in terms of being able to bring the project through a statutory approvals process and construction. It is located immediately adjoining both an SAC and SPA and so there are significant environmental hurdles which would have to be addressed. There is potential for significant changes in geomorphology, navigation and marine amenity.

Whilst the location of the barrier as proposed by the stakeholder group is potentially viable, the barrier components and budget cost as set out by the stakeholder group are not viable in their current format.

The barrier alignment, geometry, gate sizes etc. as proposed by the stakeholder group are all unsuitable and would require significant modification. A suitably designed barrier at this location (tidal only defence scheme) would likely cost in the order of €990m (Net Present Value cost). It is also worth noting that there is a significant risk that this cost would increase if a greater width of gates were needed across the 1km stretch of channel, for navigation, environmental or other reasons.

When combined with fluvial defences as proposed in the exhibited Scheme, such a solution would have a combined BCR of 0.2 and therefore is clearly not cost beneficial.

Crucially, it is evident that a tidal barrier at the Little Island location only becomes economically viable if sea level rise of circa 500mm arises. However, in this Mid-Range Future Scenario (MRFS) for climate change, its location means that it would start to become technically unviable at a similar point in time due to the limited upstream storage capacity. It therefore does not represent a viable short to medium term option and in all likelihood may well not represent the best medium to long term option.

Tidal barriers at Great Island have also been considered. A tidal barrier either side of Great Island has sufficient upstream storage to cater for sea level rise of 1m or more, as well as increases of 30% or more in river flows. Technically, it therefore represents a better long term solution in the face of climate change.

However, because of the narrowness of the channels at either side of Great Island, any barrier at this location would need to maintain flow across the full width of the existing channel to ensure continued safe navigation, reasonable velocities, and minimise changes in geomorphology.

Gates across the full width have the negative effect of significantly increasing cost but has the positive of minimising the risk of negative impacts on the SAC and SPA which are located a reasonable distance from the barrier locations. A barrier at Great Island (tidal only defence scheme) is estimated to have a Net Present Value (NPV) cost of circa €1.73bn.

It is also worth noting that at present, the Mean High Water Spring Tide is circa 1.9mOD. With 1m of sea level rise, this would increase to circa 2.9mOD which is above the current threshold of flooding in the city. A tidal barrier would therefore be required to close over 400 times a year to prevent flooding of the City by Spring tides in the High End Future Scenario (HEFS). Even in the MRFS the barrier would need to be closed approximately 100 times a year to protect the city. These closures would be in addition to any closures required to defend the city against storm surge events that present a risk of tidal flooding. Such a high frequency of closures would have a dramatic impact on navigation and the environment and would significantly increase the operational cost of such a barrier. Increasing the threshold of flooding in Cork from 2.5mOD to 3.4mOD by low level direct defences (as proposed in the exhibited scheme) would have the benefit of increasing storage upstream of a barrier, reducing the frequency (and cost) of operation of the barrier and minimising the impact on navigation and on the environment. It is therefore evident that a viable tidal barrier solution (if and when the need arises) will require to be undertaken in conjunction with low level direct defences in Cork city.

As well has having a very negative BCR, multi-criteria assessments carried out as part of the Lee CFRAMS and this study have both established that the exhibited scheme scores better than a tidal barrier scheme across all the criteria of technical, social, environment and economic.

The following can therefore be concluded:

- Low level Direct Defences in Cork (as per the exhibited Scheme) are the optimum solution for Cork to meet the short and medium term needs of the city.
- Such defences are the first step in a climate change strategy to manage flood risk in Cork and will form a key component of any future tidal barrier system. This is similar to the tidal defences for London where raised riverside walls were first enforced in 1898 followed by legislation for a Barrier in 1970, and also in Venice where river side “insular walls” were built and raised in increments before the significantly more expensive tidal barrier commenced as a longer term option. In both London and Venice, the barrier closure operations are assisted by the earlier riverside raised defences which were already in place.

- A tidal barrier is not currently viable and will not likely become viable for approximately 50 years or more. This eventuality is so far in the future and the timing so uncertain that it should not unduly influence decision making at this time.
- If and when a tidal barrier becomes viable, the optimum location is likely to be at Great Island, but a full and detailed feasibility study of the options would have to be undertaken at that point in time.

1 Introduction

1.1 Background and Context

The Lower Lee Flood Relief Scheme (LLFRS) was commissioned by the Office of Public Works (OPW) with the objective of delivering a flood relief scheme for Cork City and environs to provide protection against the 1 in 100 year fluvial / 1 in 200 year tidal flood events.

The project followed on from the pilot Lee Catchment Flood Risk Assessment and Management Study (CFRAMS) which identified the preferred scheme as being a combination of a flood forecasting and warning system, optimised dam operating procedures to reduce and control flows passed down into the Lower Lee catchment and raised waterside defences.

Following extensive study and assessment, a proposed scheme has been developed which consists of a modified version of the above measures together with a flow control structure on the south channel to rebalance flows between the north and south channels.

The proposed scheme was subsequently brought to Statutory Exhibition stage through the Arterial Drainage Act (as amended) in late 2016/early 2017.

Details of the scheme were available for inspection to members of the public between the 12 December 2016 and the 20 January 2017 at four locations around Cork City. The Scheme has also been available to view online on the project website www.lowerleefrs.ie. Submissions were invited up to the 7 April 2017.

During the exhibition stage, members of the public were invited and encouraged to submit their views in relation to the exhibited Scheme. As part of the process, a significant number of submissions were received querying whether a tidal barrier in Cork harbour offered a viable alternative to the proposed scheme, and in particular as a longer term solution in the face of climate change.

The option of a tidal barrier was considered as part of the Lee CFRAMS and was screened out on a number of grounds. It had an extremely negative benefit cost ratio (BCR) and also scored worse than the other alternatives considered in terms of the environment, technical robustness etc.

Whilst it was not part of the Brief for the Lower Lee FRS to reassess in detail the merits of a tidal barrier, it was considered again at a high level as part of the screening of potential options and was again screened out as the findings of the Lee CFRAMS were deemed to remain valid.

However, as a result of the number of submissions received, it became clear that it would be in the public interest to provide further detail and explanation as to why a tidal barrier had been screened out and was not currently a viable alternative.

OPW has therefore instructed Arup to prepare a report (equivalent in detail to a pre-feasibility report) setting out the key requirements for any potential barrier, potential locations, key constraints and considerations, likely impacts, likely costs and comparison against the proposed scheme.

The Lee CFRAMS considered 3 possible locations for a barrier at the following locations:

- Jack Lynch Tunnel
- Great Island - Monkstown and Marlogue Point
- Roche's Point

During the Exhibition process, a stakeholder group submitted a proposal for an alternative location at Little Island, downstream of Lough Mahon, suggesting that this along with some upstream measures offered a better alternative and could be delivered for similar costs to the exhibited Scheme. This proposal has been reviewed in this report.

Subsequently, HR Wallingford (HRW) were commissioned by the stakeholder group to prepare a cost estimate of its concept proposal. The HRW report whilst providing an estimate noted that significant further detailed studies would be required to define a suitable barrier, correctly noting that the cost estimate was extremely sensitive to the required gate sizes.

This report aims to review information on all potential tidal barrier locations and to assess the suitability of the different solutions on the basis of cost, technical, environmental and social impacts. It has considered all of the key issues raised by HRW as requiring further study.

Figure 1 below provides an overview map of Cork Harbour identifying the potential locations of the tidal barriers considered in the Lee CFRAMS study together with the location proposed by the stakeholder group. (The tidal barrier option at the Great Island includes two barriers, one either side of the island to prevent flood water bypassing one or the other barrier.)

Figure 1: Potential Tidal Barrier Locations in Cork Harbour

1.2 Scope and Limitations

The scope of this report includes the following:

- Review and consider submissions received at Statutory Exhibition Stage in relation to a tidal barrier
- Review of the stakeholder group proposal entitled the 'Three Point Plan' together with the HRW Cost Estimate
- Review of Lee CFRAMS findings in relation to a tidal barrier
- Establish the requirements for a barrier (in terms of flood risk, peak velocities, navigation and navigational safety, sedimentation and erosion, upstream storage, environmental and other constraints etc.)
- Establish potentially suitable/viable locations for a tidal barrier
- Consider the possible barrier types, i.e. what form would it take
- Consider the merits of a barrier versus the exhibited scheme (if any)
- Consider when a barrier will be required and how long will it last in the face of climate change
- Consider what are the likely construction and long term maintenance and operation costs
- Consider what impacts a barrier will have and what mitigation measures would be needed
- Undertake a cost benefit analysis and high level multi criteria analysis of potentially viable barriers and compare against the exhibited scheme
- Consider what further studies, investigations, surveys and consents would be required to deliver a barrier

As a result of its nature, scale and complexity, the development of a single scheme design for a tidal barrier, and a corresponding detailed cost appraisal is simply not possible at this scale of study. Therefore, this study has sought to address, at an appropriate level of detail, the queries raised at exhibition, by considering at an outline (concept) level, all of the key requirements and constraints for a tidal barrier in Cork. A concept design has been developed to aid consideration of the key issues, and to undertake a top down assessment of likely costs by reference to other comparable international barriers of a similar nature and scale.

However, if a barrier were to be constructed in the future, significant further surveys, investigations, consultation etc., would be required to finalise the optimum location and design. Notwithstanding this, the findings of the report are considered to be robust, in terms of short to medium term decision making with respect to the best solution to alleviate flood risk in Cork.

1.3 Datums

This report contains numerous references to the vertical elevation (or level) of items such as flood levels, barrier crest levels etc.

In Ireland, various reference levels, known as datums are used to allow comparison against a consistent reference point. Of particular relevance to Cork are Cork Harbour Chart Datum, Ordnance Datum Poolbeg (Dublin) which was historically the main datum and nowadays Ordnance Datum Malin Head.

For consistency, all vertical elevations (or levels) referred to in this report are to Ordnance Datum Malin Head, unless noted otherwise.

To convert levels from Malin Head Datum to the other datums the following conversions can be applied:

- To convert to Poolbeg Datum, add 2.701m to quoted levels.
- To convert to Cork Harbour Chart Datum, add 2.58m to quoted levels.

2 Barrier Requirements

2.1 General Principle of a Tidal Barrier

A tidal (or storm surge) barrier is a fully or partly moveable barrier structure which is located across a river or estuary. It can be closed temporarily to limit water levels behind the barrier to reduce the frequency and severity of fluvial and/or tidal flooding. During normal conditions, the barrier is kept open to allow for tidal exchange and navigation.

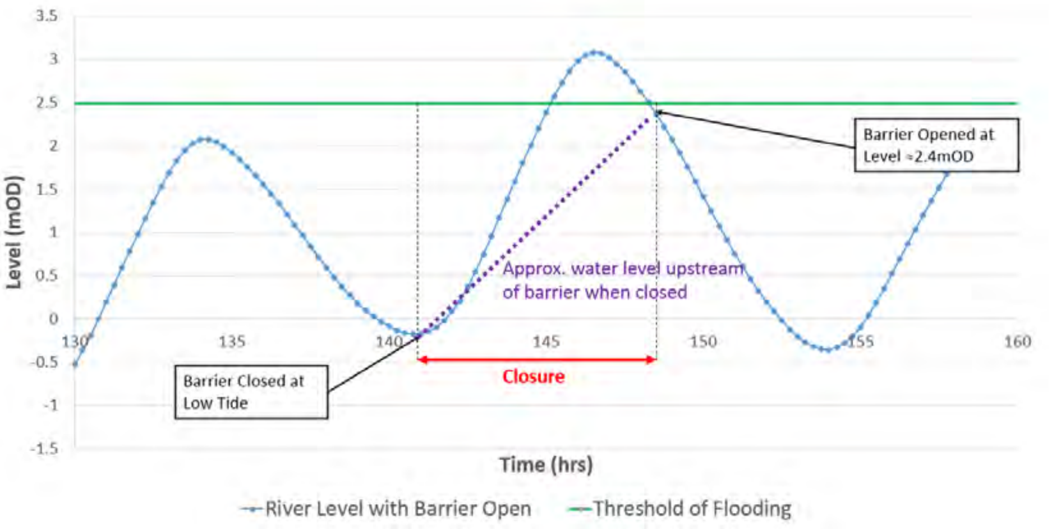
A tidal barrier in Cork Harbour would need to operate both during tidal and fluvial flooding events. It would be closed in advance of predicted high sea level conditions, such as spring tides and storm surge, in order to protect low lying land adjacent to the estuary and river, including Cork city. In addition, it would also be closed in anticipation of flood conditions in the River Lee and would exclude the inflow of an incoming tide to maintain lower river outfall levels and reduce the severity of fluvial flooding.

During both the tidal and fluvial flood events, the general barrier operating procedure would be as follows:

- Barrier gates would be closed at (or shortly after) low tide, in advance of a predicted flood event,
- Water level at the sea side of the barrier would rise with the tide and storm surge (in the tidal event preventing tidal flooding in the city),
- Water level behind the barrier (in the estuary) would slowly rise due to river inflow (in the fluvial event allowing space for the river inflow)
- When the level at sea drops below the level behind the barrier, the barrier gates would be opened to release water stored in the estuary, and closed again at the next low tide if necessary,
- This would be repeated until the event has ended.

This process is schematised in Figure 2 below.

Figure 2: Schematic of Barrier Operation Philosophy



2.2 Tidal and Storm Surge Range

When considering a tidal barrier, the normal tidal range and levels, together with potential extreme water levels are the key parameters, as they dictate the required crest level of the barrier, the potential depth of flow gates, influence depths for navigation, influence peak flows, and will be a key driver of the type of barrier required.

The normal tidal range in Cork varies from circa 2m during neap tides to 4m during spring tides.

In Cork City for example, Mean Low Water Spring tide (MLWS) and Mean High Water Spring tide (MHWS) are circa -1.97mOD and 1.93mOD respectively.

The equivalent neap tides are -0.97mOD and 1.03mOD.

The tidal range varies within Cork Harbour and higher tide levels are experienced in the inner harbour at Cork City as a result of the geometry of the harbour and the amplification of surge in the estuary together with the effects of fluvial flows.

Typically water levels in the outer harbour at Cobh/Ringaskiddy are 300mm lower than in Cork city.

The predicted 1 in 200year tide level in Cork City is circa 2.98mOD reducing to circa 2.68mOD at Cobh.

2.3 Sea Level Rise

The Lee CFRAMS Study established that the Mid-Range Future Scenario (MRFS) and the High End Future Scenario (HEFS) projections for sea level rise and land settlement by 2100 are 550mm and 1050mm, respectively.

Applying these figures to the existing tide levels, we can expect future extreme tide levels in Cork Harbour to be in line with the levels presented in Table 1 below. The figures for Little Island are interpolated between Tivoli and Cobh.

Table 1: Predicted Water Levels Including Sea Level Rise

Details	**Cork City (Tivoli)**	**Little Island (Interpolated)**	**Cobh**	**Remark**
	mOD	mOD	mOD	
Predicted Maximum Water Levels 1/200 year (current)	2.98	2.83	2.68	Current Scenario (excluding Climate Change)
Predicted Maximum Water Levels 1/200year with MRFS Climate Change	3.53	3.38	3.23	MRFS
Predicted Maximum Water Levels 1/200year with HEFS Climate Change	4.03	3.88	3.73	HEFS
Freeboard	0.5	0.5	0.5	Figures adopted in Lee CFRAMS and used in this report. Higher freeboard required than for city defences due to freeboard required for wave action.
Minimum Top of Barrier Level / Crest Level for current scenario	3.48	3.33	3.18	Current
Minimum Top of Barrier Level / Crest Level for MRFS	4.03	3.88	3.73	MRFS
Minimum Top of Barrier Level / Crest Level for HEFS	4.53	4.38	4.23	HEFS

The Lee CFRAMS established that a tidal barrier at Great Island may start to become cost beneficial if sea level rise of circa 315mm arose, anticipating that this scenario may arise between 2050 and 2075. However, we would note that this was premised on an estimated barrier NPV cost of €341m. We would note that this is likely to be a significant underestimate of the cost and so, it would likely require an even greater level of sea level rise to be cost beneficial, i.e. closer to the MRFS of 0.5m of sea level rise.

A tidal barrier by its nature does not lend itself easily to being modified in the future to cater for climate change, and so differs from the exhibited scheme in this regard.

Therefore, if an investment in a tidal barrier were to be considered at this time, it is imperative that the location, type and constructed level are considered not only in the short term, but also in terms of suitability and adaptability for the longer term.

Therefore, the barrier location has been considered on the basis of the requirement for the HEFS, i.e. allowing for reasonable further increases in sea level rise beyond the MRFS which is the point at which a tidal barrier may start to become economically viable.

Details and costings of possible barriers have been considered for both the current scenario and HEFS for elements which can be easily adapted in the future, and for HEFS only where the element would need to be constructed for the future level at the present time. Such elements cannot cost effectively be adapted in the future.

As well as impacting design flood levels, in the context of a tidal barrier, it is also worth noting that the current MHWS level in Cork City is circa 1.93mOD while the MHWN is circa 1.03mOD. If sea level rise of 1m arose (i.e. in HEFS), this would increase to circa 2.93mOD and 2.03mOD respectively.

In such a scenario, in the absence of complimentary raised waterfront defences in Cork City, barrier closures would be required very regularly (over 400 times a year) as the threshold of flooding would be exceeded whenever the peak water level exceeds 2.5mOD. This would have a very significant negative impact on navigation, recreation and environmental receptors and as the long term operation of the barrier. This point is discussed further later in this report.

2.4 Required Operating Philosophy

In order to consider the likely effects and impacts a tidal barrier would have in Cork Harbour, it is necessary to understand the required operation philosophy of a tidal barrier. This section of the report investigates the current and future scenarios of when the barrier would open and close to deal with high tide/flooding scenarios.

Under present day conditions, the barrier would close only a few times a year while under future scenarios and as the effects of climate change are realised, this number would increase proportionately in response to the corresponding increase in mean sea levels.

As discussed in the Lee CFRAMS study, a tidal barrier will need a tidal flood forecasting system so that the flood protection scheme is robust and to give advance warning to users of the harbour (maritime vessels / shipping).

The relevant tide levels applicable at Little Island/Great Island has been estimated by interpolating between Tivoli Docks and Cobh.

The required crest level of a tidal barrier has been assumed to be 4.38mOD allowing for a 1 in 200 return period tide level, a 1.05m rise in sea level for the HEFS and a 0.5m freeboard.

2.4.1 Current Conditions

In the current scenario, the barrier would be closed predominantly to protect from tidal flooding at times of high tides and storm surges. A typical daily tidal peak of circa 1.9mOD occurs in Cork City under spring tide conditions (excluding storm surge and without significant fluvial flows) so the barrier would not need to close at this tide level.

The barrier could also be closed during extreme fluvial events to reduce the downstream tidal boundary in Cork City and thus reduce the fluvial flood levels through the eastern part of the city.

It has been observed that the threshold of flooding to Cork City centre is circa 2.4mOD to 2.5mOD. This is based on the ground levels adjacent to the quay at South Terrace/Morrison's Island, which is the first location where tidal flooding occurs in the city. Therefore, in the absence of direct defences in the city, it would be necessary to operate the barrier when the tide level is expected to exceed 2.5mOD.

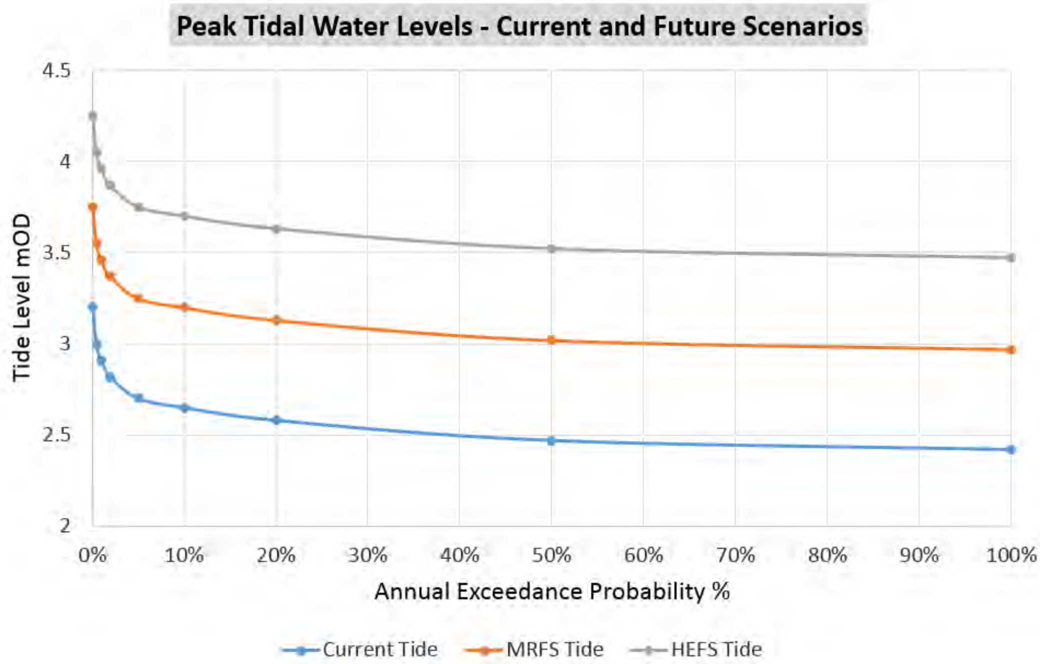
We note however that water can escape the channel at elevations lower than 2.5m OD but this only results in minor localised ponding of water adjacent to the South Channel and does not lead to any significant flooding of the city.

Based on peak tidal levels for the current scenario, as presented in the Lee CFRAMS study, a design water level of 2.47mOD will on average be reached once every 2 years.

Table 2: Peak Tide Levels in Cork City

Peak Tide Levels - Current and Future Scenarios									
Annual Exceedance Probability (AEP)	**100%**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**	**0.5%**	**0.1%**
Current	2.42	2.47	2.58	2.65	2.70	2.82	2.91	3.00	3.20
MRFS	2.97	3.02	3.13	3.2	3.25	3.37	3.46	3.55	3.75
HEFS	3.47	3.52	3.63	3.7	3.75	3.87	3.96	4.05	4.25

Figure 3: Peak Tide Levels in Cork City

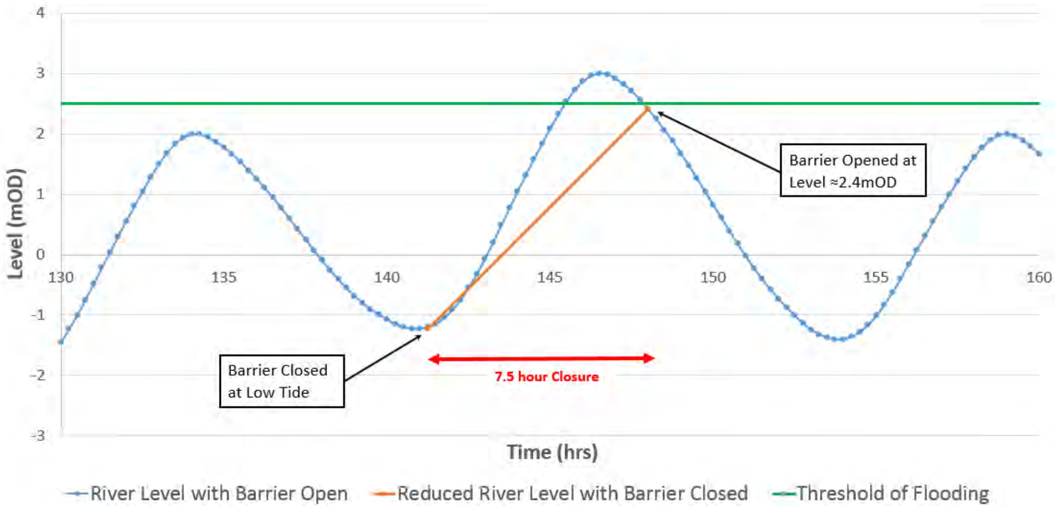


A potential tidal barrier located at Great Island was tested as part of the Lee CFRAM Study for both current and future scenarios and concluded that under current conditions, the barrier would close at a minimum of once every 2 years and typically remain closed for between 4 and 9 hours during a storm event depending on the timing of closure with respect to the tidal cycle.

2.4.1.1 Tidally Dominated Event

Figure 4 below shows the tidal cycle for the 1 in 200year extreme tide level (astronomical tide plus surge event) in Cork City for the current scenario.

Figure 4: Extreme Tidal Cycle for 1 in 200year event (1.95m astronomical peak with 1.05m surge)



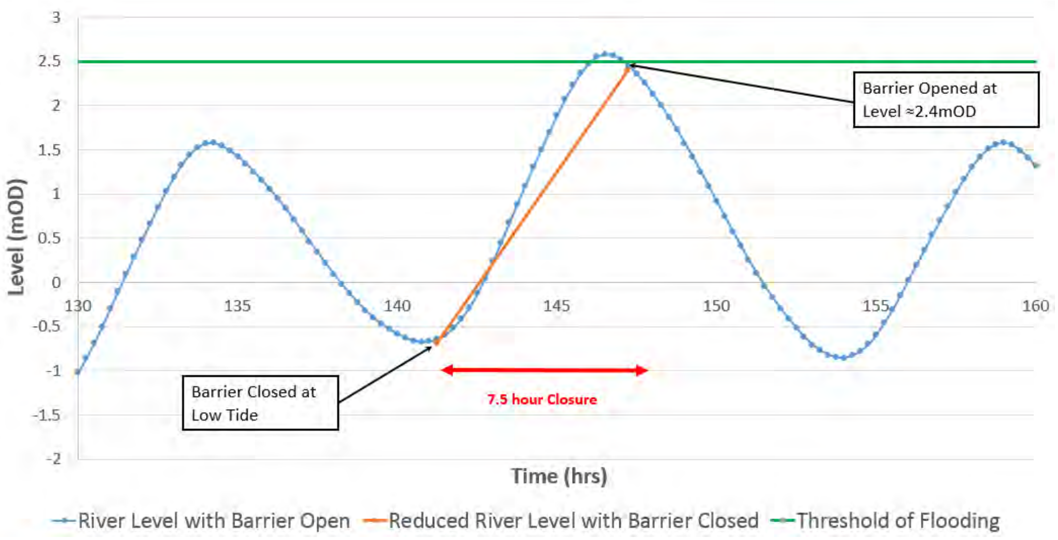
The duration of the tidal cycle is approx. 12.5 hours and the tidal amplitude is circa 4m.

If the barrier is closed at the preceding low tide level of circa -1.22mOD and reopened when the sea level is less than the threshold of flooding in Cork (taken at circa 2.4mOD), the barrier closure tie would be 7.5 hours (excluding the actual time taken to fully open and close the barrier). Therefore, allowing 1 hour for opening and closing, sufficient upstream storage would be required for an 8.5 hour period for incoming flow. This storage volume would be required between the low tide level of -1.22mOD and the threshold of flooding in Cork, taken as 2.4mOD. (Note: Low tide will vary.)

2.4.1.2 Fluvially Dominated Event

Figure 5 below shows a 1 in 5 year tidal event in Cork. This tide in conjunction with the 1 in 50 year fluvial event is within the design envelope of the scheme and would need to be catered for, and hence would require a barrier closure. We note that the tidal amplitude considered in this scenario is 3m which will reduce the volume of available storage upstream of the barrier. The tidal elevation when the barrier is closed will be higher than the case of a 4m amplitude tide.

Figure 5: Theoretical Tidal Cycle for 1 in 5 year event (1.45m astronomical peak with 1.05m surge)



If the barrier is closed at the preceding low tide level of circa -0.7mOD and reopened when the sea level is less than the threshold of flooding in Cork (taken at 2.4mOD), the barrier closure time would be 7.5 hours (excluding the actual time take to fully open and close the barrier).

Therefore, allowing 1 hour for opening and closing, sufficient upstream storage would be required for an 8.5 hour period for incoming flow. This storage volume would be required between the low tide level of -0.7mOD and the threshold of flooding in Cork, taken as 2.4mOD.

As the storage available in this case will be less than in the tidally dominated case (because of same duration but higher river level at the point in time at which the barrier is closed) and is combined with a larger fluvial event, it will be the critical case to be considered as regards evaluating upstream storage. This evaluation is done in Chapter 5 when considering the potential barrier locations.

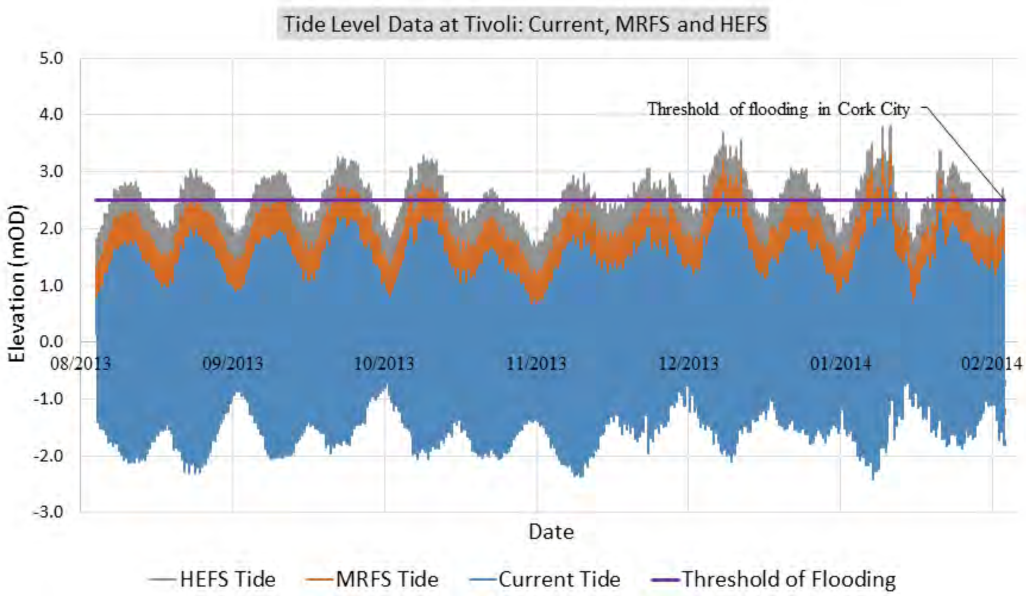
2.4.2 Future Scenarios

The frequency of barrier closures in the future will be related to the extent and rate of sea level rise and the frequency of storm surge events. If the existing threshold of flooding in the city remains the same at circa 2.5mOD (i.e. in the absence of direct waterfront defences in Cork City), the frequency of barrier closures will increase in the future. This increase will correspond to sea level rise and the frequency of storm surge events in the harbour.

In the HEFS (mean sea level increase of 1.05m), a MHWS water level of circa 2.9mOD in Cork City would lead to extensive flooding of Cork City given the current threshold of flooding. Even without the occurrence of a storm surge event in Cork Harbour, the city could be extensively flooded by a spring tide. Without direct waterfront defences in the city, a tidal barrier would need to be closed twice a day during spring tide conditions to defend the city against the tide. The HEFS would therefore result in a considerable number of barrier closures before, during and after spring tide conditions which typically last a number of days. It is estimated that the closure time would need to be somewhere between 5 and 9 hours per tidal cycle, (or between 10 and 18 hours per day). Such a scenario, would fundamentally alter the use of the harbour in terms of shipping and use of pleasure crafts. It is also likely to have very significant effects on the SAC and SPA designated areas in Cork Harbour, including effects on harbour flows and velocities, sediment transport and salinity. The repeated closures would also involve considerable cost.

Figure 6 presents recorded data from Tivoli Docks for a six month period between September 2013 and March 2014. In order to illustrate the likely impact on water levels in the MRFS and HEFS, 0.55m and 1.05m have been added to the recorded data respectively and are also presented in the plot.

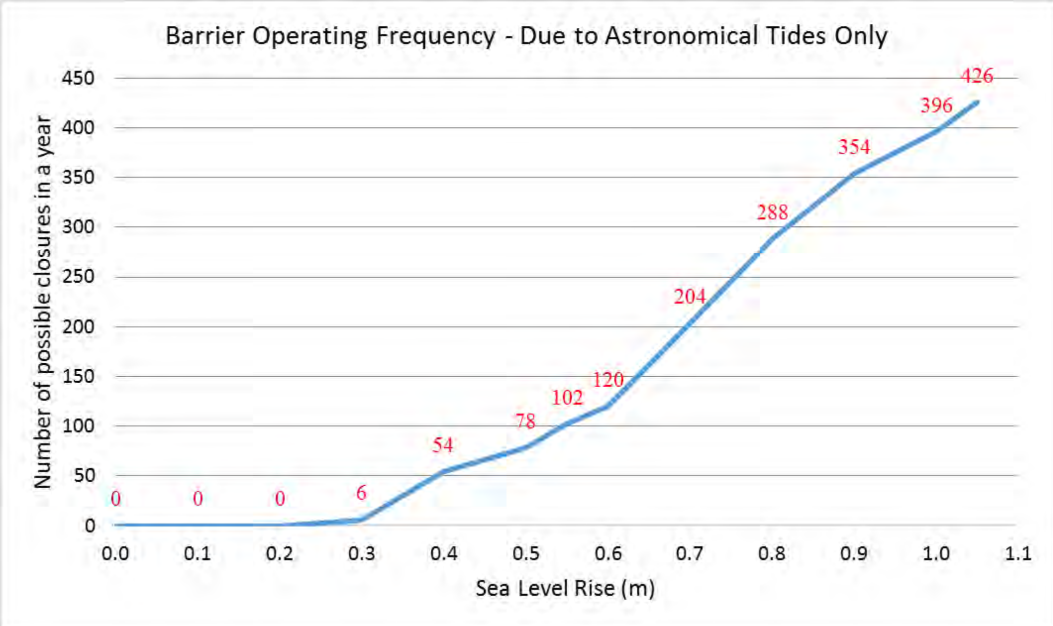
Figure 6: Tide level data for Tivoli for recent 6 month window sample, amended to account for sea level rise



It can be seen from Figure 6 that the threshold of flooding in the City was exceeded four times between January and February 2014. During this period an unusually high number of severe Atlantic Storms hit Ireland in relatively quick succession causing extensive damage and coastal flooding in various parts of the country.

It can also be seen from Figure 6 that in the absence of any defences in the city for both the MRFS and HEFS, the barrier would need be closed on a considerable number of occasions to defend the city against the tide. In order to quantify this, the number of times in which the peak elevation of a tidal cycle, for various sea level rise scenarios, exceeds the current threshold of flooding in the City (and therefore requires a barrier closure) has been calculated. The results are presented in Figure 7. The tidal data from January and February 2014 has not been included in the analysis as it is not representative of typical tidal conditions and would skew the results. The frequency of exceedance events has therefore been calculated by counting the number of peak tidal elevations above the threshold between September 2013 and March 2014 (a four month period) and multiplying by 3 to derive an estimate of the likely number of closures per year for the various sea level rise scenarios.

Figure 7: Frequency of barrier closures to defend only against the tide for various sea level rise scenarios



The number of closures shown in Figure 7 above only accounts for the number of closures due to astronomical tides. In addition to these closures, the barrier would also need to be closed to defend against any storm surge events that present a risk of tidal flooding to the City. The likely frequency of such events cannot be predicated with any certainty for future scenarios, but is likely to increase from the present day scenario as sea level rises.

It can be seen from the figure that in the MFRS (0.55m increase in sea level) the barrier would need to be closed approximately 100 times a year to defend against the tide. For the HEFS (1.05m increase in sea level) the barrier would need to be closed approximately 420 times a year to defend only against the tide.

Based on analysis undertaken as part of the Lee CFRAMS in conjunction with revised costings undertaken in preparing this report, it is evident that a tidal barrier at Great Island, with barriers at Monkstown and Marlogue, may become cost beneficial with sea level rise of circa 0.5m. At this level of sea level increase, the barriers would need to close almost once per week on average, which is unlikely to be viable on a number of grounds including environmental impacts, navigation impacts, operational costs etc. If sea level rise of 1m were to arise, this frequency would increase to several times a week.

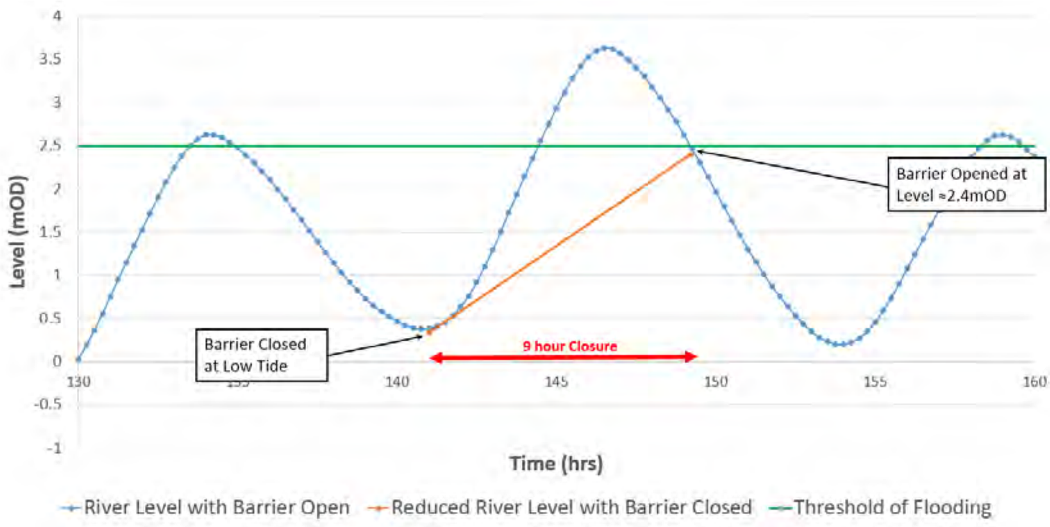
Therefore, it is likely that these tidal barriers could only be implemented in conjunction with low level direct waterfront defences in the city (as are currently proposed as part of the exhibited Lower Lee Flood Relief Scheme) which would minimise the frequency of closures as the city defences would defend against the most frequent events and the tidal barrier would only be required to deal with more extreme events.

2.4.2.1 Fluvially Dominated Event – HEFS

As illustrated above when considering the current scenario, the critical case for considering the available storage versus that required will be the fluvially dominated case, and therefore the same case need only be considered for the future scenario.

Figure 8 below shows the theoretical tidal cycle for the 1 in 5 year extreme tide level in Cork, in the HEFS. This tide in conjunction with the future (HEFS) 1 in 50 year fluvial event would need to be catered for, and would require a barrier closure.

Figure 8: Theoretical Tidal Cycle for HEFS 1 in 5 year event (2.45m astronomical peak with 1.05m surge)



If the barrier is closed at the preceding low tide level of circa 0.3mOD and reopened when the sea level is less than the threshold of flooding in Cork (taken at 2.4mOD), the barrier closure time would be 9 hours (excluding the actual time take to fully open and close the barrier). Therefore, allowing 1 hour for opening and closing, sufficient upstream storage would be required for a 10 hour period for incoming flow. This storage volume would be required between the low tide level of circa 0.3mOD and the threshold of flooding in Cork, taken as 2.4mOD.

2.4.3 Control Systems

A tidal forecasting system would have to be implemented within the Cork Harbour area to determine the timing and duration of tidal barrier closures, based on accurate analysis of the expected tidal magnitude.

The forecast of the high tides and the closing of the barrier can be fully automated, where no human intervention would be required. That could be achieved by a control system making real time meteorological predictions and water level assessments, importing the outputs into a computer model. The frequency of the predictions could be updated every 10 minutes.

If necessary, the responsibility for closing the barrier can be delegated to a manager based on a warning from the forecast system. Alternatively, a completely automated system would exclude the risk of human error.

It is also possible to have a combined approach, where the decision of closing the gate is taken by a manager, but the barrier operates with a failure proof system in order to avoid any situation where the tidal forecast system has warned of a high tide scenario and the manager has not activated the gate closing. In that case, an automatic closure procedure will close the barrier gate.

3 Review of Lee CFRAMS findings on Tidal Barrier

In preparing the Lee Catchment Flood Risk Management Plan (CFRMP), as part of the Lee CFRAMS, the option of a tidal barrier was considered. Three possible locations were investigated, one at the Jack Lynch Tunnel, one either side of Great Island (at Monkstown and Marlogue), and one at Roche's Point.

Hydraulic modelling was undertaken for a barrier at each location to establish if there was sufficient upstream storage, both in the current scenario and in the MRFS and HEFS. It was established that there was insufficient upstream storage at the Jack Lynch tunnel location and this option was subsequently discounted on the basis that it would not achieve its objectives.

The options at Great Island and Roche's Point were costed and the Benefit Cost Ratio for the tidal only solution was also established as shown in Table 3 below.

Table 3: Lee CFRAMS Costs and BCR for Tidal Barrier

	Great Island Barriers	Roche's Point Barrier
Cost	€341,429,000	€2,709,304,000
Benefit	€79,773,000	€90,947,000
BCR	0.23	0.03

It can be seen that neither option comes close to being cost beneficial and therefore these options were not considered to be viable.

Both locations were also subjected to a Multi Criteria Analysis (MCA) scoring system, as was the preferred option (which is similar to the exhibited scheme).

Relevant MCA scores are shown below in Table 4 below.

Table 4: Lee CFRAMS MCA Scores

	Great Island Barriers	Roche's Point Barrier	Preferred Scheme
MCA Score	-7515	-71340	774

Further analysis of the MCA scores reveals the following noteworthy points:

Roche's Point Barrier

- Technical Score of -100 mainly due to significant interventions required and H&S concerns about construction and maintenance at such depths.
- Economic Score of -71720.
- Social score of 660 because of elimination of risk to entire harbour.
- Environmental Score of -180 due to significant concerns in relation to both short term and long term impacts on ecology and environment, particularly in terms of the designated sites in the harbour.

Great Island Barriers

- Technical Score of -50 – not as poor as Roche's Point due to shallower depths and thus reduced H&S concerns.
- Economic Score of -7945 – order of magnitude better than Roche's Point due to order of magnitude difference in BCR.
- Social score of 660 – same as Roche's Point and same rationale.
- Environmental Score of -180 – same as Roche's Point and same rationale.

Preferred Scheme of Direct Defences

- Technical Score of 75 – Positive where barrier scores are negative indicating it was considered a technically superior solution.
- Economic Score of 197 – Positive BCR versus negative BCR for all tidal barriers.
- Social score of 660 - same as Barriers.
- Environmental Score of -155 – negative score reflecting some negative environmental impacts in Cork City but still considered less harmful to environmental receptors than a tidal barrier.

The Lee CFRMP notes that '*The introduction of the floodwalls would also result in a permanent change in visual amenity in this sensitive cityscape, which includes sensitive areas designated as Landscape Protection Zones.'* But it goes on to conclude that *'The appearance of floodwalls would be designed appropriately to minimise visual impacts, particularly on areas of sensitive cityscape value. The use of demountable defences could be considered in any areas of particularly sensitive views/landscape'.*

Combinations of all of these mitigation measures are proposed in the exhibited scheme.

The CFRMP notes that *'Tidal barriers were assessed for a number of locations in Cork Harbour and are not viable under existing conditions but may become so in the future.'*

In terms of climate change, the CMFRP noted the following:

'Around Cork Harbour the impact of climate change on tide levels and surges is anticipated to be greater than the impact on fluvial flood flows elsewhere and could become significant in terms of flood defence into the future. Currently, flood defences are considered the overall preferred option for managing the flood risk in Cork City and Midleton in the short-to-medium term. The MRFS and HEFS projections for sea level rise by 2100 are 550mm and 1050mm, respectively, and with these projections tidal barriers at Monkstown and Marlogue Point are likely to become cost-beneficial with an estimated rise in sea levels of 315mm, which is expected between 2050 and 2075. This eventuality is so far in the future and the timing so uncertain that it should not unduly influence decision making at this time. If and when sea level rise of this order occurs, a full and detailed feasibility study of the options would have to be undertaken.

The cost of the tidal barriers option is estimated at approximately €340 million at the present time, which will increase with inflation, and schemes with this order of cost will, at any time, be subject to detailed scrutiny and decision-making at high levels of government.'

Following a review of the Lee CFRAMS findings in relation to a tidal barrier, the following conclusions can be summarised:

- Direct defences in Cork are the optimum solution for Cork in the short and medium term.
- Tidal barriers score worse than the exhibited solution on all criteria except for social where they are equal. In these criteria, the barriers have negative scores whereas the exhibited scheme has a positive score.
- A tidal barrier has an extremely negative BCR.
- A tidal barrier is not currently viable and will not likely become viable for approximately 50 years or more. This eventuality is so far in the future and the timing so uncertain that it should not unduly influence decision making at this time.
- If and when a tidal barrier becomes viable, the optimum location is likely to be at Great Island, but a full and detailed feasibility study of the options would have to be undertaken at this point in time.

4 Constraints and Key Considerations

4.1 Navigation and Navigational Safety Requirements

4.1.1 Introduction

There are a range of users of Cork Harbour whose right to navigation and navigational safety must to be taken into account when considering any potential tidal barrier. These include: recreational, leisure, commercial and tourism.

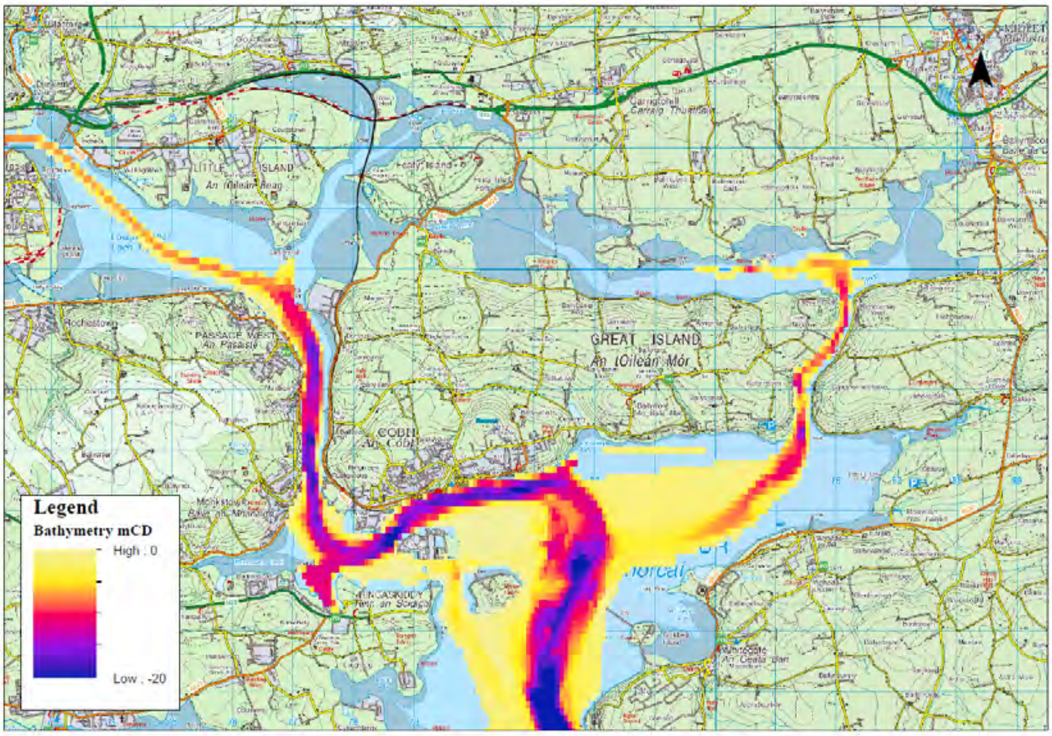
Port of Cork Company considers that there are four distinct public port facilities in the harbour as illustrated in Figure 9 below. These are City Quays, Tivoli Docks, Ringaskiddy Deepwater and Ferry Terminals and the Cobh Cruise Terminal.

Figure 9: Port Facilities in Cork Harbour (Port of Cork Development Plan, 2010)

There are also a number of privately owned port facilities in the harbour namely Whitegate, Passage West, Hawlbowline Island, Rushbrooke, Cobh and Marino Point.

The location and bathymetry of the main navigation channels through the harbour is shown in Figure 10.

Figure 10: River Channel Bathymetry (Infomar.ie)



The likely requirements are discussed below, with particular reference to the requirements of Port of Cork Company.

4.1.2 Consultation with Port of Cork Company

As the installation of a tidal barrier would have significant implications for port and related maritime activities in the harbour, it is important to ensure that such activities are appropriately considered when developing a concept for any potential tidal barrier. For this reason, Port of Cork Company (POCC) were consulted in preparing this report, to ensure that its requirements/concerns were appropriately considered and assessed.

The Port of Cork Strategic Development Plan proposes to move its container terminal (LoLo) business from Tivoli Docks to Ringaskiddy. Planning permission has recently been granted for the development of a container and Ro-Ro facility, Port of Cork anticipate that the Ringaskiddy Container Terminal may be operational by 2020.

Whilst this may reduce the number of vessels requiring to cross a tidal barrier in the upper harbour, it is important to recognise that other commercial businesses remain in Tivoli and the City Quays.

Whilst Port of Cork Company is at the early stages of its planned move of some of its facilities and activities to the outer harbour, predominantly to Ringaskiddy, there remains a great deal of uncertainty in relation to the achievable timescale.

Beyond this, it is considered likely that the maritime significance of Cork will ensure that there will remain a requirement for vessels, cruise ships, Naval vessels, survey vessels and visiting sailing ships to navigate as far into the harbour as the city quays. For these reasons, navigation requirements are a key driver of the design of a potential tidal barrier.

As part of its normal operations works, the Port of Cork carry out dredging of the navigation channels and ports in Cork Harbour. The Port of Cork reports that berths are dredged to 9m below CD at City Quays and Tivoli Docks.

It facilitates cargo ships notionally up to a length of 152m, beam 18m, draught 8.5m.

POCC advised that its primary requirements/concerns could be summarised as:

- Minimising changes to existing flow regime and velocities.
- Ensuring navigational safety and operational efficiency.
- Minimising potential impacts of wider marine leisure activities.
- Minimising impacts on future port development and operations.

POCC noted that the existing channels at West and East Passage are narrow and therefore result in significant velocities. It agreed with Arup's recommendation that any barrier at Great Island would need to maintain velocities at levels equivalent to at present.

In terms of navigational safety, it noted its requirement to maintain the navigation channel at current widths and depths and that navigational gates in any tidal barrier would need to be appropriately sized and orientated to ensure navigational safety. It noted that new layby berths may be required at either side of the barrier to allow for ships to berth safely and wait during barrier closures. The full extent of navigational requirements will only become known after a full simulation study has been completed. Navigational requirements in other ports have included but are not limited to increased tug availability at the barriers, radar monitoring, early warning systems between the barrier operator and the Port, Emergency protocols etc.

POCC noted the extensive number of marine leisure activities in the harbour and the importance of such activities for Cork, noting that significant changes in velocities, flow paths, sedimentation patterns could be detrimental for such users.

POCC also noted that any proposed barrier at Monkstown would have to be carefully designed to ensure that there was no significant increase in velocities during ebb tide conditions, as this could result in erosion and/or sedimentation at its facilities in Ringaskiddy. This would also affect the safe navigation of vessels entering and departing Ringaskiddy Basin. This is a period of navigation where vessels are at their most critical stage as the vessels speed is greatly reduced, hence all external forces (wind, current and tide) has greatest effect.

Marino Point has been acquired by new owners as a JVC with the Port Company, it is the intention to operate this facility to its full capability. It is envisioned that large vessels will operate to/from the berth, ranging in size from 3000 GT to

30,000GT. Any increased flows in this area will affect berthing and unberthing, resulting in increased risk when manoeuvring at slow speed. The deployment of additional mooring services such as tugs and mooring boats would be necessary to offset such risks. This will increase costs to the ship operator.

Similarly, the potential for increased sedimentation as a result of a barrier at Little Island would also need to be carefully considered as increases in dredging costs could jeopardise the commercial viability of port activities. POCC also noted that significant frequencies of barrier closures would have significant impacts on navigation and port activities and the associated increased costs could jeopardise the competitiveness of the Port of Cork.

POCC noted that at a minimum, it would require the following detailed studies to be undertaken before a tidal barrier could be further considered in any detail:

- Hydraulic modelling of flows/velocities.
- Sedimentation modelling.
- Impact assessment on Port Users including operational and shipping cost analysis.
- Detailed Navigation Studies including ship movement simulation etc.
- Analysis of recreation use.

4.1.3 Consideration of Navigation Issues

POCC's requirements/concerns have been considered in developing a concept design for potential tidal barriers. An assessment of some of these issues is set out below:

4.1.3.1 Required Clearances

A paper prepared by JD Shinkwin entitled "The Lee Tunnel, Cork, Ireland – planning, contract strategy and conceptual design" (1997) set out the shipping requirements of Port of Cork Company (then the 'Harbour Commissioners') discussed during the feasibility design of the River Lee Tunnel, now known as the Jack Lynch tunnel, when a high level bridge or opening bridge were being considered as alternatives.

The report states that in order to provide unrestricted access up the river to the City berths, for the maximum size of vessel (then 20,000 dead weight tonnes) which can use the upper section of the navigational channel in the river, it was agreed that the following navigational clearances should be provided:

- Depth below low water at Mean Spring Tide: 7.2m
- Height above high water at Mean Spring Tide: 46m
- Width of full depth channel on straight: 75m
- Width of full depth channel on bend: 90m

These figures would need to be re-examined prior to any potential barrier being designed.

4.1.3.2 Barrier Orientation

A navigation opening should be orientated perpendicular to the navigation channel so that incoming vessels are approaching the opening in a straight line. This will avoid a vessel having to swing or pass through the opening sideways. If this cannot be achieved, it may be necessary to dredge the approaches to provide more flexibility for approaching vessels.

Ideally the angle of approach to the channel should be at right angles to the navigation opening. If vessels approach the opening at an angle, this effectively reduces the available navigation width for vessels.

4.1.3.3 Sill Depth

For all options, the depth of the sill at the navigation opening will provide a limit on the size of vessels and the extent of the tidal window that the larger vessels can cross the barrier. That is, larger vessels would not be able to cross the barrier near low tide. The modelling assumed that the sill is matched to the existing bed level and in this case access for larger vessels would be no different from existing.

4.1.3.4 Gate Options

It may be desirable to have two navigation gates rather than one single navigation gate. This would give more flexibility to maintain navigation traffic if there is a failure of one of the gates. To achieve this, and still maintain the current navigation channel width, additional dredging would be required in the area of the proposed barrier.

In either scenario, safe and designated holding and waiting areas would be required for vessels, located both upstream and downstream of the barrier. Upstream, vessels may wait at berth until given clearance for navigation through the barrier without having to wait at sea. Downstream, holding areas would need to be identified and agreed with the Port of Cork which may include additional dredging, navigation controls and coordination with other Ports.

A tidal barrier (if not constructed over the current full width of the channel) will concentrate the tidal flows through a relatively narrow channel at the navigation opening. These concentrated flows could lead to significant increases in velocities which may be a challenge to navigation and vessel manoeuvres.

Therefore, additional flow gates, normally left open, will also be needed to spread the tidal flows over a wider area and reduce the concentrated flows at the navigation opening. If a tidal barrier option were to be advanced, further detailed navigation surveys, studies and modelling would be required to test any such proposals for navigational safety.

The most suitable tidal barrier type for the Port can only be ascertained by much more hydraulic and simulation research.

4.1.3.5 Navigation Controls

Navigation controls will need to be in place to allow for vessels crossing the barrier in one direction at a time. This implies that there will need to be safe holding areas for vessels, located both upstream and downstream of the barrier.

Navigation control systems will also need to be agreed with the Port of Cork for normal operations (gates open) and for extreme surge events when the gates are closed.

The Port of Cork have noted that Vessel monitoring and Vessel Traffic Service (VTS) controls would need to be included in any tidal barrier solution.

4.1.3.6 Construction and Maintenance

There will also be obstructions to navigation during construction and maintenance of the barrier. Some form of by-pass channel would be required while the barrier is constructed across the existing navigation channel.

In addition, the following factors should also be studied in further detail.

- Port of Cork strategic plans and future proofing.
- City of Cork's view of residual flood risks taking account of potential barrier maintenance/accidents/failures.
- Costs (capital and operational).
- Ease of maintenance.

4.2 Geotechnical and Hydrogeological Considerations

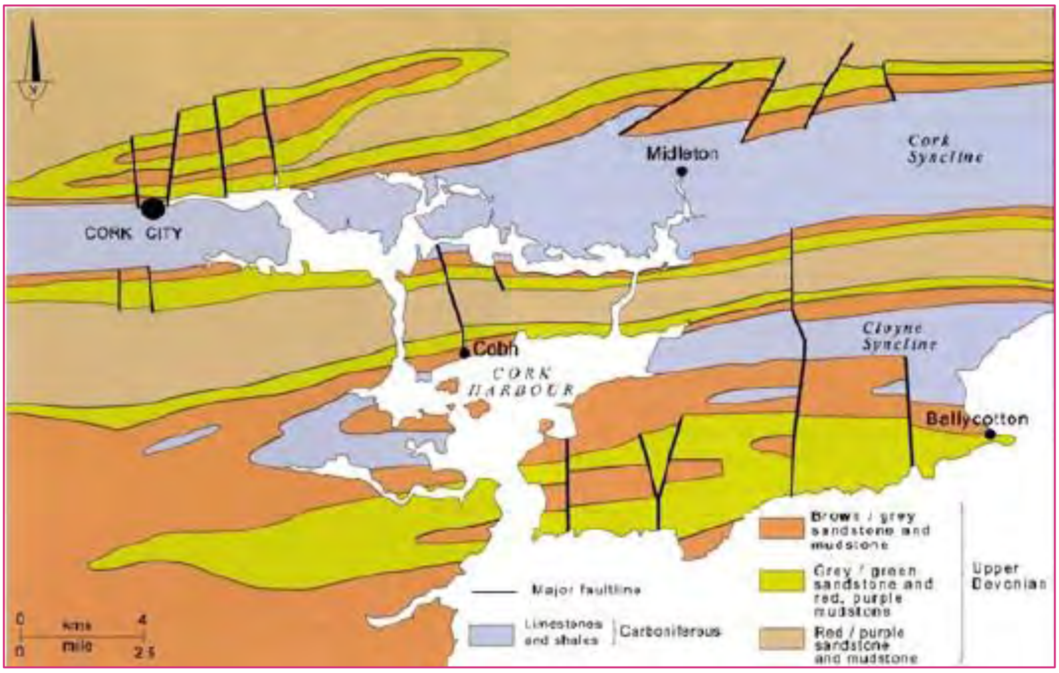
Due to the scale of any potential tidal barrier and the large loads/forces involved, the foundations required for a tidal barrier will be very significant, with a potential wide range in costs dependent on the existing ground conditions.

It is beyond the scope of this study to undertake detailed site investigation, but if a barrier were to be considered in the future, a significant programme of site investigation would be required.

In this study, we have limited our investigation of likely ground conditions to a desk study review of readily available information at each of the potential barrier locations.

Figure 11 below is an extract from a paper (Long & Roberts, 2008), which illustrates the rock geology in and around Cork Harbour. It is composed of alternating limestone synclines (Cork Syncline and Cloyne Syncline) and sandstone/mudstone anticlines.

Figure 11: Solid geology of Cork city centre (Long & Roberts, 2008)



The syncline structures typically have significantly greater depths to limestone bedrock and are infilled with high permeability sands and gravels. The syncline bedrock also has higher permeability limestone that may contain karst features.

The anticline structure is underlain by lower permeability sandstones and mudstones and is considered to have shallower depths to bedrock.

Figure 12 below illustrates the deposition of glaciofluvial sediments during the deglaciation period.

Figure 12: Deposition of glaciofluvial sediments during deglaciation (Long & Roberts, 2008)

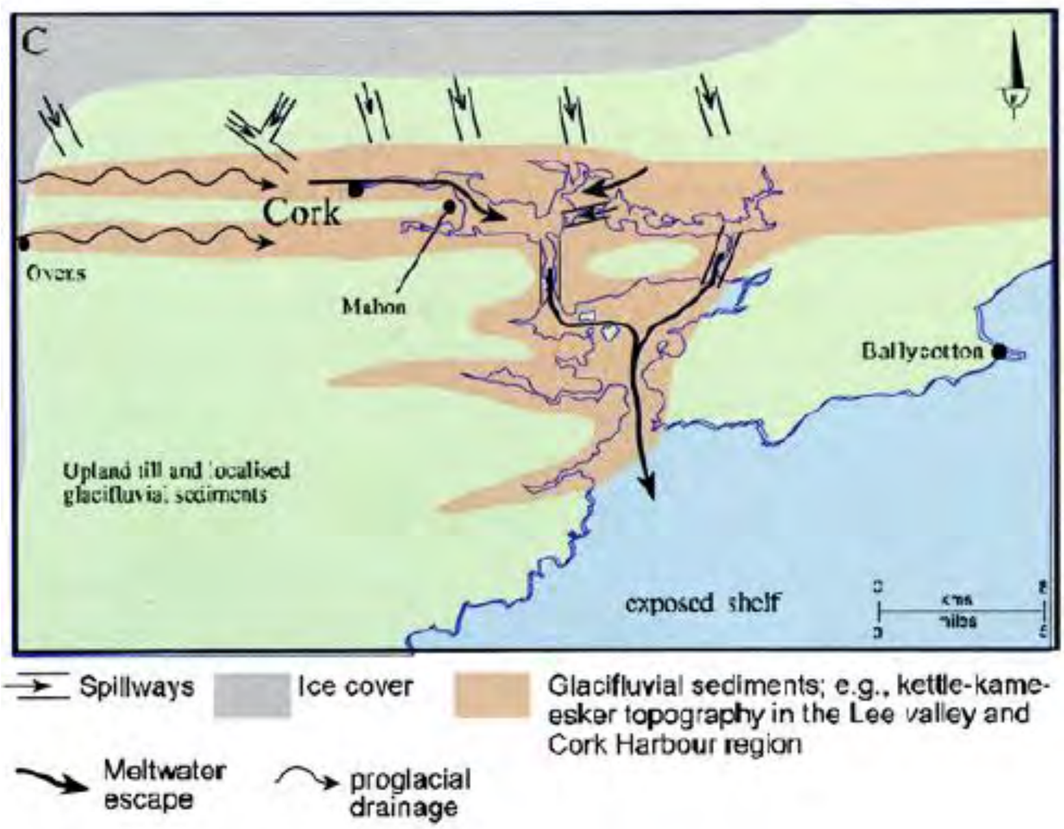


Figure 13 shows a section from a conceptual model of the late Pleistocene-Holocene Buried Valleys in the Cork Syncline, while Figure 14 shows a block model which gives a farfield cross-section though the synclines in Ballincollig.

The block model of the Ballincollig-Cork City Harbour regions shows the relationship between the topography and the distribution and structure of the various geological formations in the subsurface. The dashed line shows the form of the bedding planes schematically. Note the deeply incised (up to 140m deep) east-west trending buried valleys infilled with glacial outwash sediments on the margins of the Cork and Cloyne Synclines.

Figure 13: Extract from Late Pleistocene - Holocene Buried Valleys in the Cork Syncline (Davis, MacCarthy, Allen, & Higgs, 2005)

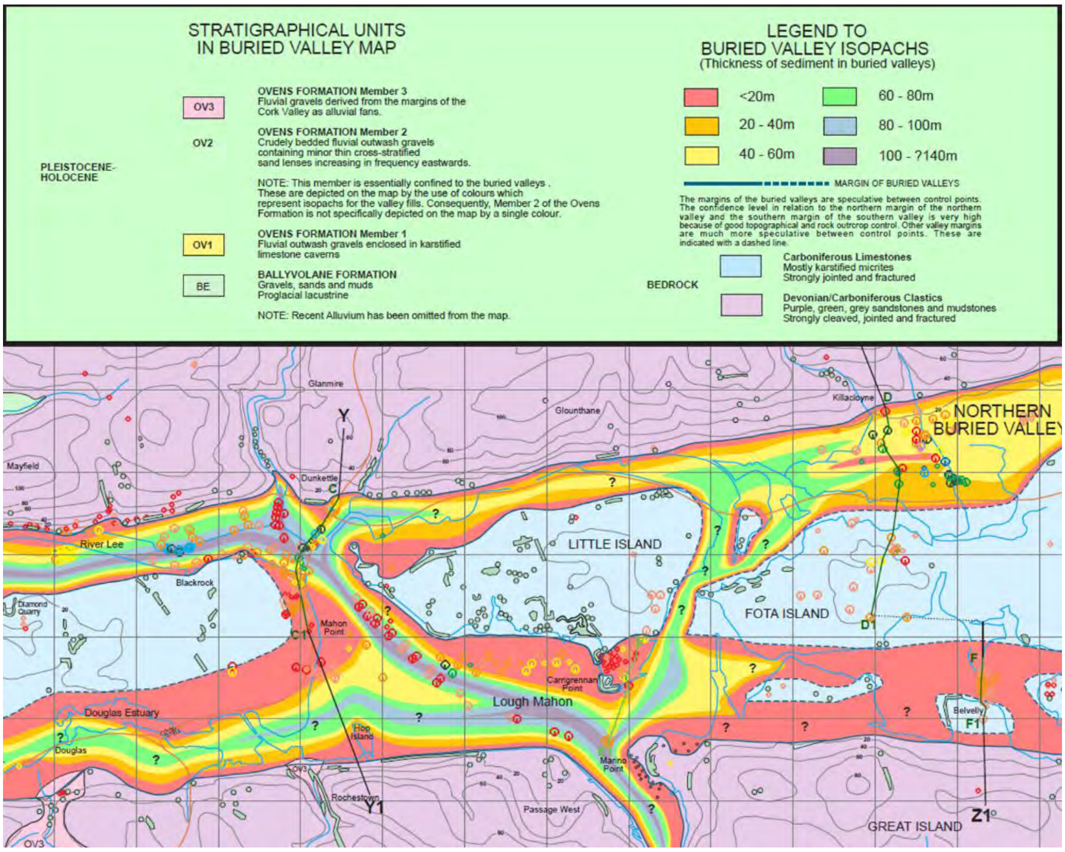
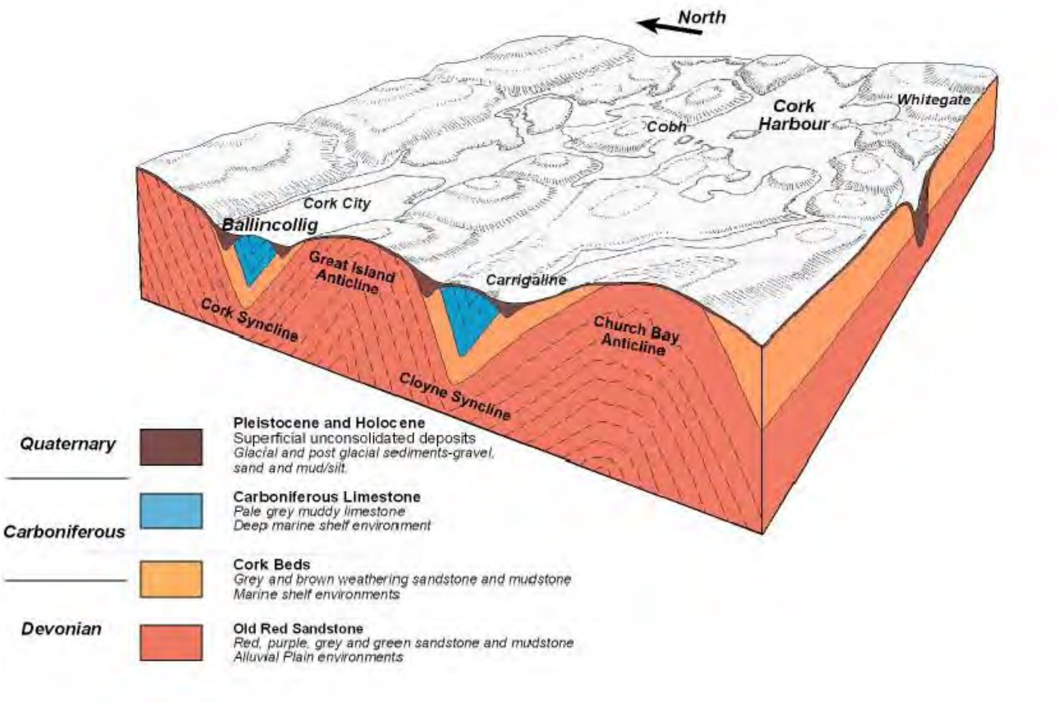


Figure 14: Block Model of farfield cross-section through synclines in Ballincollig (MacCarthy, 2012)



At the majority of the barrier locations, there are thick deposits of cohesive material in the river bed, introducing the potential for the tidal barrier to be susceptible to excessive long term settlement. Where the cohesive deposits are classified as soft, the embankment/tidal barrier will be also at risk of bearing failure.

This means that the structures for the navigation and flow gates will likely have to be piled. Accordingly, the depths and strengths of the fluvial gravels and rock will need to be investigated in detail.

Karst features in the limestone locations may present a risk of collapse of overlying material, or for large groundwater flows beneath the tidal barrier/embankment.

In the embankment locations, other potential mitigation measures options may consist of excavation and replacement of soft material, ground improvement (surcharging/preloading and/or vertical drains) of the cohesive deposits. Where excavation and replacement or surcharging of the (soft) cohesive deposits is not viable, the embankment may require to be constructed in stages, or to be piled. Embankments may be designed to accommodate future settlements. Treatment of karst features could include further investigations (e.g. geophysics) to more accurately define size and extent, and filling of cavities.

In undertaking a high level assessment of the feasibility of the four tidal barrier locations from a hydrogeological perspective, the following data sources were considered;

- GSI groundwater vulnerability maps,
- Teagasc/GSI subsoil maps,
- GSI bedrock map, and
- Paper by Mike Long et al: Engineering Characterisation of the Glaciofluvial Gravels of Cork City, 2008

Three key hydrogeological features have been considered when assessing the viability of the tidal barrier locations:

1. High permeability sand and gravel glaciofluvial deposits which are located in this valley.
2. The presence of low permeability silt on the river bed. If the silts/clays are present on the river bed and are able to remain in-situ through construction of the tidal barrier they can significantly retard flow bypassing the proposed tidal barrier.
3. If the silt is either not present or must be removed for construction of the tidal barrier, cut-off of the groundwater to the bedrock may be required.

In conclusion, from a geotechnical and hydrogeology perspective, barrier locations in the anticline would be preferred to those located in the syncline due to the following:

- Higher bedrock levels and no karst features in sandstone/mudstone anticline will likely result in less significant foundations.
- Shallower depths of gravels and no karst features in sandstone/mudstone anticline will mean a lower risk of seepage or bypass underneath the tidal barrier and thus reduced likelihood of cut-off being needed and/or reduced depth of cut-off required.

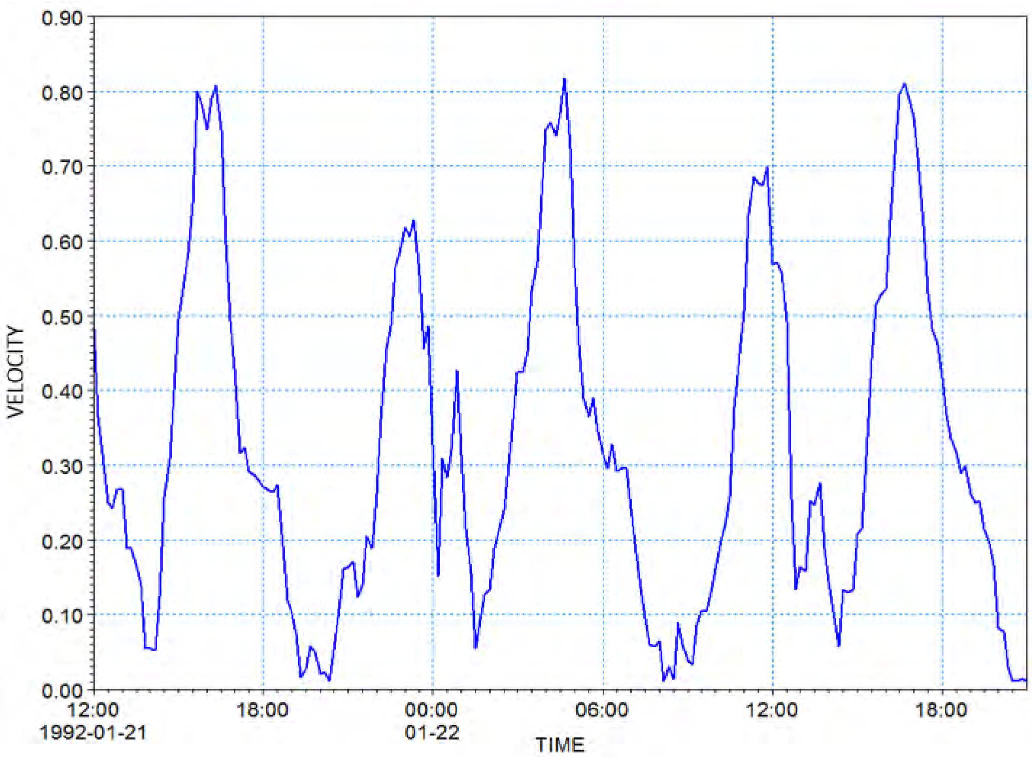
4.3 Cork Harbour Hydrodynamics

Cork Harbour is a shallow macro-tidal estuary that experiences a twice daily tidal oscillation in water levels of approximately 4m during spring tides and approximately 2m during neap tides. This vertical motion of the water is accompanied by a large horizontal oscillatory motion leading to a dynamic movement of the tide in the harbour with temporal variation in velocities throughout the harbour.

The bathymetry of the harbour varies considerably in terms of the bed elevations and the width of the different areas of the harbour. The dominant feature is a relatively narrow deep channel that extends from Roche's Point at the entrance to the harbour, through the outer harbour and West Passage, and into Lough Mahon in the inner harbour. This deep channel is surrounded by shallow mud flats that are subject to flooding and drying by the rising and falling of the tide. In addition to the temporal variation, the geometry therefore also leads to considerable spatial variation in the velocities throughout the harbour with the velocities generally higher in the deeper narrower channel than on the mudflats.

Figure 15 presents a graph of the recorded velocity during a spring tide and neap tide from the centre of Lough Mahon. This data was taken from a hydrographic survey of the harbour undertaken as part of the impact assessment of Carrigrennan WWTP. The peak velocity on the spring flood tide is circa 0.8m/s and on the ebb tide it is circa 0.6m/s. On the neap tide (not shown on the graph) the peak velocities are less and are circa 0.4m/s.

Figure 15: Lough Mahon Recorded Velocities



Lough Mahon is subject to stratification due to discharge from the River Lee, Glashaboy River and Tramore River. In times of high fluvial flows on these rivers a significant amount of freshwater can discharge into Lough Mahon and mix with the saline seawater. As freshwater tends to flow over the denser, but diluted, seawater underneath, variations in the water density will occur throughout the water column and hence lead to stratification in the flow.

Introduction of a tidal barrier at any location in the harbour will impact on the hydrodynamics as it will act as obstacle to the flow and force all the water passing the location through the various gate openings. Should these gate openings not be appropriately sized (i.e. if they are not wide enough to ensure the cross sectional area is not significantly reduced), the barrier will lead to significant increases in velocities through the various openings of the barrier as well as significant reductions in velocities in areas adjacent to the barrier. These impacts have the potential to have a very negative impact on safe navigation of both commercial and leisure craft, sediment transport and on the environment. If the velocities through the openings are excessively high, they can also impact on the functioning of the barrier as the force of the water passing through the barrier can lead to excessive vibration of the structure and its associated mechanical and electrical equipment and cause operational issues. We note that the Eastern Scheldt barrage and Eider barrage are examples of existing barrier structures in the world that have experienced operational issues many years after construction due to excessively high velocities of water passing through their openings.

Given its critical importance, we have undertaken a detailed assessment of the change in hydrodynamics resulting from constructing a tidal barrier in the harbour. This work has been undertaken in two stages:

- A simplified analysis utilising the conservation of mass to determine the increase in velocity arising from constructing the barriers. This work is presented in Section 6.2.1 of this report and allows us to determine at a high level the likely required gate dimensions in order to ensure that velocities associated with flow through the barrier openings are not excessively high;
- Very detailed analysis utilising a two-dimensional hydrodynamic model of Cork Harbour developed in MIKE 21 software. By first considering a baseline scenario model (i.e. with no barrier in place) and then reconfiguring the model to represent a particular tidal barrier, the impact of the barrier on the hydrodynamics in the harbour can be clearly established. This work is presented in Section 7 of this report and allows us develop a detailed understanding of the impact of any of the barriers considered. The findings of the analysis are then used to assess the impact of the barriers on safe navigation in the harbour, sediment transport and on the environment.

4.4 Cork Harbour Morphology

The transport of sediment in a macro-tidal estuary such as Cork Harbour is complex and depends on various factors such as:

- The tidal and fluvial hydrodynamics and associated salinity gradient,
- The quantity and type of sediment discharging into the harbour from numerous sources such as watercourses, the open boundary at Roche’s Point and directly from land;

- The composition of the bed which varies spatially and temporally;
- The particle size distribution of sediment in the water column,
- Biological forcings in the water column;
- The rate at which sediment processes such as flocculation, bed erosion, consolidation occur;
- The influence of additional forcings such as wind shear stresses acting on the water surface, thrusters and wave action of passing ships etc.

Despite the complexity of the distribution and transport of sediment, the geomorphology of the estuary is relatively stable as regards sediment dynamics with only localised areas of erosion and deposition.

The area of Lough Mahon can be characterised as an area of deposition due to fine grained particles held in suspension in the River Lee (and to a lesser extent the Glashaboy and Tramore Rivers) falling out of the water column as velocities in the channel drop due to water entering the relatively wide expanse of the Lough downstream of Blackrock Castle.

The Port of Cork are responsible for port operations and navigation in the harbour. As part of their operations they maintain a regular dredging programme in the harbour to maintain navigable depths along both the navigation routes and within their port facilities at Cork City, Tivoli, Ringaskiddy and Cobh.

In the Lower Harbour area dredging is undertaken at three locations in the channel to maintain navigation:

- Roche's Point – dredged to provide depth of -12.75mOD Poolbeg
- Spit Bar – dredged to -10.85mOD Poolbeg
- Ringaskiddy bed – dredged to -10.85mOD Poolbeg

The navigation channel between Passage West and Cork (which included Lough Mahon) is man-made and has been dredged and maintained since 1840. In 1994 the channel was deepened to provide an advertised depth of -6.35m OD Poolbeg between Passage West and the Port facilities at Tivoli. We note however that the actual bed along the channel may be deeper than this. It has been the practice of Port of Cork to undertake formal dredging every two years approximately.

4.5 Known Environmental Constraints

Cork Harbour is a sheltered coastal environment, with a diverse natural heritage that accommodates a range of activities and uses. The topography of the landscape is gently undulating, with a mixed coastline consisting of built infrastructure, shallow cliffs, intertidal mudflats, reed beds, shingle and rocky foreshores. The western extent of the Harbour is characterised by estuarine influences where the River Lee discharges to the complex estuary zone. The navigation channel in the Harbour is maintained at a depth of circa 11m for shipping and maritime transport.

Cork Harbour is of major international importance for waders (20,000) and wildfowl (5,000), and is designated as both a Ramsar wetland site of international importance and a Special Protection Area for birds.

Other designations within the Harbour protect important habitats and include candidate Special Areas of Conservation and proposed Natural Heritage Areas with the River Lee designated as a salmonid river under the EC Directive. Conservation Areas are shown in Figure 16 below.

Figure 16: Designated Environmental Sites in Cork Harbour

4.5.1 Great Island Channel SAC

While the footprint of a barrier could be kept outside the SAC and away from protected habitats, there may be potential for accretion of sediment around the new structure(s) changing the existing formations of mudflats and sandflats. Whether this would have a negative impact on the SAC cannot be definitively established at this level of study. A more detailed understanding is required of the hydro morphological changes that would follow construction. A barrier built in the Little Island location would also require significant ancillary work to be completed within the SAC to prevent overland flows bypassing the barriers to the North. This would likely have a negative impact on the SAC, though further study would be required to measure the extent of this impact.

4.5.2 Cork Harbour SPA

The impacts on Cork Harbour SPA are potentially more significant and therefore more relevant. The site is protected for 23 birds and their associated wetland habitat. Based on a high level assessment, we know that a number of these birds roost/forage in the immediate vicinity of the proposed barrier during the winter period e.g. Shelduck, Teal, Oyster Catcher, Dunlin, Curlew and Black Headed Gull.

It is evident that the above referenced environmentally designated and sensitive sites will need to be very carefully considered when selecting a suitable site for a tidal barrier.

4.6 Marine Leisure/Activities in the Harbour

4.6.1 Leisure Activities

Cork harbour and its adjacent surroundings hosts a range of leisure and recreational activities such as rowing, sailing, canoeing, wind surfing, swimming and sea angling. Several sailing/yacht clubs are based in the harbour including Cove Sailing Club (Cobh), The Royal Yacht Club (Crosshaven), Lower Aghada Tennis and Sailing Club (Aghada), East Ferry Marina (Great Island) and Monkstown Bay Sailing Club (Monkstown).

A number of rowing clubs are situated in the harbour including Shandon Boat Club & Naomhóga Chorcaí, Lee Rowing Club, Cork Boat Club and Blackrock Rowing Club, which are all situated on The Marina, Ballintemple. Irish Coastal Rowing Federation Clubs which utilise Cork harbour include Blackrock, Passage West, Crosshaven, East Ferry, Cobh Fishermen, Commodore, Maritime College and Naval Service rowing clubs.

Meitheal Mara is a maritime cultural organisation based in Cork. It was founded in 1994 as a community employment Currach building project and frequently uses the harbour for boating activities. Meitheal Mara organises the annual Ocean to City Race for rowing boats and canoes. The race takes place during the summer at a high tide (preferably spring tide) when there is enough depth in the channel for larger boats such as cruisers. Other annual sailing races in the Harbour include Cork Week, which is held every two years.

The deep water berth located at Ringaskiddy is one of Cork Harbour’s premier shore fishing locations. Coalfish and Conger can be caught all year round and Ray can be caught during the summer. During the winter months, bottom fishing will yield Flatfish, Whiting and Codling.

There exists a large angling community in Cork Harbour. Several sea angler’s clubs exist in the harbour including Crosshaven Sea Anglers Club (Crosshaven) and Cobh Sea Anglers Club (Cobh).

4.6.2 Aquaculture

The Great Island North is one of 63 designated shellfish growing sites existing on Ireland’s coastline.

The main species cultivated in Cork Harbour are oysters. Aquaculture licences occupy the area east of Long Point and Cuskinny for the purpose of farming oysters.

The design of a tidal barrier would need to carefully consider the potential impact on aquaculture and marine activities in the harbour in terms of changes in currents, sedimentation patterns, saline content etc.

4.7 Works Duration

Another key concern in relation to the construction of any potential tidal barrier is the delivery and construction timescale.

The duration of construction works for tidal barriers internationally varies between 4 years and decades. The effect of the construction work over this long period of time on navigation, navigational safety and the environment requires further study, but it is likely to be very significant.

Given the potential scale of any barrier required in Cork Harbour, and including investigation, planning and design time, it would be reasonable to estimate that it would be at least 10-15 years from now before the structure would be operational.

It is also worth noting that throughout the planning and construction process, the tidal barrier will not provide any tidal protection until it is finished. The city would also remain at risk from fluvial flooding for an extended period of time until the barrier is complete. This is unlike the exhibited scheme which will incrementally reduce the flood risk as every phase is completed.

5 Potential Barrier Locations

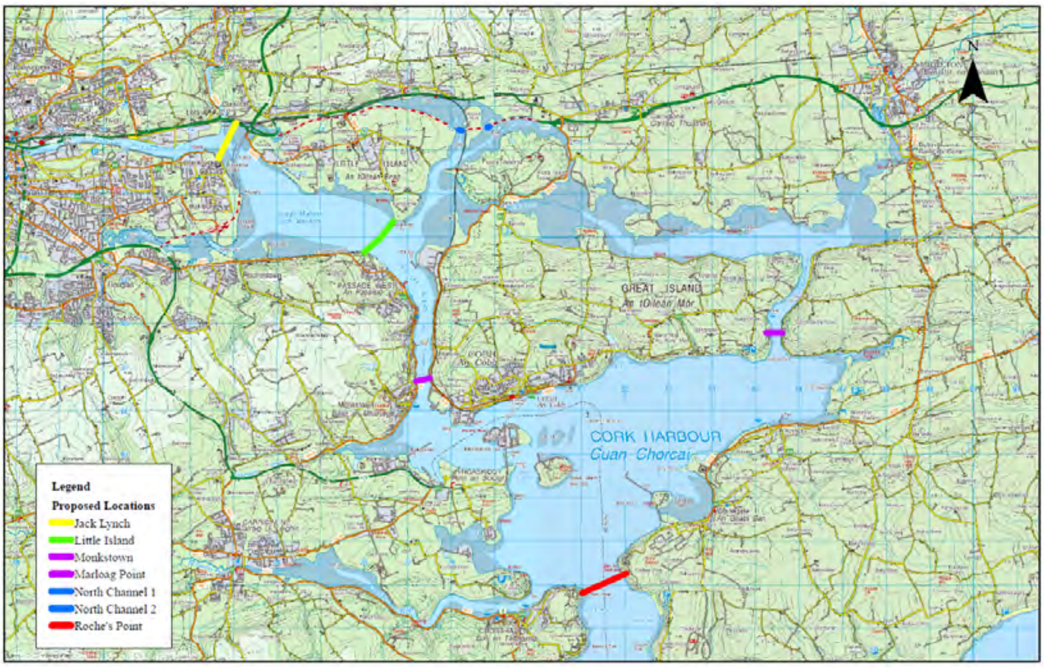
5.1 Overview of Potential Barrier Locations

Four potential tidal barrier locations have been reviewed in preparing this report, to determine their potential viability and potential benefits/impacts on the area.

The Lee CFRAMS study considered three barrier locations; one at the Jack Lynch Tunnel, a double barrier at Monkstown and Marlogue Point, and a barrier at the mouth of the harbour at Roche's Point. The fourth barrier location to be examined in this report is at Little Island as proposed by the stakeholder group.

The four potential locations are shown graphically in Figure 17 below.

Figure 17: Cork Harbour – Potential Tidal Barrier Locations



5.2 Barrier Adjacent to Jack Lynch Tunnel

5.2.1 General Description

A tidal barrier at the Jack Lynch Tunnel was considered as part of the Lee CFRAMS as shown in Figure 18 below.

Figure 18: Jack Lynch Tunnel Tidal Barrier Location

This location was considered as it was the furthest downstream location in the Lee Estuary upstream of Lough Mahon and therefore was relatively narrow and located in relatively shallow waters versus the deeper harbour downstream of Lough Mahon.

The CFRAMS study noted that a barrier at this location would be approximately 375m in length. It would have an approx. height of circa 14m in the Navigation channel but significantly shallower outside of the dredged navigation channel.

5.2.2 Geotechnical and Hydrogeology Considerations

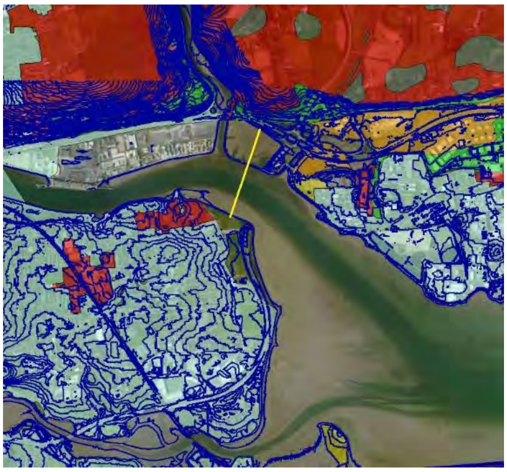
From a geotechnical and hydrogeology perspective, this location is less attractive than say the Great Island location for the following reasons:

- Excessive deposits of cohesive material described as soft in river bed likely to increase foundations costs.
- Risk of karst due to limestone bedrock and faulting present which may give rise to deeper deposits of cohesive material.
- Located on Cork syncline feature which has been infilled with highly permeable sand and gravel deposits. There is therefore a risk that water could bypass underneath the barrier.
- The depths to bedrock in this area may be considerable so cut off of the groundwater routes through sand and gravel could be difficult.
- Even if a tidal barrier provides cut off to bedrock (see point above) it is located partially on limestone bedrock which has high hydraulic connectivity.

Bypass flow of water via limestone bedrock is not likely to be as high as the sand and gravels but this would need further investigation to ensure no karst features present which will allow conduit flow of water.

- Gravel deposit is noted on the northern bank of the river at this location (see green zone subsoil map below). The tidal barrier would need to extend beyond the gravel deposit to ensure water does not bypass along the side of the barrier.

Figure 19: Jack Lynch Tunnel (Cork City) – LiDAR, subsoil maps, bedrock map and vulnerability map

 Subsoil map with LiDAR	 Subsoil –gravels (green & yellow) which could allow water to bypass barrier Red – sandstone glacial till
 Syncline - limestone bedrock underlies river and south bank. Greater hydraulic conductivity in limestone & or karst. Sandstone/mudstone underlies north bank	 Vulnerability map indicates rock close to surface on south side of bank (pink and red areas) but not on north bank

5.2.3 Landscape and Visual Considerations

From a landscape and visual perspective, this location lies within the inner reaches of Cork Harbour, a short distance west of the Jack Lunch Tunnel, north of Blackrock Castle and the suburb of Blackrock, and south of the Tivoli Docks industrial area.

This location lies just inside the City boundary, and surrounding land uses reflect those of an area on the urban fringe. A walkway runs south of the proposed barrier location, from Blackrock along the shores of Lough Mahon.

It lies within the City Harbour and Estuary Landscape Character Area as defined by the Cork County Draft Landscape Strategy 2007. This Landscape Character Type comprises the city and the harbour as far as Roche's Point as well as the ridge to the north of the city.

The Strategy classifies this Landscape Character Type as Very High Value, Very High Sensitivity and Normal Importance.

Views and Prospects - There are a number of linear views which relate to Blackrock Castle:

- View BC1: View from Marina Walkway to Blackrock Castle
- View BC2: View from Lee Tunnel Slip Road to Blackrock Castle
- View BC3: View from Tivoli Docks to Blackrock Castle

To the south of the proposed barrier, there are areas designated as Areas of High Landscape Value (AHLV) under the Cork City Development Plan 2015-2021

Close to this proposed barrier location, to the east, the landscape is designated as High Value Landscape (HVL) in the Cork County Development Plan 2015-2021. These are Landscape Character Types which have a high or very high landscape value, and high or very high landscape sensitivity, and which are of county or national importance.

5.2.4 Ecology

This barrier is located within the Cork Harbour SPA and a barrier at this location would result in loss of wetland habitat within the SPA. In addition, the area immediately around the barrier supports thirteen species of birds with 3 roost locations. Species include both foraging and roosting shelduck, Blacktailed Godwit, Curlew and Wigeon, roosting Cormorant, Blackheaded gull, Blackbacked gull, foraging Grey Heron in small numbers, bar tailed Godwit and Dunlin, roosting Oystercatchers and Lapwing.

5.2.5 Technical Viability

The Lee CFRAM study concluded that a barrier in this location is not hydraulically feasible, as modelling indicated that there is an insufficient storage volume behind the barrier to store fluvial flows on the River Lee when the barrier gates are closed. This results in the barrier elevating water levels in the city and increasing flood risk rather than reducing them for the critical design case.

As part of this study, we have again considered the hydraulic capacity upstream of this location and the findings are presented in the table below.

Table 5: Storage calculation upstream of the tidal barrier for the current scenario

Parameter	**Value**	**Comment**
Storage volume upstream of Jack Lynch tidal barrier location	3,590,385m^3	Calculated from survey data and based on the limiting elevation of the threshold of flooding in the city of 2.4mOD and barrier closure level of -0.75mOD.
Required barrier closure time	8.5 hours	Assuming the barrier is closed at low tide and only reopened when the tide levels has receded to a level lower than upstream of the barrier
Average inflow that can be accommodated within the available storage volume during the required barrier closure time	120m^3/s	Assuming a constant discharge during while the barrier is closed. Calculated by dividing the storage volume available by the required barrier closure time

The storage required to accommodate fluvial inflows upstream of the Jack Lynch Tunnel Barrier during the design tidal event are very likely to exceed the available storage as presented in Table 5. Even if we assumed that all flow from Inniscarra dam was stopped during the design event (i.e. all flow upstream of the dam was stored in the reservoirs) which is very unlikely, the design flow from the catchments downstream of the dam will by themselves exceed the average inflow that can be accommodated upstream of the barrier. This is evident if we consider:

- The peak flow on the Shournagh alone during the design event is likely to be circa 188m^3/s.
- The Shournagh sub catchment makes up only about 40% of the catchment area between Inniscarra dam and the barrier.
- The actual flow in the design event that is required to be stored is therefore likely to be much higher than 188m^3/s.

It is therefore evident that there is insufficient storage at this location. Furthermore, in even the MRFS for climate change, the available storage would reduce because of:

- A higher low tide level reducing available storage volume,
- The duration of closure would increase because the barrier could not be opened until later on the ebb tide
- Fluvial inflow would increase because of increases in peak inflows of circa 20%.

5.2.6 Conclusion

On account of insufficient water storage being generated as discussed above, a potential barrier at the Jack Lynch Tunnel has been ruled out and will not be considered further in this report.

5.3 Barrier at Roche's Point

5.3.1 General Description

This option involves the provision of a tidal barrier at the entrance to the Harbour at Roche's Point, located between Rams's Head to the west and Carlisle Fort to the east as shown in Figure 20.

Figure 20: Location of Barrier at Roche's Point.

The barrier would be approximately 1 kilometre in length with a maximum height of 34 metres.

5.3.2 Geotechnical and Hydrogeological Considerations

From a geotechnical and hydrogeology perspective, there are no major issues as it is located on a sandstone/mudstone anticline which is preferable. Rock outcrops on either side of barrier would prevent water bypass along the sides of barrier via overburden.

However, it is noted that a barrier in this location will affect a large geographical area and the constructability is likely to be more challenging given the exponential increase in construction complexity with depth. A barrier at this location would be 10m deeper than at Great Island and would be almost twice as wide.

Figure 21: Roche's Point: maps of subsoil, bedrock and groundwater vulnerability

Subsoil – bedrock either side (grey) so less risk of bypass. Lower permeability glacial till (red) on land.

Sandstone/mudstone – low hydraulic conductivity so little risk of bypass

Vulnerability map indicates rock close (red)/ or at surface (pink) on either side of bank

5.3.3 Landscape and Visual Considerations

The location of the proposed barrier lies north of Roche's Point, at the entrance to Cork Harbour. This is located between Ram's head (near Camden Fort) and Dun an Daibhisigh which is near Carlisle Fort.

From a landscape and visual perspective, this location lies within the City Harbour and Estuary Landscape Character Area as defined by the Cork County Draft Landscape Strategy 2007. This Landscape Character Type comprises the city and the harbour as far as Roche's Point as well as the ridge to the north of the city.

The Strategy classifies this Landscape Character Type as Very High Value, Very High Sensitivity and Normal Importance.

The Cork County Development Plan lists several scenic routes in the vicinity. The proposed barrier at Roche's Point is close to several scenic routes.

- S51 runs along the harbour edge to the east, Regional and local roads from Ballynacorra to Roche's Point.
- S58 runs from Carrigaline to Crosshaven
- S59 includes roads between Crosshaven, Myrtleville, Church Bay, Camden, Weaver's Point and Fountainstown.

The land on either side of the channel is designated as High Value Landscape in the Cork County Development Plan 2015-2021.

5.3.4 Navigational Considerations

From a navigation perspective, a barrier at this location will need to consider the Port of Cork's planned move to Ringaskiddy, the potential for larger draught vessels, larger volumes entering the wider harbour including key ferry lines such as the Cork-Roscoff and Cork-Swansea ferries.

In this regard, it is worth noting that the peak tidal flow at this location is circa 12,000m^3/s which is also significantly greater than at any of the other locations. Average velocities are circa 0.75m/s. Therefore, to ensure that velocities for navigation are constrained to manageable levels, the cross section area of flow gates required at this location will be significantly greater than at other locations further in the harbour.

5.3.5 Technical Viability

It is readily apparent that a barrier at this location has sufficient storage volume to cater for extreme fluvial events during a closure of the barrier, even allowing for the greater sources of inflow versus that at other barrier locations, e.g. Owenacurra, Owenaboy etc. Furthermore, because of the large volume of storage, it may be possible to reduce the required period of closure of the barrier, i.e. close it later than at low tide.

It is worth noting however that there are no examples of tidal barriers in the world with a depth below mean sea level of greater than 20m, whereas a barrier at Roche's Point would need to be circa 30m below mean sea level. This therefore would present very significant challenges in the engineering design of a barrier at this location.

5.3.6 Economic Viability

Notwithstanding any of the above, this option ultimately falls away on economic grounds given the presence of a more viable solution at Great Island and the order of magnitude difference in cost.

The CFRAM study concluded that a barrier at this location would likely cost €2.7 billion. As a barrier of this scale has never been constructed before, undertaking a bottom up build-up is simply impossible at this level of study.

Undertaking a top down estimate is also fraught with uncertainty as there are no relevant examples of similar projects as noted above. However, it is possible to estimate using a top down analysis. As will be seen in Section 11, we have undertaken analysis to develop a correlation between the area of the structure in elevation and cost. Whilst this correlation is likely to underestimate the exponential increase in cost with depth, it nonetheless suggests a cost of > €2.7bn. The Venice Barrier cost is circa €4.6bn and given that it is marginally longer at 1.5km but only half the depth at 15m below mean sea level, it is evident that this cost estimate is not unreasonable.

5.3.7 Ecology

This tidal barrier is outside the boundary of both the SAC and SPA. However, this site has been monitored for bird activity (White Bay to Graball Bay) by National Parks and Wildlife Service (NPWS). Small numbers of Great Crested Grebe and known to forage here with Cormorant and blackheaded foraging and roosting sites present. Oyster Catcher uses the coastline in this location for foraging and roosting. In total there are 9 roost locations and 7 species are known to use the site. While it is outside the SPA consideration of impact on these birds would need to be considered and appropriately mitigated against.

5.3.8 Conclusion

It is evident that this is not currently a viable option and would only potentially become viable if the extent of sea level rise and increased river flows were such that a barrier at Great Island became technically unviable.

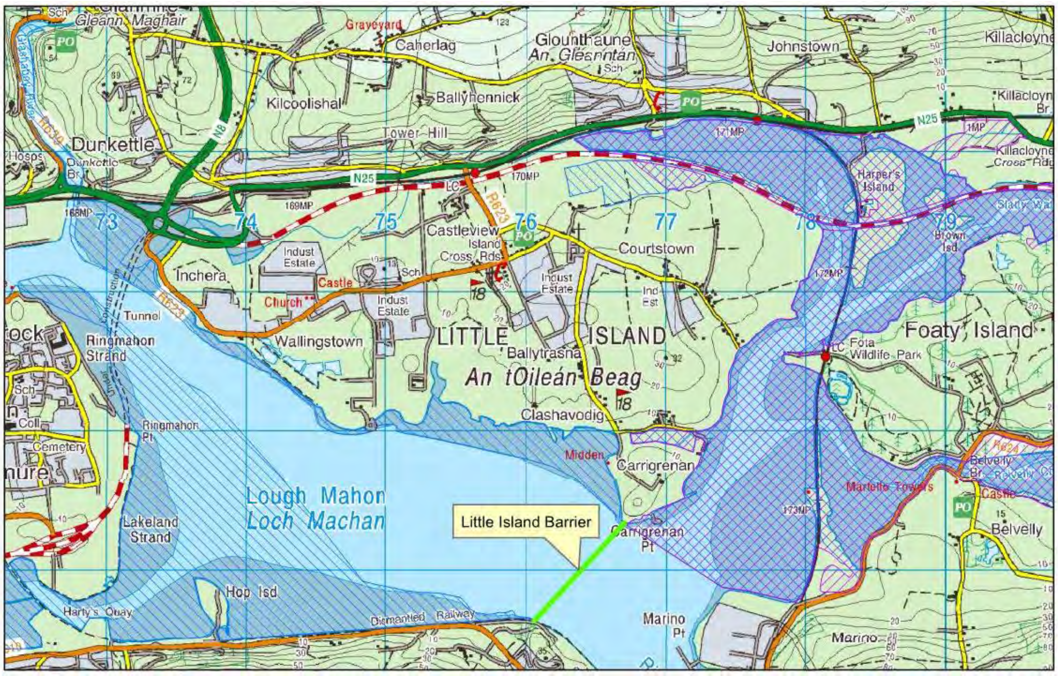
5.4 Barriers at Little Island

At exhibition stage, a stakeholder group submitted various iterations of a proposal for an alternative solution including a tidal barrier. In May 2017, it submitted a final proposal for flood management for Cork which it entitled 'Potential Cork, The Save Cork City Solution'. In these submissions, the stakeholder group proposes a three-point plan to control flooding in Cork by using a downstream tidal barrier in combination with the repair of quay walls and upstream catchment management measures. It should be noted that the quay wall element in this scenario would not actually serve a flood risk management function but rather would simply be an investment in the repair of the historic quays.

The barrier solution finally proposed by the stakeholder group comprises two constituent elements. The main tidal barrier is proposed at Little Island at the downstream end of Lough Mahon. As part of consultation with the stakeholder group during the exhibition process, the design team pointed out that a barrier at this location could be bypassed via the low lying lands to the north along the railway line. The stakeholder group subsequently included an allowance for what it describes as 'minor supplementary measures' to the north of Little Island.

The main tidal barrier location at Little Island is between Leecarrow to the southwest and Carrigrennan Point to the northeast. See Figure 22 below.

Figure 22: Little Island Barrier Location



The stakeholder group's proposal advises that such a barrier would be approximately 910m in length, in a depth of water between 1m to 8m deep with protection for 0.5% Tidal AEP and with sufficient storage for a 1% Fluvial AEP event.

The proposal does not give further details on the overall height of the barrier.

The stakeholder group proposes that the minor barrier would be 20m wide, in a depth of water of less than 5m but does not give any further detail as to the location of this barrier.

The submission states that such a barrier would have a total cost of €135 million, including maintenance. However, no further detailed information was provided in relation to the build-up of this cost.

A subsequent cost estimate report commissioned by the stakeholder group and produced by HR Wallingford estimated a cost of €140 million for the tidal barrier concept (HR Wallingford, 2017). This excludes operation and maintenance, costs to deal with the bypass and a number of other project costs which have either been excluded or underestimated.

The potential viability of a barrier at this location is assessed further in Chapters 8 and 9 of this report. Costs are considered in Chapter 11.

5.5 Barriers at Great Island – with Separate Structures at Monkstown and Marlogue Point

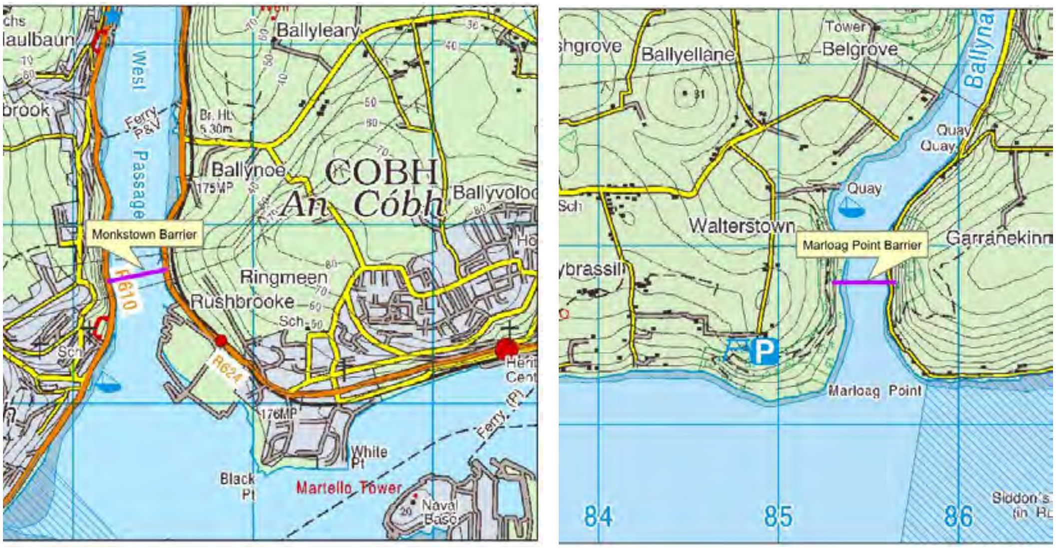
This option was considered as part of the Lee CFRAMS and includes two barriers east and west of the Great Island in Cork Harbour.

The tidal barrier proposed at the Monkstown side is located between the coast road R610 on the west and Summer Point/R624 to the east. The proposed barrier is approximately 310m in length with a height of circa 23m.

The tidal barrier proposed at Marlogue Point is located between Walterstown to the west and Garranekinnefeake to the east. The proposed barrier is approximately 295m in length with a height of circa 13m.

The proposed locations are shown in Figure 23 below.

Figure 23: Monkstown and Marlogue Point Tidal Barrier Locations



A barrier at these locations has the added benefit, over the barrier at Little Island, of protecting Midleton, Little Island, Glounthaune and Passage West as well as providing significantly greater upstream storage. Therefore, it is more likely to be a viable location for a barrier in the longer term in the face of climate change. A more detailed assessment of this location is undertaken in Chapter 10 of this report.

The CFRAM study concluded that these barriers would cost in the order of €341m. However, we consider that this likely significantly underrepresents the potential costs of such a scheme. Further detailed cost information is provided in Section 11 of this report.

6 Configuration Options

Based on a desk study review of feasible barrier types in use around the world, this section of the report provides a summary of the gate types that that could be considered for Cork Harbour. Consideration of the barrier has been broken down into the three primary constituent elements of a typical tidal barrier as follows:

- Navigation Gate Options
- Flow Gate Options
- Impounding tidal embankment/wall.

6.1 Navigation Gate Options

The main types of navigable storm surge gates include:

1. Mitre Gate – Double leaf gate
2. Vertical lifting gate
3. Vertical rising gate
4. Flap gate
5. Sector gates – rotating around vertical axis
6. Radial gates – sector gate rotating around horizontal axis
7. Segment gates – rotating around horizontal axis
8. Inflatable rubber dams mounted to the sill.

Based on Port of Cork requirements, navigation gates in Cork would need to provide the following:

• Depth below low water at Mean Spring Tide:	7.2m (-10mOD)
• Clearance height above high water at Mean Spring Tide:	46m (50mOD)
• Width of full depth channel on straight:	Min 75m
• Width of full depth channel on bend:	Min 90m

In the case of Cork Harbour, a number of gates types can be summarily ruled out for the navigation gate element for the following reasons:

- Mitre gates because they are difficult to control under flow or wave action and are suitable for only limited spans of up to 30m approx. which would be insufficient for size of ships in cork.
- Vertical lifting gates as they would require 60m high towers to lift barrier clear for the required navigation height clearance and would be an unacceptable intrusion in such a sensitive landscape.
- Vertical rising gates because required navigation depth would result in excavating between 10m and 20m below bed level, potentially in rock and or dense gravels so likely to be cost prohibitive versus other options.

- Radial gates because they are not typically used for navigation spans greater than 50m.
- Inflatable rubber barriers as the solution is unproven for the type of heights and tidal range required in Cork (i.e. 15m to 25m).

Therefore, because of the required height of barrier in Cork (15m to 25m, circa 5mOD to -20mOD) the most likely viable solution would be one of the following;

- Flap gates
- Sector gates
- Segment gates

These are discussed further below.

6.1.1 Flap Gate

Curved or straight gates hinged to the sill. The gate pivots around a fixed axis at the bottom of the sill, and as it lifts up the gate becomes closed. When opened, the gates remain submerged and flat at the bottom.

Example: MOSE, Venice, Italy.

The pros and cons of such gates are illustrated below.

Table 6: Pros and cons of Flap Gates.

Pros	Cons
Relatively short closing period process.	Complex design and construction.
Low visual impact.	Problems with sedimentation and maintenance.
No navigation constraints.	Can't handle heavy wave loads.
	Overtopping problems.
	Future expansion is difficult to achieve.

This barrier option is likely unsuitable for Cork for a number of reasons including the difficulty involved in their maintenance and issues with sedimentation. A preliminary analysis also suggests that this type of gate is unlikely to prove the most cost effective for Cork.

6.1.2 Sector Gate (or Floating Gate)

This solution consists of two twin circle shaped horizontal gates, supported with a steel frame that transfers the loads into bearings located in the sides of the barrier. The gates rotate around two vertical axes with the centre at the bearings. The gates can float for ease of closing and opening. When gates are not operational (in open position), gates are housed in a built dock. Example: Maeslant Barrier, the Netherlands, St. Petersburg Barrier, Russia and the Seabrook Floodgate Complex, US. The pros and cons of such gates are illustrated below.

Table 7: Pros and Cons of Sector Gate

Pros	Cons
Low sedimentation issues.	Longer closing period process than other gates. Requires long term planning.
Can handle heavy loads.	Leakage of water may occur between two gates.
No overtopping problems.	High space requirement due to large structure.
Easier maintenance as the gates are housed on land.	Difficult design and construction.
No navigation restrictions.	Future expansion is difficult to achieve.
Proven technology.	Ideally requires flat land at either side of opening for efficient construction of housing.
	Width of housing is wide and provides significant barrier to flow.

This type of barrier isn't particularly suitable at the Great Island location due to the narrow channel and high ground at either side limiting the ability to efficiently construct a dry dock, without significantly impact flow.

The use of sector gates at the Little Island location could be an option, if you only required one navigable channel. There would be sufficient space to construct dry dock housing either side of the navigation channel, although it would require significant dredging. However, for redundancy and navigation reasons, it would be preferable to have two navigable channels. Due to the requirement for large dry dock housing, it is unlikely two sector gates would fit side by side within the current dredged navigable channel. Also the presence of the dry dock housing in the middle of the navigation channel would have a negative impact on the environment and conditions in the river due to the altered velocities. Other gate types would be preferable in this scenario.

6.1.3 Segment Gate

The segment gate rotates around a horizontal axis which passes through the bearing centre. In the opened position, the gate sits in the sill, allowing navigation. The gate is brought to a closed position by turning through 90°. By turning through another 90°, the gate is lifted above the water for maintenance and inspection.

Examples similar in scale to that needed in Cork would include the Thames Barrier, London, UK and the Ems Barrier, Germany.

The pros and cons of a vertical rotating segment gate are outlined below.

Table 8: Pros and cons of vertical rotating segment gate

Pros	Cons
Proven technology.	High maintenance costs.
Less sedimentation issues compared to other underwater systems.	Overtopping problems.

Pros	Cons
Short closing period process	High visual impact as significant portion of the structure is above water level
Lifting gate enables easier maintaining process.	Future expansion is difficult to achieve.
Allows navigation with no depth or height restrictions.	Complex building process for sill structures.
Width of piers is small in proportion to opening so low impact on flow area over length of structure. Allows flow gates to sit immediately adjacent minimising turbulence.	Large space requirement.

From our preliminary analysis, we consider that a segment gate is likely to be a viable navigation solution for any tidal barrier in Cork either at the Little Island or Great Island locations.

6.1.4 Comparison of Shortlisted Gate Options

Based on the barrier requirements discussed previously, the following table summarises a number of the criteria that are considered important in the Cork Harbour setting based on a traffic light system.

A Segment Gate is considered most likely to represent the optimum navigation option for Cork at the Little Island or Great Island Location, in particular for the Great Island locations. A sector gate may also provide a suitable option at the Little Island location.

Table 9: Comparison of Gate Type Options

Barrier Gate Type	Flap Gate	Sector Gate	Segment Gate
Reliability	Cannot handle heavy wave loads. Still unproven as Venice not yet complete.	Proven technology, number of examples worldwide.	Sufficiently proven technology, quick to close.
Maintainability	Difficult to maintain as the gate stays underwater in open position.	Easy maintenance as the gate in open position is in dry dock.	Lifting gate allows for easier maintenance.
Future sea level rise	Very Difficult to expand in the future.	Very Difficult to expand in the future.	Not as difficult to expand.
Resistance to sedimentation	Problems with sedimentation as the gate stays underwater in open position.	Less sedimentation issues as gate is out of water in open position.	Less sedimentation issues compared to other underwater systems.

Barrier Gate Type	Flap Gate	Sector Gate	Segment Gate
Visual Impact	Lowest visual impact.	Visual impact in Cork would be significant.	Significant visual impact as large structures above water.
Navigation	Minimal navigation restrictions when in open position.	Minimal navigation restrictions when in open position. Dependant on gate width.	Minimal navigation restrictions when in open position. Dependant on gate width.
Access	Cannot be combined with a road/bridge. Requires access to foundation which will be difficult in Cork situation.	Would need access from both sides but achievable at Little Island location. More difficult at Great Island.	Would need access from both sides with possible movable bridge for central pier.
Cost	Likely to be highest cost due to most significant underwater element.	Cost dependent on location and gate lengths. Likely to be more expensive than vertical segment gate.	Likely to be least expensive option.
Constructability	Most complex to construct, new technology.	Difficult and complex design and construct. Not suitable for Great island location due to adjoining topography.	Complex to construct but proven examples.
Compatibility with complimentary flow gate	Can sit immediately adjacent to likely flow gate structures.	Size of Dry Dock impacts compatibility with other structures.	Can sit immediately adjacent to likely flow gate structures.

6.2 Flow Gate Options

The requirement for the flow gate elements are significantly different to that of the navigation gates in Cork.

The required navigation depth is to a minimum of circa -10mOD meaning that the navigation gates would need to be at least 15m high.

However, low spring tide is circa -2mOD meaning that the flow gates would only need to be greater than 6m high.

Furthermore, as the navigation clearance height requirement will not apply at the location of the flow gates, the options of vertical lift gates (which are typically less expensive and easier to maintain) become an option.

The requirements will also differ significantly between the Little Island location and the Great Island location for the following reasons:

- There is a significantly greater tidal peak flow at Great Island than at Little Island requiring a larger flow area.
- Because of the narrower channel either side of Great Island and thus higher velocities, it is probable that the Great Island location will be more sensitive to any change in cross sectional flow area, thus increasing the requirement for increased flow area.

To assess the flow gate options, it is first necessary to estimate the likely flow area required, extra over the flow area provided through the navigation gates. This exercise is described below separately for both the Little Island and Great Island location.

6.2.1 Flow/Velocities at Little Island Location – Initial Assessment

A simplified method has been used to estimate the existing average velocity at the location of the Little Island barrier and determine the required combined width of gate opening in order to ensure that the velocities with the barrier in place are not excessively high. In preparing this report, we have also undertaken detailed hydrodynamic modelling of various barrier options in order to assess in greater detail the impact of the barrier on the hydrodynamics. This work is presented in Chapter 7.

The steps in the initial assessment method presented here are:

1. Calculate the tidal prism upstream of the proposed tidal barrier location;
2. Using the continuity equation, determine the average velocity through the openings of the barrier assuming that the volume of water passing in a single tidal cycle is equivalent to the tidal prism.

The calculation is presented in Table 10 below.

Table 10: Hydraulic Calculation for Little Island Barrier Location - Spring Tide

Hydraulic Calculation for Little Island Barrier Location - Spring Tide Conditions				**Comments**
		Average	Peak	
Tidal Prism Calculation	Upstream surface area (m^2)	6,600,000		
	Max tidal range during Spring Tide (m)	4		
	Time for tidal fall (hrs)	5		
	Rate of tidal fall (m/hr)	1		
	Flow rate (m^3/s)	1,467	2,347	**Assume peak is circa 1.6 times the average**
	Existing cross section area at MSL (m^2)	4,600	4,600	
	Existing Velocity during Spring Tide (m/s)	0.3	0.5	

Hydraulic Calculation for Little Island Barrier Location - Spring Tide Conditions				**Comments**
		Average	Peak	
	Proposed Navigation gate width (m)	120	120	
	Depth of water through navigation gates (m)	9	9	
	Water cross section area at navigation gate (m^2)	1,080	1,080	
	Velocity with navigation gate only (m/s)	1.4	2.2	**Too High - Need Flow Gates**
With additional openings	Proposed area of additional flow gates (m^2)	750.0	750.0	**Note that as the tidal elevation varies, the available area of flow will vary for fixed width gates**
	Total cross sectional flow area with additional gates (m^2)	1,830.0	1,830.0	
	Velocity through navigation gate with additional gates (m/s)	0.8	1.3	
	Bed Elevation at gate (mOD)	-0.50	-0.50	
	Water elevation (mOD)	2.00	2.00	
	Water depth (m)	2.50	2.50	**Assumed at mid tide**
	Total width of gates (m)	300.00	300.00	

It can be seen from the table that with no barrier in place, the average velocity passing the proposed Little Island barrier is 0.3m/s. By reference to recorded data from Lough Mahon (Figure 15) we can see that 0.3m/s is a good estimate of the average velocity at this location.

If we first assume that only a 120m wide navigation opening is to be provided in the barrier design, (i.e. with no additional flow gates and a sill level approximately the same as the bed level), the average velocity through the main navigational opening would be circa 1.4m/s which is deemed too high for safe navigation.

However, by inclusion of additional flow gates, the area available to flow is increased and the average velocity is reduced as a consequence. We can see from the table that by the inclusion of an additional 750m^2 of flow area, the average velocity is reduced to 0.8m/s. This is considered closer to an acceptable level in the context of safe navigation at this location, particularly given the smaller scale of pleasure craft prevalent at this location.

The area available for flow is the width of flow gate (which is fixed) multiplied by the depth of water flowing through the gate (which will vary depending on the tide). The provision of an additional 750m^2 of flow area at mid tide (when the average depth of water at the flow gates is circa 2.5m) in the barrier can be achieved by providing 300 linear metres of flow gates at different locations along the barrier.

It should be noted that for a fixed length of additional flow gate openings, the actual area available to the flow varies as the water depth will vary due to the tide. For this reason, it is important that an optimal height is set for the gates as well as setting an appropriate sill level vertically in the channel.

As mentioned previously, Cork Harbour experiences approximately a tidal level range of 4m during spring tides and approximately a 2m range during neap tides. Based on the larger tide variation of 4m and to provide a suitable flow area, 6m high gates set at the existing bed would be appropriate for this flow regime.

It is likely that a number of gates spread across the barrier length would provide a more suitable flow setting for water to flow and prevent silt building up in localized spots around the gates and barrier in general.

It should be noted that this arrangement still means than only circa 40% of the existing width of Lough Mahon would be available to convey flows. As this will likely have significant impact on sedimentation patterns, dredging requirements and the SAC/SPA, it is possible that after further detailed study, the area of flow gates might have to increase (with associated increases in costs).

The impact of various barrier arrangements is considered further in later chapters of the report.

6.2.2 Flow/Velocities at Great Island Location

A similar analysis was undertaken for the proposed barriers either side of Great Island. At these locations, the channels are extremely narrow for the peak tidal flows conveyed, meaning that the existing velocities are significantly greater than at the Little Island locations. Average velocities at these locations are already approaching 1m/s and therefore any reduction in flow area at these locations would have a detrimental effect. Therefore, at these locations, it is recommended that flow gates be included across the full width of the channel such that the reduction in cross sectional flow area is limited to the area taken by the piers for the navigation and flow gates.

6.2.3 Type of Flow Gate

In addition to the gate types discussed and described above, some of the other gate types, deemed unsuitable for the navigation gate element in Cork, could be suitable for the flow gate element. These include the following:

- Vertical lift gate
- Inflatable gate
- Radial Gate
- Rolling gate
- Swing gate

These are discussed further below:

6.2.3.1 Vertical Lift Gates

Vertical lift gates are lifted vertically from the sill to open. Lifting is undertaken using a tower with overhead cables, sheaves and bull wheels to support the gate during its operation. Even for a flow gate the visual impacts of this structure would be significant in Cork Harbour.

6.2.3.2 Inflatable Gates

An inflatable gate is basically a sealed tube made of a flexible material, such as synthetic fibre, rubber, or laminated plastic. It is anchored to the sill and walls by means of anchor bolts and an airtight and watertight clamping system. The gate is inflated with air, water, or a combination of the two. This is a low visual impact option but could be considered technically inferior to some other options due to slow gate operation and risk of vandalism.

6.2.3.3 Radial Gates

A radial gate is similar to sector gate however is rotates around a horizontal axis rather than a vertical. It is also generally much smaller and can accommodate maximum spans of approximately 50m. In the closed position the segment gate rests on the sill or raised above the water level. The visual impact would be dependent on the closed position.

6.2.3.4 Rolling Gates

Rolling gates are closure panels which are rolled into position in anticipation of a flood event, and stored adjacent to the waterway under normal conditions. This is a high visual impact option and is only suitable in a sheltered environment and for spans less than 60m in length.

6.2.3.5 Barge Gates

A barge gate, also known as a swing gate, is a caisson stored on one side of a waterway, pivoting around a vertical axis to close. This is a high visual impact option and is only suitable in a sheltered environment.

Notwithstanding that visual impact would require further careful consideration, for concept purposes, we have assumed that vertical lift gates would be feasible in Cork as they are likely to be the most cost effective and are a very well proven technology.

6.3 Impounding Embankment

At Little Island there would be a requirement for an embankment or bund component to extend from land and connect to the flood gates located in the deepest part of the channel, as shown in the typical cross section of the channel bed levels in Figure 59.

The embankment would also have a small access road across the top of the barrier for maintenance and inspection purposes and for ease of access to the gates. A 5m wide crest has been assumed for this assessment.

Given the sensitivity to flooding behind the barrier when closed, it is assumed that the barrier would need to be impermeable and therefore its construction would need to take this into account. On this basis, an embankment with the following characteristics would likely be suitable;

- Side slopes of 1: 2.5, with a crest width of 5m;
- An outer layer of rock armour, 1.9m thick made up of 1 to 3 tonne rock;
- An under layer of rock armour, 0.9m thick made up of 60 to 300kg rock;
- Core material made up of selected sand/clay to achieve impermeability;
- Sheet piling that will be installed to bedrock

We would note that the final make-up of any impounding embankment is subject to detailed design and will need to consider the particular geological and hydrogeological conditions at the location, together with the choice of flow gates and navigation gates and required access to same.

7 Hydrodynamic Modelling

7.1 Introduction

In order to assess the impact of constructing a tidal barrier in Cork Harbour, a detailed high-resolution hydrodynamic model of the harbour has been developed as part of the study. Three alternative barrier locations have been assessed.

The model has been developed using the flexible mesh (FM) version of MIKE 21 HD which is produced by the Danish Hydraulics Institute (DHI). MIKE 21 is recognised internationally as being one of the leading edge coastal and estuarine modelling software systems in the world.

The model was first configured to represent the existing (baseline) scenario i.e. with no barrier in place. The geometry of the model was then reconfigured to represent various tidal barriers at a number of locations in the harbour. By comparing the results of the baseline scenario model against each tidal barrier model, the impact of the barriers on the velocities and water levels in the harbour can be established. The findings of the analysis can then be used to develop an informed assessment of the impact each potential barrier would have on navigation, sediment transport and the environment.

A detailed description of the model build and its calibration is detailed in Appendix A. The results of the model are presented in this section.

7.2 Baseline Conditions in the Harbour

Figure 24 presents the maximum[1] modelled velocities reached over a complete spring tidal cycle for the baseline scenario. We can see from the plot that the maximum velocities vary considerably in the harbour. In the outer harbour, the highest values range from circa 0.1m/s to 1m/s with the highest values confined to the deep navigational channel. The highest velocities in the harbour are in the East Passage where they exceed 1.2m/s. In the West Passage it can be seen that the maximum values vary spatially between Monkstown and Marino Point and are generally in excess of 0.8m/s. Maximum velocities in the navigational channel in Lough Mahon range from circa 0.9m/s to circa 0.5m/s.

The maximum velocities on the shallow mudflats throughout the harbour are relatively low and are typically less than 0.3m/s.

[1] Over the course of each model simulation the velocity at every cell in the computational mesh of the model will, at some specific moment, reach a maximum value. These maxima, at each and every cell, may be extracted from the result files of a model run and potted on a single diagram to present the spatially varying maximum velocity over the entire model simulation period or a portion of the model simulation.

Figure 24: Maximum velocity for a full tidal cycle – baseline conditions

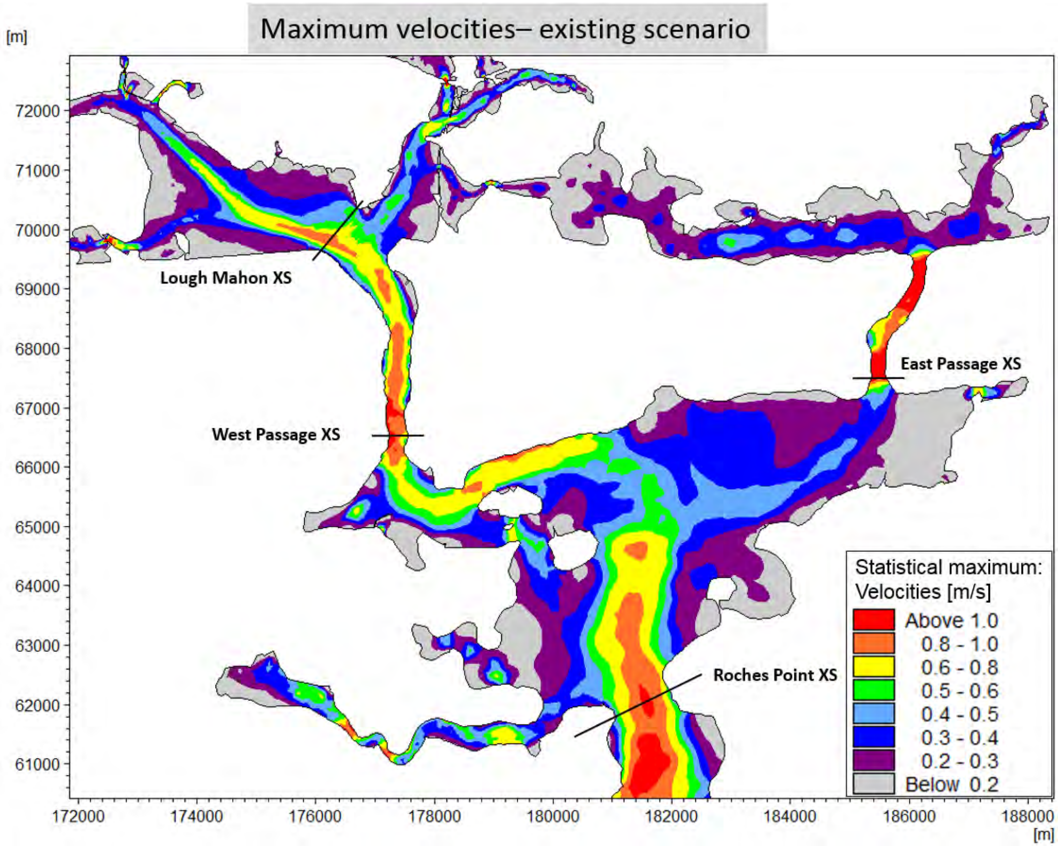


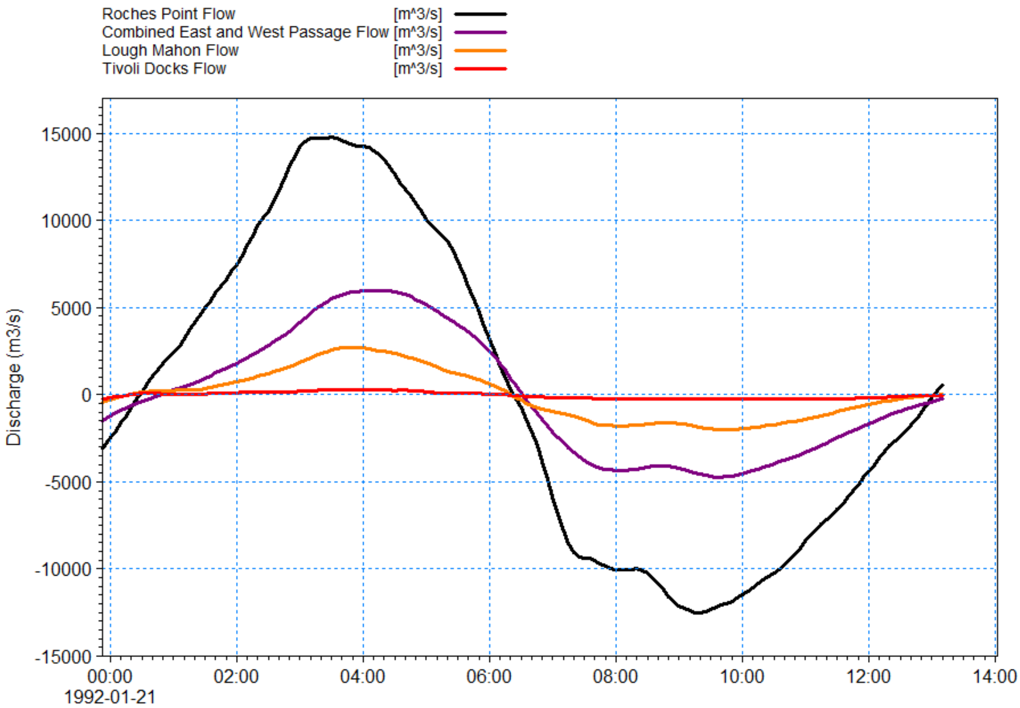
Figure 25 presents the discharge time series[2] for the four cross sections marked on Figure 24 with black lines: Roche's Point, East Passage, West Passage and Lough Mahon.

It can be seen from Figure 25 that the peak discharge into the harbour at Roche's Point is circa 14,800m^3/s on the flood tide and circa 12,000m^3/s on the ebb tide.

The peak discharge entering Lough Mahon on the flood tide is circa 2,700m^3/s and circa 2,000m^3/s on the ebb tide.

[2] MIKE 21 facilitates the extraction of discharge time series across defined cross sections of the model.

Figure 25: Discharge time series for a number of sections located in the harbour



7.3 Proposed Barrier Options Modelled

Three different barrier options were modelled as follows:

- Option 1 – Barrier at Little Island as per the layout submitted by a stakeholder group. We note however that we have assumed the location of the three additional flow gates along the structure as these locations were not identified by the stakeholder group.
- Option 2 – Amended version of Little Island Barrier as presented earlier in Section 9 with layout and dimensions considered to represent a potentially viable version of Option 1. We note that this option involves larger gate openings than the first option and also has an improved alignment.
- Option 3 – Barriers either side of Great Island (gated across the full width of each location).

Section 7.4 outlines the elements of Tidal Barrier at Little Island Option 1 and presents the model results. Section 7.5 does likewise for Tidal Barrier at Little Island Option 2. The third Barrier Option (Monkstown and Marlogue Point) is presented in Section 7.6.

In order to aid the reader in understanding the impact of the barrier on the hydrodynamics, the results of the baseline scenario model are also presented to assist the reader in comparing the proposed case against the existing.

We have assumed in all of our barrier models that the various flow gates are fully opened. Due to maintenance needs, there will be occasions when some of these gates need to be closed. Consequently, there will be times when the area available to flow will be less than what we have modelled and hence there will be times when the velocity of the water passing through the gates will be increased over what is presented in the various plots.

7.4 Model Results for Proposed Tidal Barrier at Little Island (Option 1)

This section presents the results of the hydrodynamic modelling for the Tidal Barrier as proposed by a stakeholder group at Little Island (Option 1).

Tidal barrier Option 1 at Little Island, consists of a 60m navigation gate in the deepest part of the channel with three additional 30m wide flow gate openings. While an alignment for this barrier has been proposed by the stakeholder group, the position of the three 30m wide flow gate openings along the alignment have not.

The main 60m wide navigation gate is located in the centre of the deep channel with a flow gate set at either side set back at an appropriate distance. We have assumed that the third flow gate is positioned on the Northern mudflat in order to allow an exchange of water at this location in order to minimise the impact of the barrier on sediment transport. We have assumed in our model that the sill level of all the openings in the barrier are equivalent to the existing bed levels at their respective locations.

7.4.1 Velocity Plots

Figure 26 presents the velocities on the flood tide for circa 1.5 hours after low tide. It can be seen that the barrier is acting as an obstacle to the incoming tide and forcing water through the single navigational gate opening and the additional flow gates. As the available cross sectional area offered by all of the openings is much less than the cross sectional area in the baseline scenario, the water is forced to speed up as it passes through the openings. It can be seen that the velocity through the openings is greater than 1.6m/s at this stage of the tide which represents a significant increase over the baseline. Velocities adjacent to the embankment section of the barrier (away from the gate openings) however, are reduced as the barrier is acting as an obstacle to the flow and blocking water from moving upstream across the width of Lough Mahon.

Figure 26: Flood tide conditions - Circa 3 hours after low tide

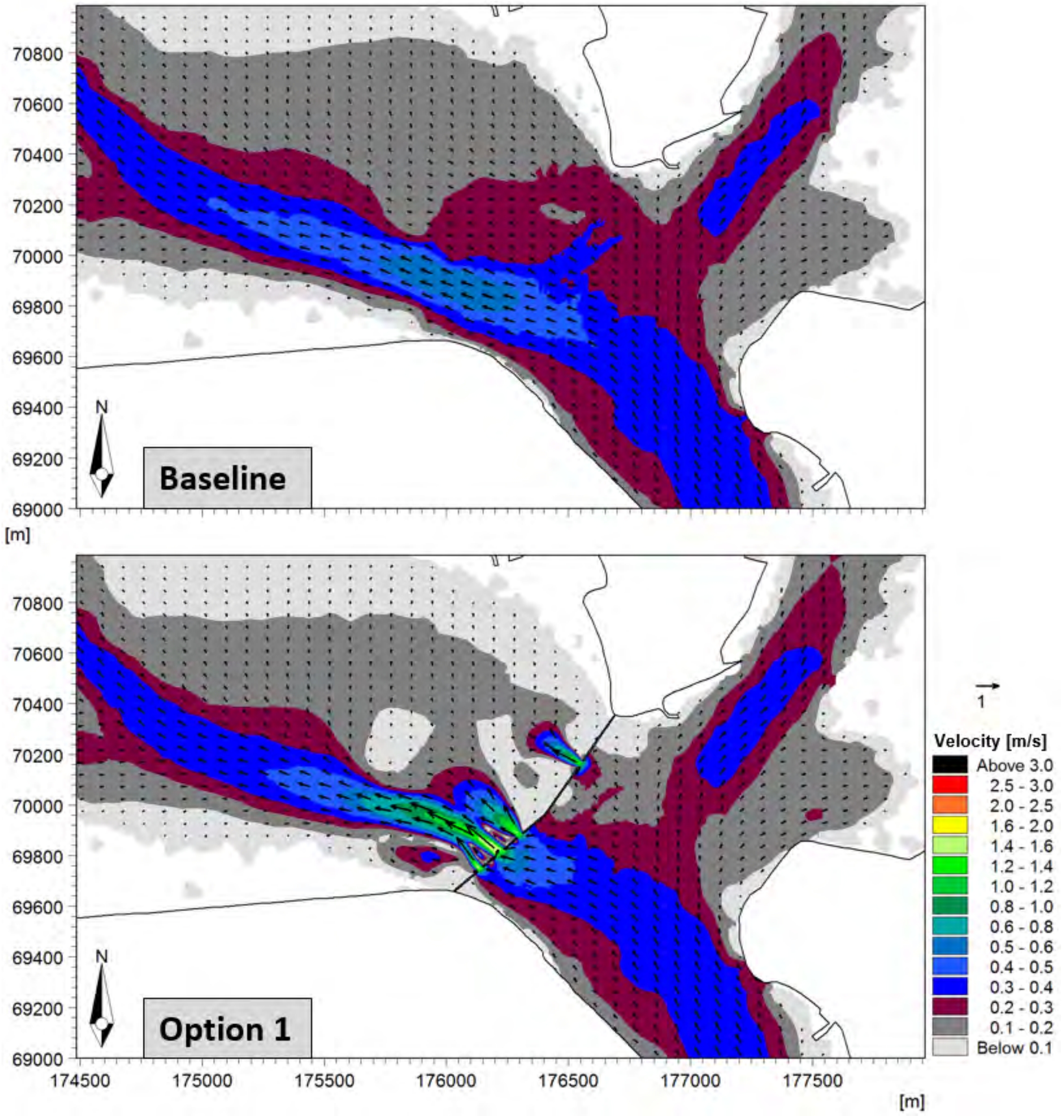
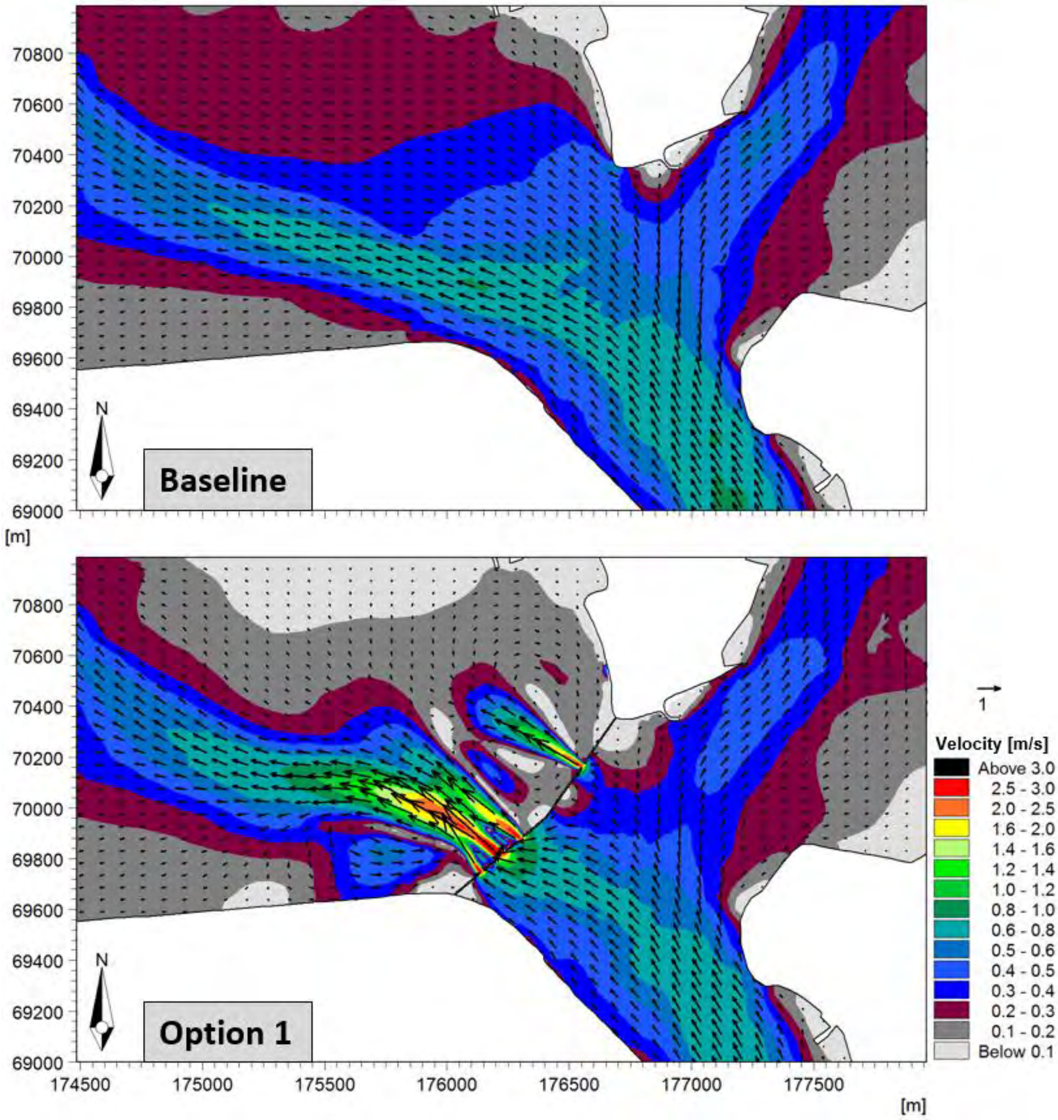


Figure 27 presents the velocities from the time at which they reach their maximum on the flood tide (circa 3.2 hours after low tide). It can be seen that the barrier has a very significant impact on the velocities at this stage of the tide: the peak velocity through the main navigational gate exceeds 3m/s which is extremely high and represents a very significant increase over the baseline of circa 0.9m/s. The peak velocity though the additional flow gates are also extremely high and are just under 3m/s.

Figure 27: Peak velocities on the Flood tide - Circa 5 hours after low tide



In addition to causing a very significant increase in velocity through the openings, the results of the model clearly indicate that the tidal barrier also exerts a very significant influence on the overall hydrodynamics in the vicinity of its openings. While this is evident from Figure 27, it is better examined by inspecting the model results close up i.e. by zooming in the results as presented in Figure 27.

Figure 28 therefore presents the same results as shown in tidal barrier plot of Figure 27, but with a view zoomed in on the navigational gate opening. It can be seen from the plot that there is a very significant spatial variation in the hydrodynamics in the vicinity of the upstream side of the barrier. The flow through the openings of the barrier are acting as fast flowing high energy jets of water with peak velocity in excess of 3m/s. Between the jets of water however the hydrodynamic conditions are very different as the jets have created eddies and the water is flowing back against the barrier. The velocities in this region are very low and are virtually slack in some areas.

This very significant difference will lead to very high shear stresses in the water column between the fast flowing jet of water and the very slow moving area of slack water which in turn will create very high turbulence in the water column adjacent to the barrier openings.

Figure 28: Peak velocities on the Flood tide (Zoomed in to navigation gate)

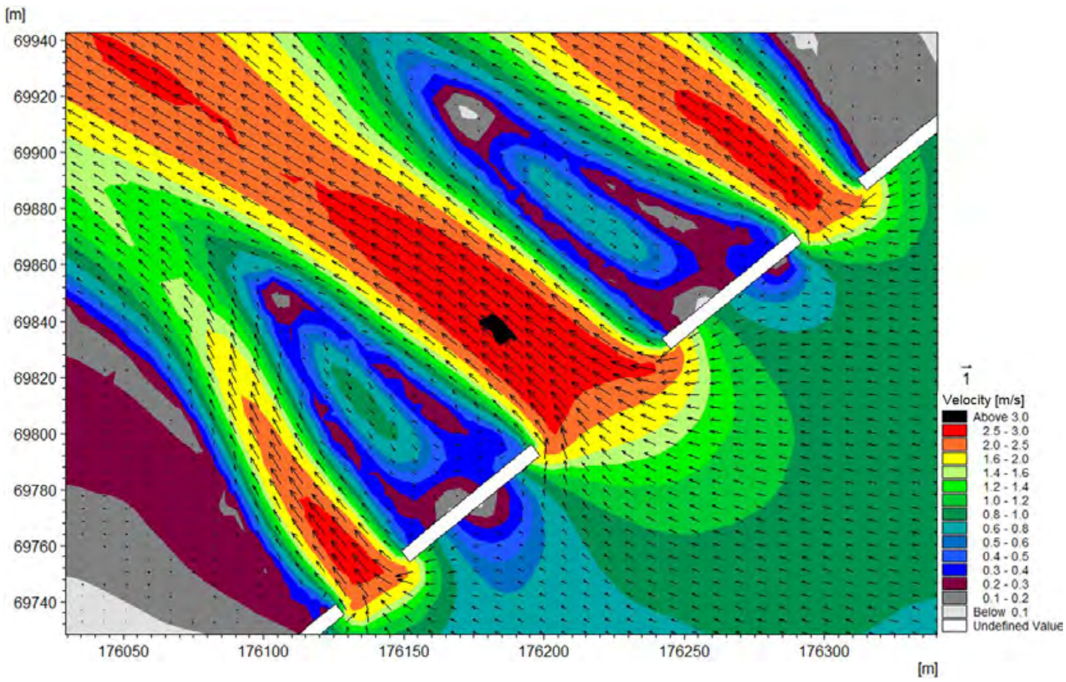
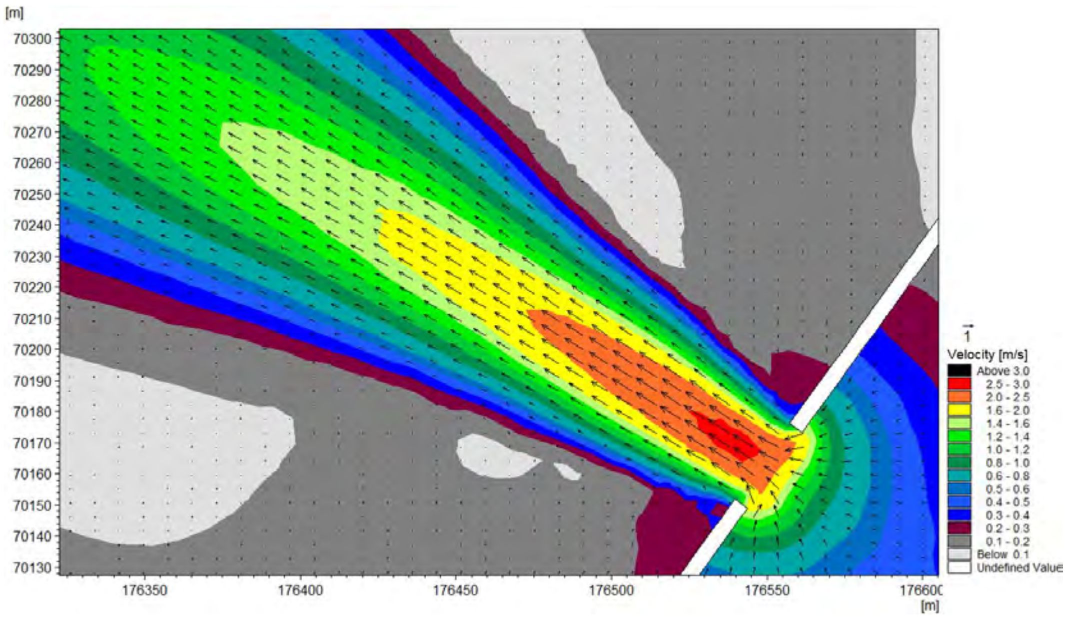


Figure 29 presents a zoomed in view on the additional flow gate on the northern mud flat of Lough Mahon. It can be seen from the plot that just as with the flow through the main navigational gate, a very fast flowing high energy jet of water has formed due to water being squeezed through the flow gate opening. The maximum velocities are up to 3m/s. Adjacent to the jet of water however the water is moving very slowly which again will lead to high stresses in the water column and high turbulence.

Figure 29: Peak velocities on the Flood tide (Zoomed in to northern mud flat)



The Calculator tool in MIKE 21 allows individual results files to be extracted from each other. We have subtracted the baseline model results from the Tidal Barrier Option 1 model results to determine the difference in velocities between both scenarios.

Figure 30 presents the difference for the time at which maximum velocity occurs i.e. the difference between the two plots presented in Figure 27. As the calculation was undertaken by subtracting the baseline scenario model from the barrier model, a reduction in the velocity is represented by negative values in the figure and an increase in the velocity is represented by positive values. In order to allow the reader easily interpret the results, the increases and decreases have been presented on two separate plots in the figure.

It can be seen from the figure that velocities have been increased by over 1.5m3/s through all the gate openings. Equally we can see that the velocities have also been reduced in some areas upstream of the barrier by circa 0.8m/s. These changes in velocities are deemed to be very significant and will have considerable adverse impacts on the safe navigation of ships through the barrier opening, sediment transport and on the environment. The impact is discussed further in Section 8.4 of the report.

Figure 30: Difference in velocity versus baseline for peak velocities on the flood tide

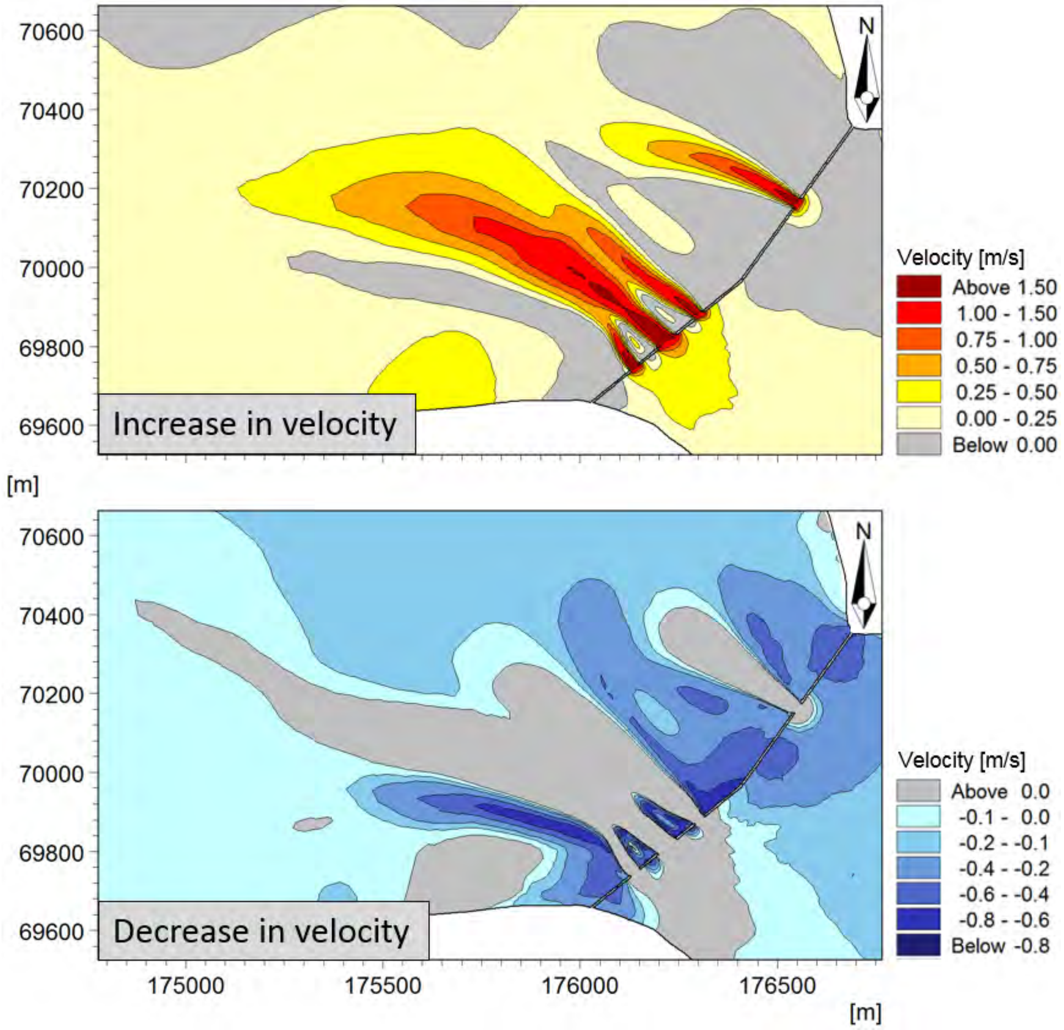


Figure 31 presents the velocities for ebb tide conditions circa 2 hours after high tide. It can be seen that as with flood tide conditions, the barrier is acting as an obstacle to the flow and is forcing water through the various openings resulting in a significant increase in the velocities over the baseline. In some areas the velocities are reduced due to the barrier acting as an obstacle to the flow and preventing water from moving downstream across the full width of Lough Mahon.

Figure 31: Ebb tide conditions – circa 2 hours after high tide

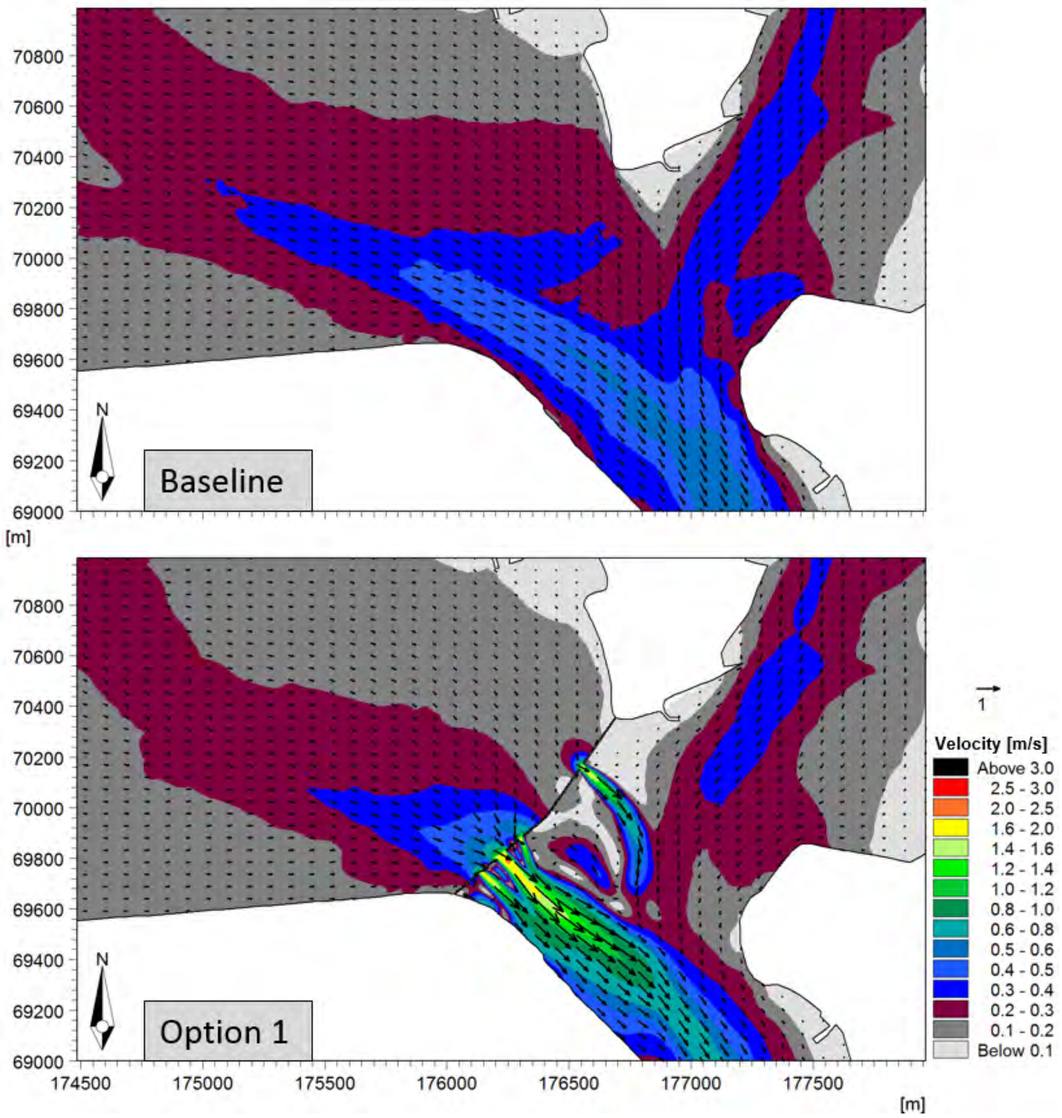


Figure 32 presents the velocities for the time at which the ebb tide velocities reach their maximum (circa 3.5 hours after high tide). It can be seen that the increase is similar to flood tide conditions – through the main navigational gate opening and additional flow gate openings the velocities have been increased by circa 1.5m/s to just under 3m/s; velocities adjacent to the embankment of the barrier however have been reduced by as much as 0.4m/s to 0.6m/s. This represents a very significant change in the hydrodynamics.

Figure 32: Peak velocities on the Ebb tide - Circa 3.5 hours after high tide

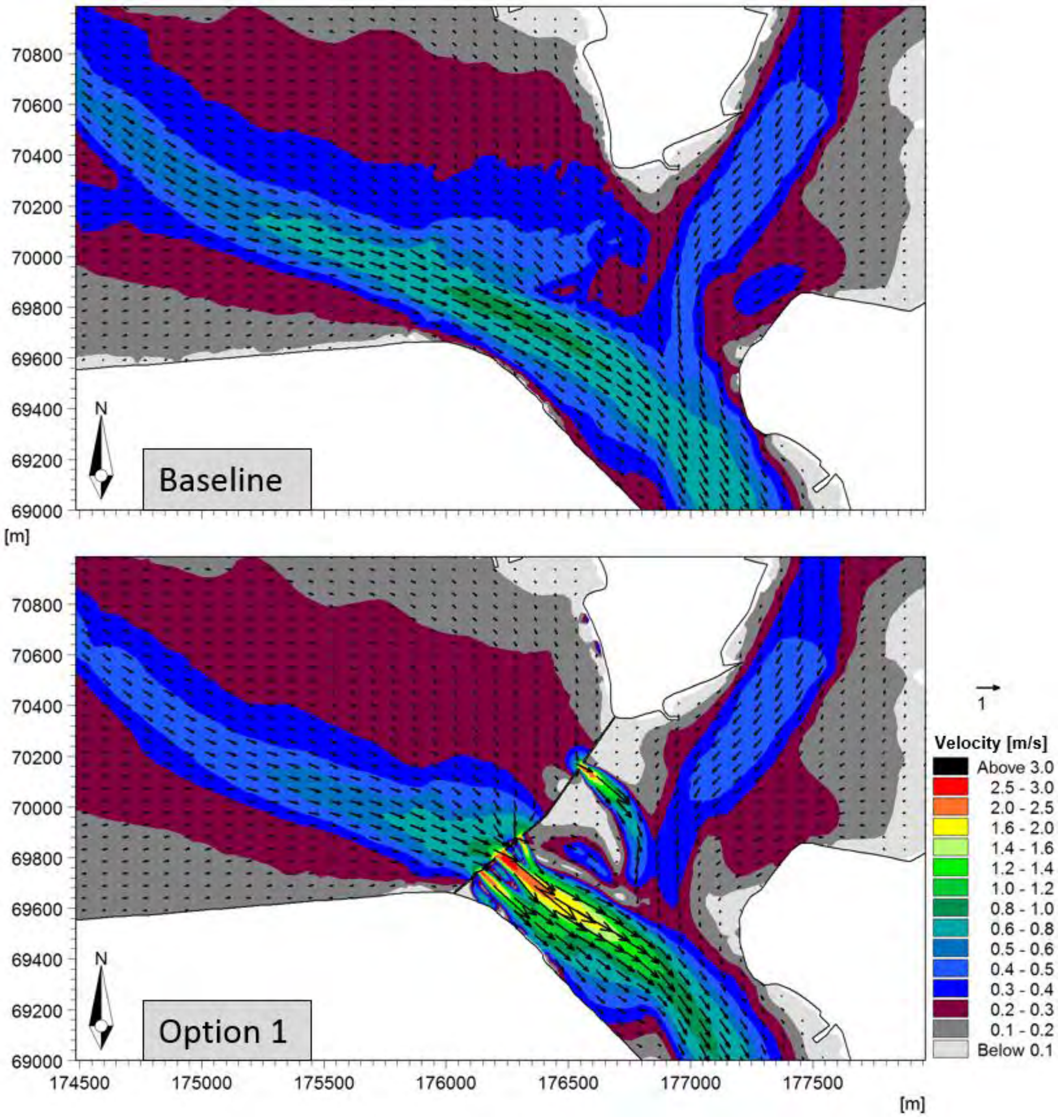
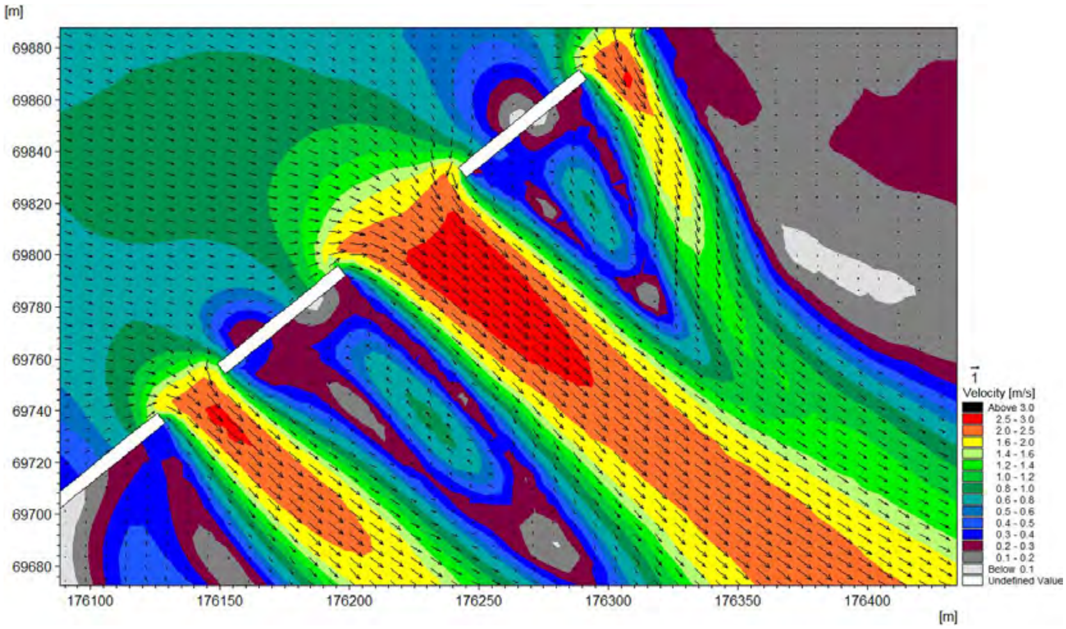


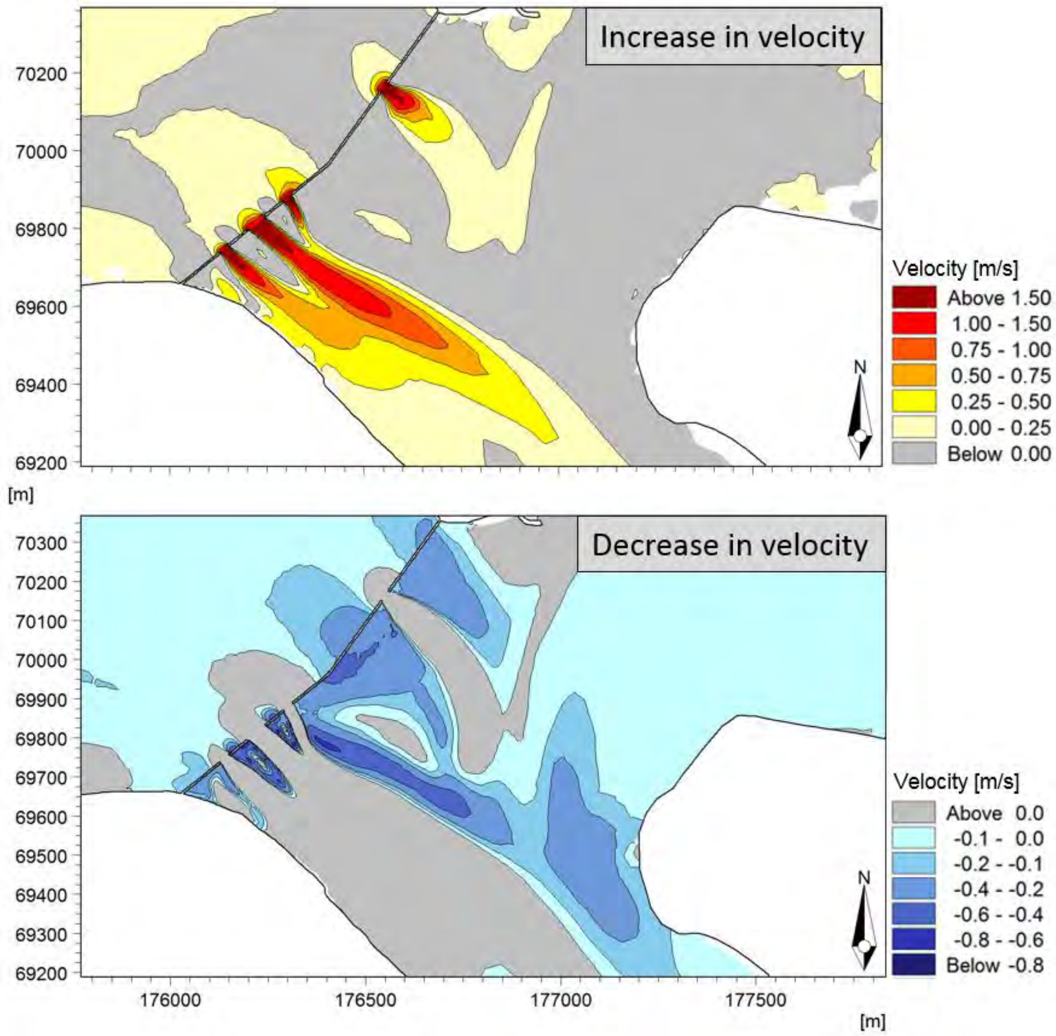
Figure 33 presents the results from Figure 32 but with a view zoomed in on the main navigational gate. As with the flood tide results presented in Figure 28, the barrier is having a very significant impact on the hydrodynamics in the vicinity of the gates with eddies being formed inbetween the fast flowing high energy jets of water. There will be very significant shear stresses and high turbulance in the water column associated with these conditions which will impact greatly on safe navigation, sediment transport and the environment.

Figure 33: Peak velocities on the Ebb tide (zoomed in to Navigation gate) - Circa 3.5 hours after high tide



The difference between the results presented in Figure 32 (i.e. the baseline and Barrier Option 1 scenarios on the ebb tide) plots are presented in Figure 34. It can be seen that as with conditions on the flood tide, velocities through the openings on the ebb tide are increased by circa 1.5m/s which represents a very significant increase. Velocities are also reduced in the vicinity of the barrier by greater than 0.6m/s.

Figure 34: Difference in velocity versus baseline for peak velocities on the ebb tide



7.4.2 Maximum Velocity Plots

Figure 35 presents the maximum velocities over the flood tide for the baseline and Barrier Option 1 scenarios. It can be seen that the change in maximum velocities as presented on the plots is, as expected, very similar to the results for the time at which the velocity reached its maximum and presented earlier in Figure 27. The change in maximums is very significant with the barrier in place – flow through the openings are increased to over 3m/s. Velocities downstream of the barrier in some areas are also considerably reduced on the flood tide.

Figure 35: Maximum velocities over the entire flood tide

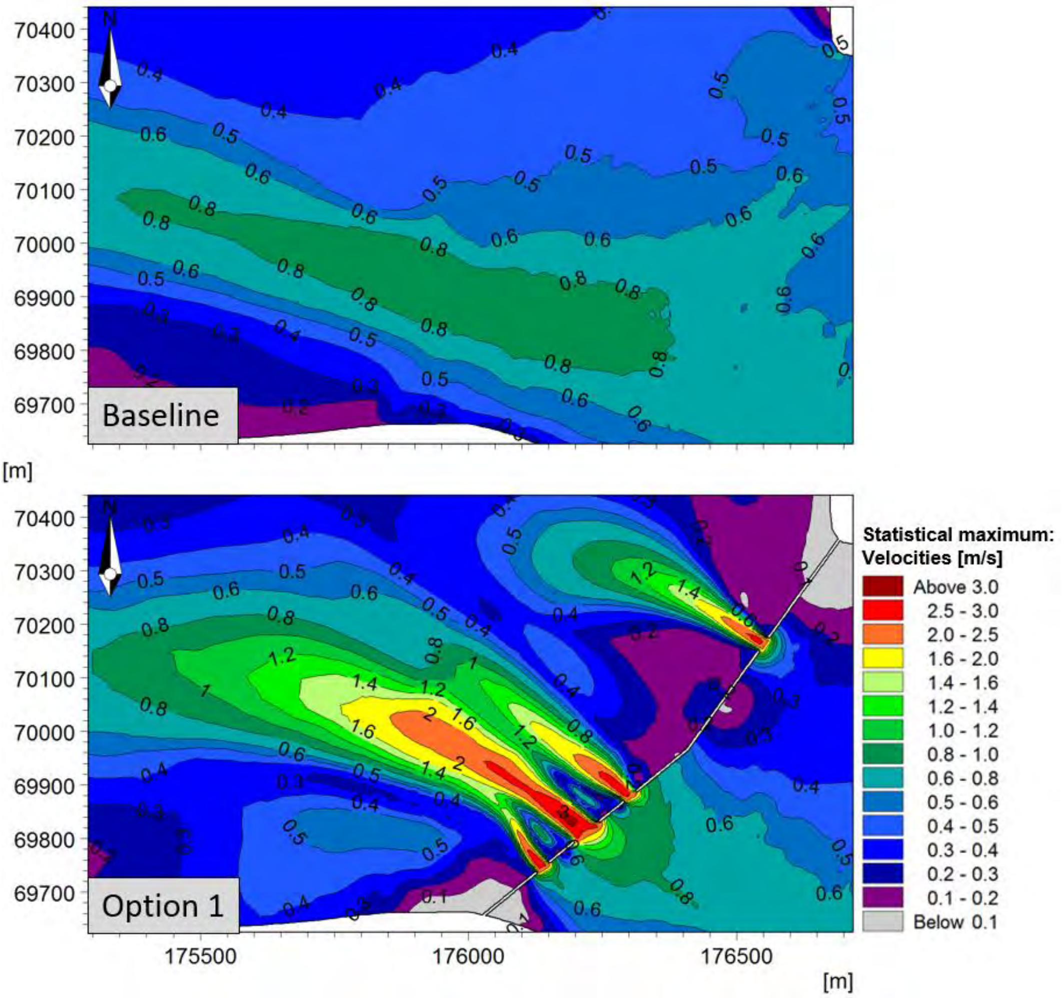
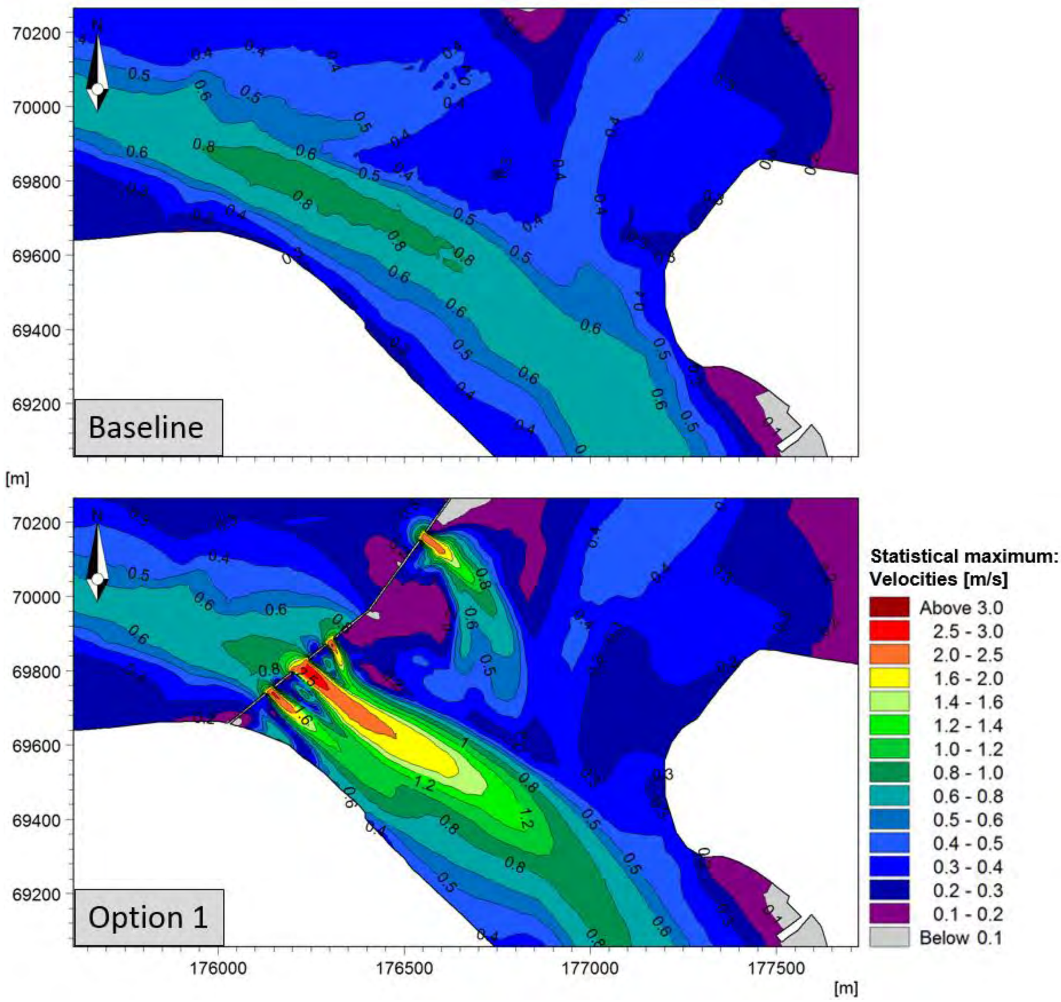


Figure 36 presents the maximum velocities over the ebb tide for the baseline and Barrier Option 1 scenarios. Similar to flood tide conditions, velocities through the openings of the barrier are increased to almost 3m/s on the ebb tide. Velocities upstream of the barrier in some areas are also considerably reduced.

Figure 36: Maximum velocities over the entire ebb tide



7.5 Model Results for Amended Version of Tidal Barrier at Little Island (Option 2)

This section presents the results of the hydrodynamic modelling for the Tidal Barrier Option 2 model.

Tidal barrier Option 2 is also located at the Little Island location and consists of a 120m navigation opening with six additional flow gate openings each of 50m width.

The presentation of the results follows the same format as in the previous section.

7.5.1 Velocity plots

Figure 37 presents the velocities for the time on the flood tide at which they reach their maximum. It can be seen that as with the first barrier option considered in Section 7.4, the incoming tide is being squeezed through the various openings of the barrier leading to an increase in the velocities over the baseline as the cross sectional area available to the flow is much reduced with the barrier in place.

As the total width of gate openings in this barrier option is greater than the width of gate openings in the first barrier option, there is a greater area available to the flow and hence the increase in velocity over the baseline is not as pronounced as it was for the first barrier option. It can be seen from the plot that the maximum velocity through the main navigational gate opening for this scenario is less than 1.6m/s which is approximately half the velocity through the main navigational gate opening of Tidal Barrier Option 1.

We note that this barrier is also aligned more appropriately than Barrier Option 1 which allows the flow through the opening to be more streamlined.

Figure 37: Peak velocities on the Flood tide - Circa 5 hours after low tide

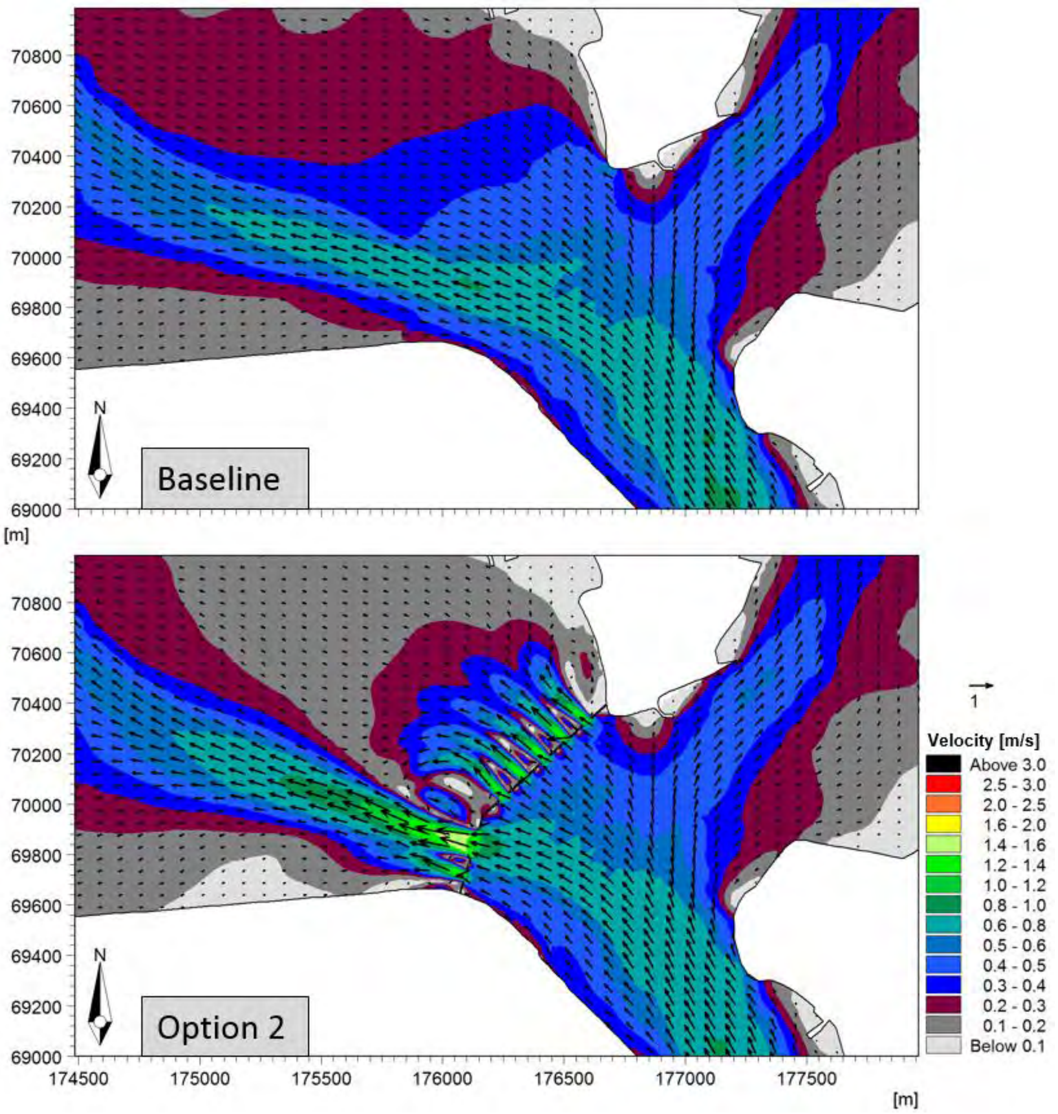


Figure 38 and Figure 39 present the same results as in Figure 37 but with a view zoomed in on the gates. We can see from the figures that the incoming tide forms high energy jets of water as it is being squeezed through the various openings of the barrier. The jets however have much less energy than the jets which developed for the Tidal Barrier Option 1 given the greater area available to flow. We note however that areas of slack water have formed upstream of the barriers in a similar manner to what was observed from the results of the Barrier 1 option.

Figure 38: Peak velocities on the Flood tide (zoomed in to navigation gate)

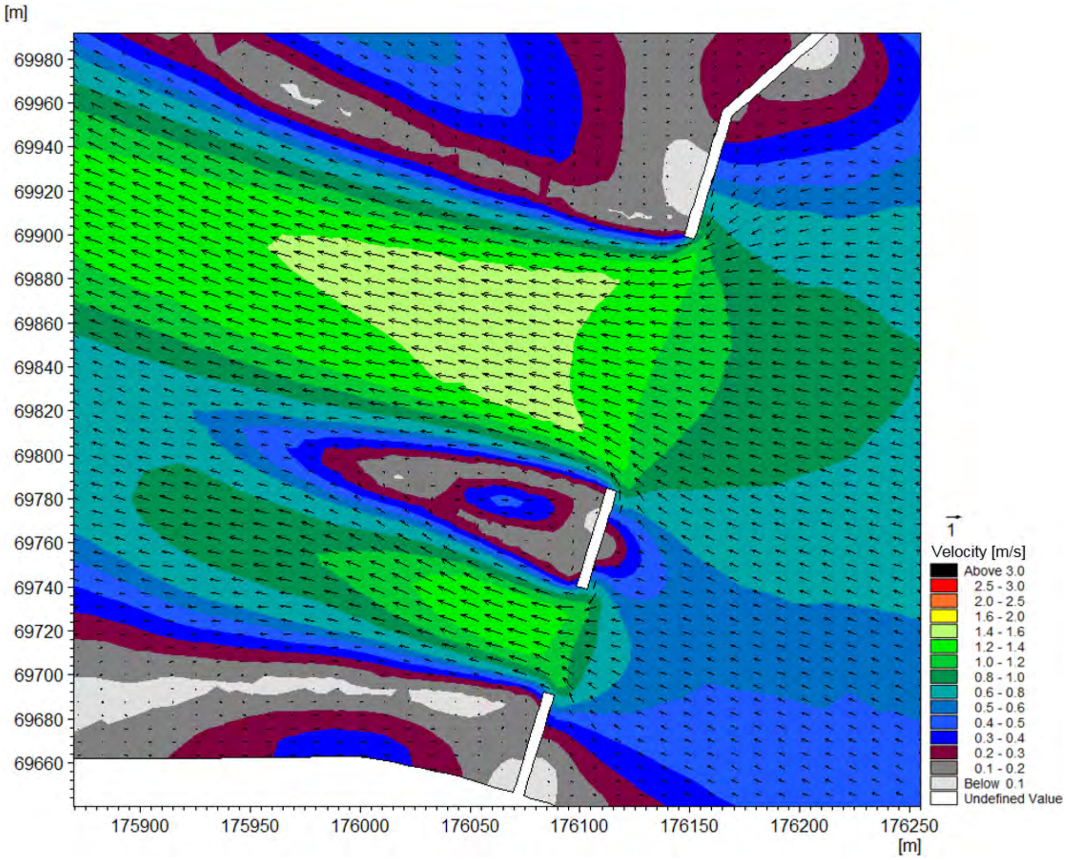


Figure 39: Peak velocities on the Flood tide (zoomed in to flow gates)

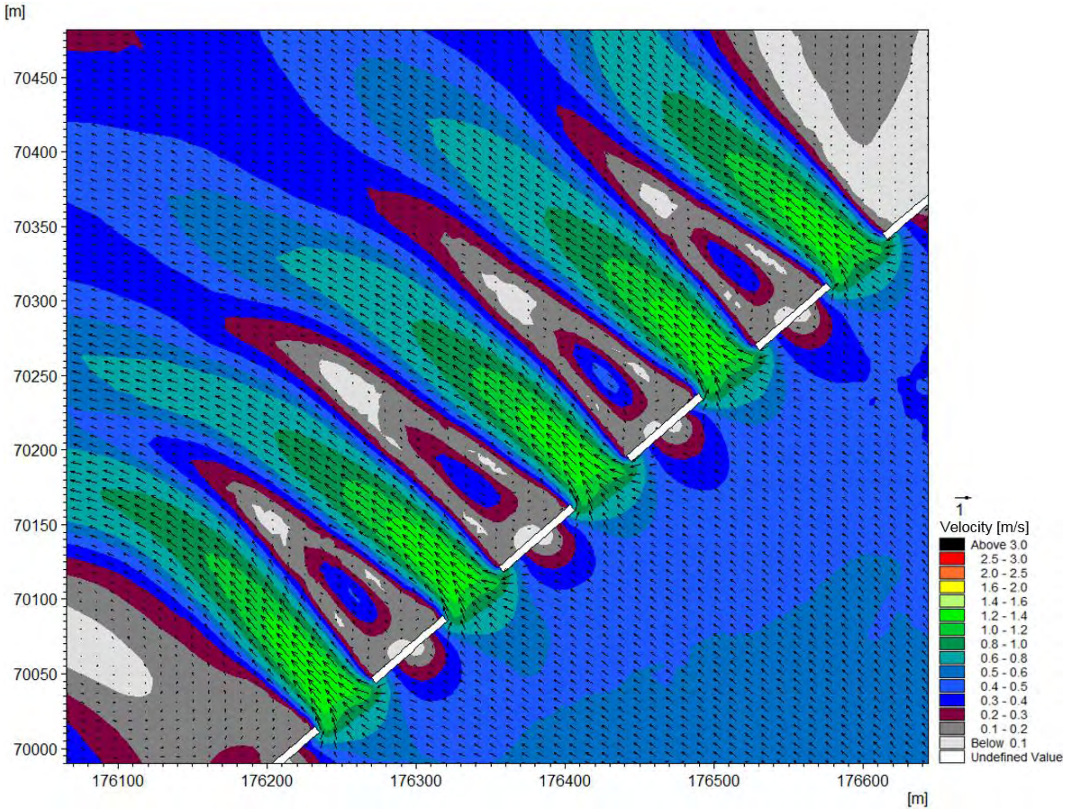


Figure 40 presents the difference in velocity for the time at which maximum values occurs on the flood tide. It can be seen from the figure that the increase in velocity through the main navigational is circa 0.75m/s which is deemed to be significant. For the narrow openings the increase in velocity is higher at circa 1m/s. It can also be seen from the figure that the largest decrease in velocity is circa 0.8m/s and arises immediately upstream of the main navigational gate opening.

Figure 40: Difference in velocity versus baseline for peak velocities on the flood tide

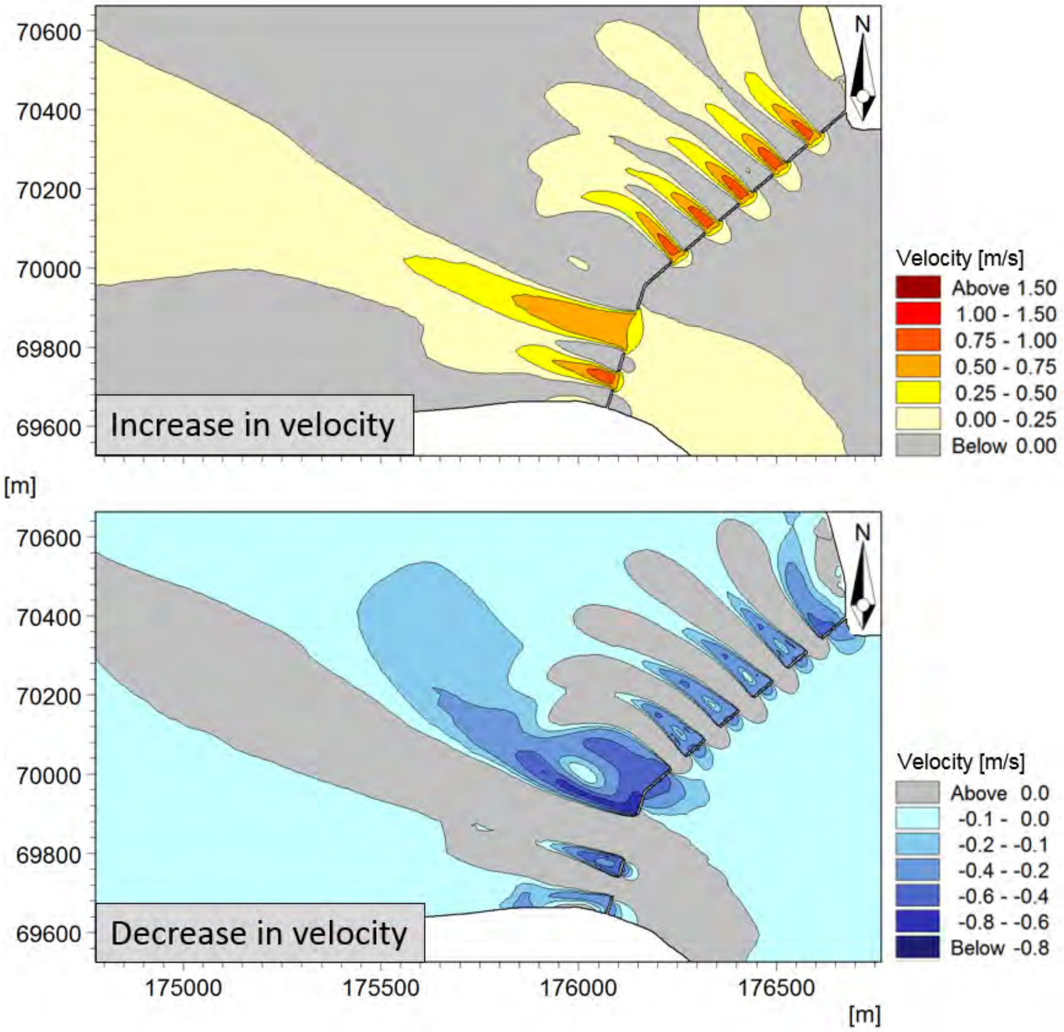
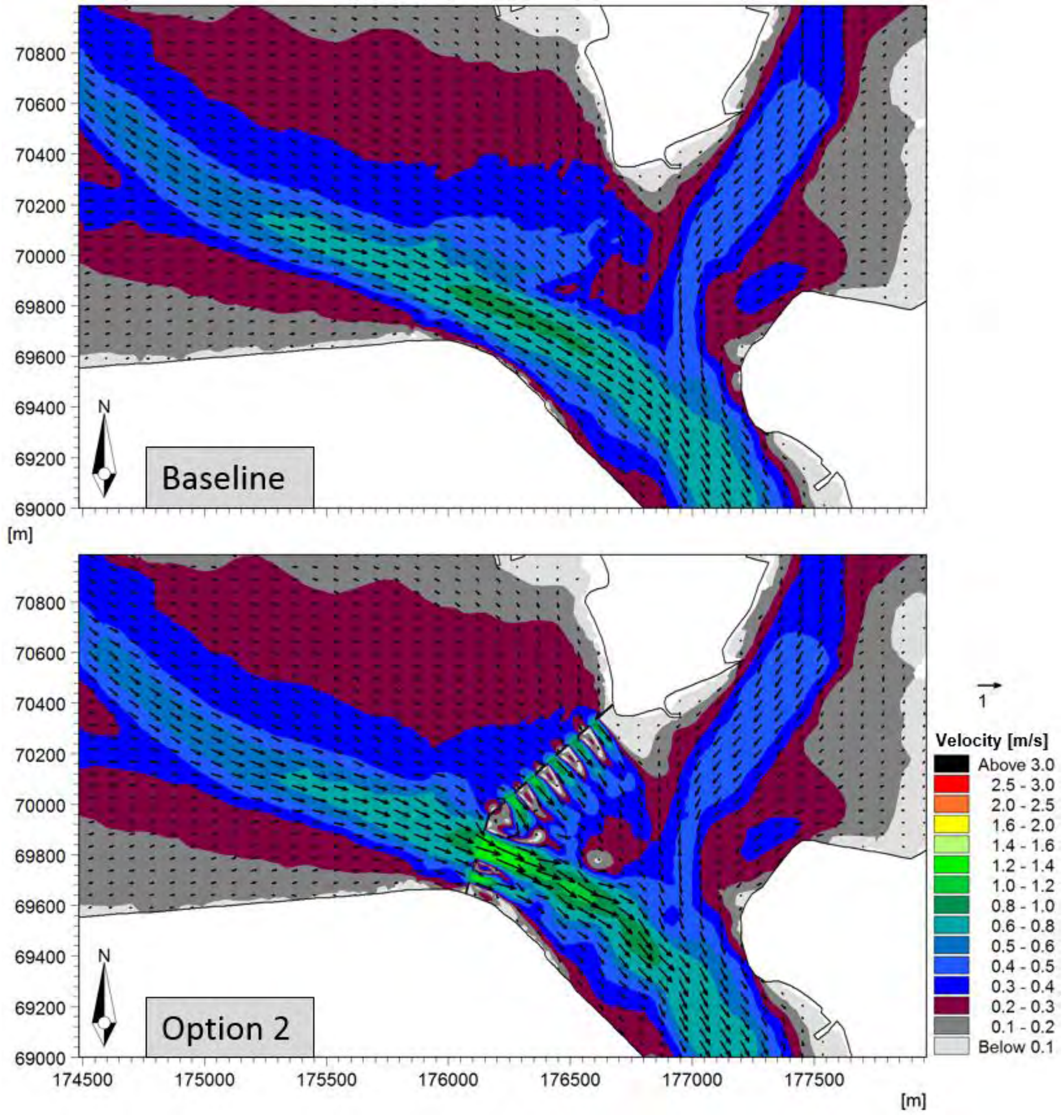


Figure 41 presents the velocities for the time on the ebb tide at which they reach their maximum. Peak velocities on the ebb tide are circa 1.6m/s through the main navigational gate opening which is a similar value to the modelled peak velocities on the flood tide.

Figure 41: Peak velocity on the Ebb tide - Circa 5 hours after high tide



Close up views of the results presented in Figure 41 are presented in Figure 42 (main navigational gate) and Figure 43 (additional flow gates on the mud flats). As with flood tide conditions, eddies and areas of slack flow have formed downstream of the barrier in between the fast flowing jets of water leading to back flow against the barrier.

Figure 42: Peak velocities on the Ebb tide (zoomed in to navigation gate)

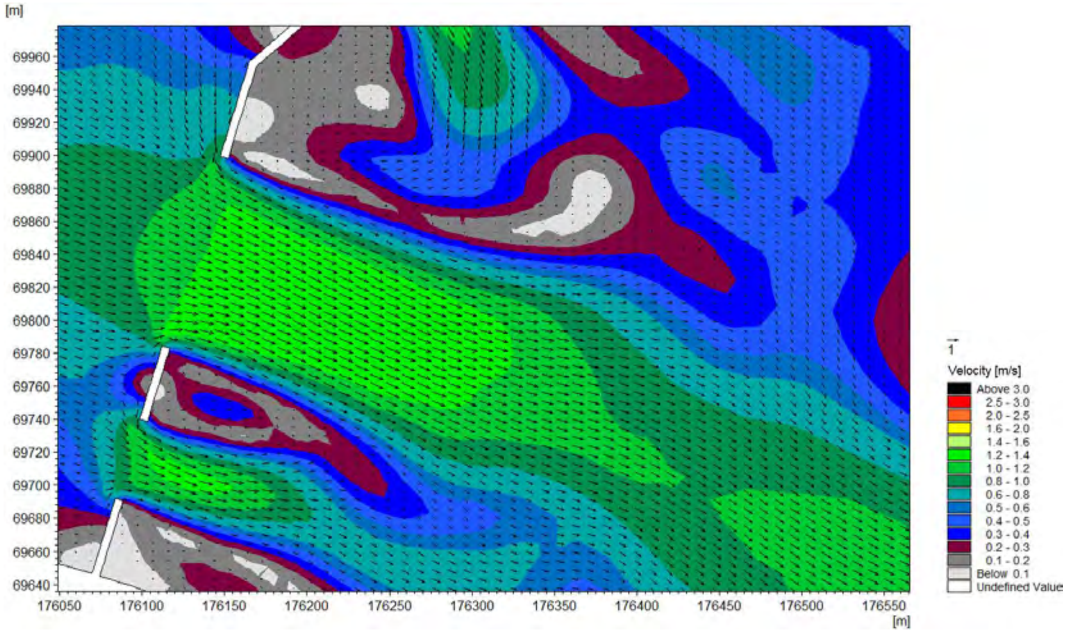
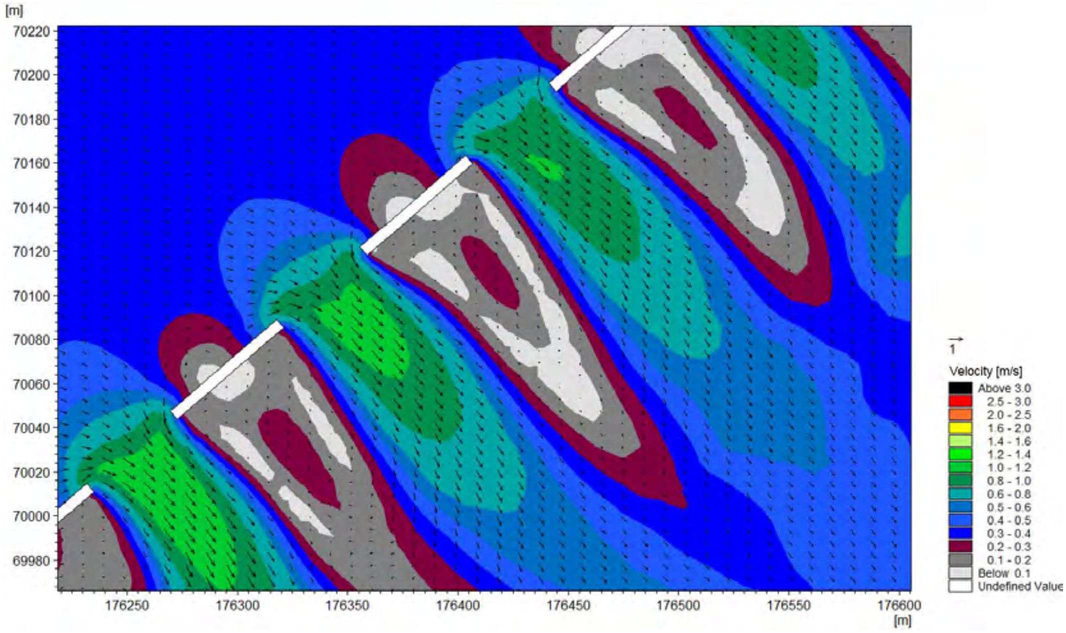
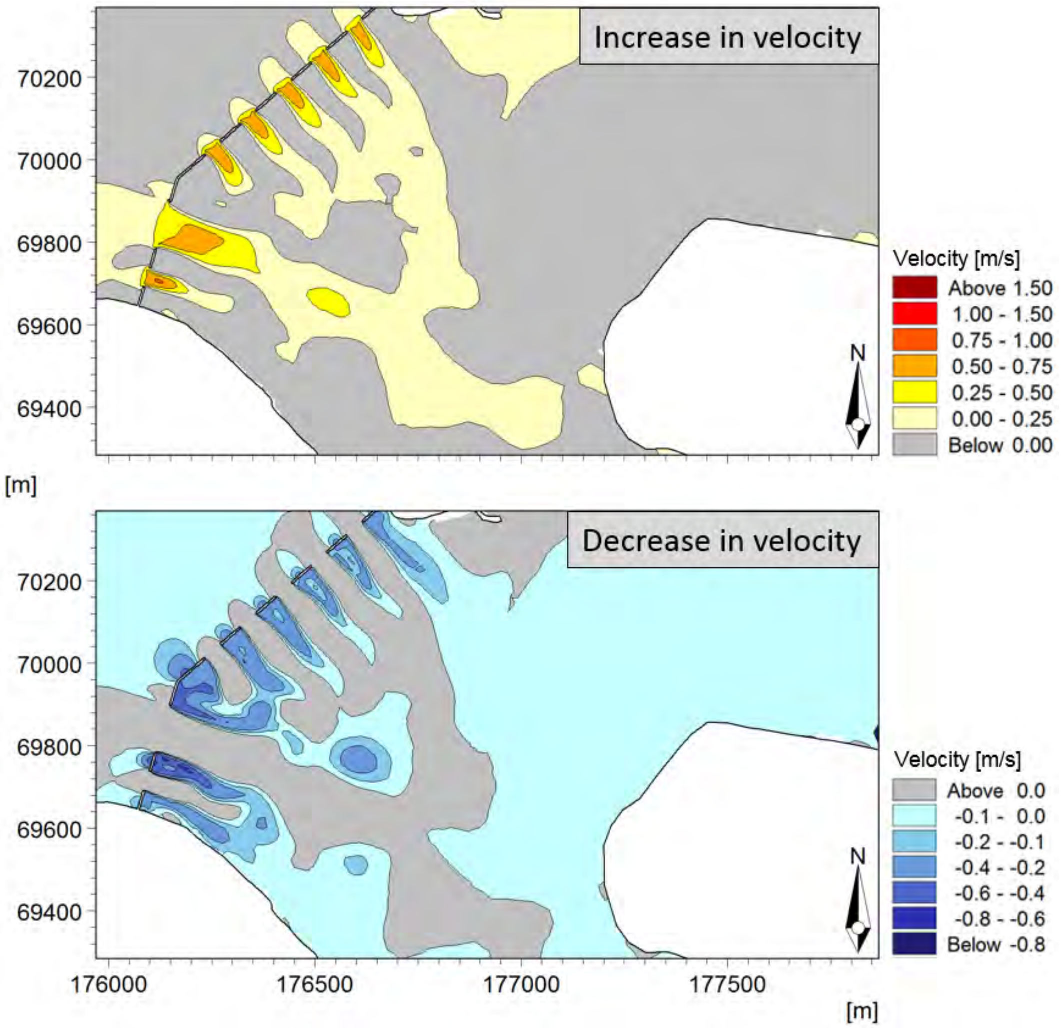


Figure 43: Peak velocities on the Ebb tide (zoomed in to flow gates)



The difference in velocity for the ebb tide conditions is presented in Figure 44. It can be seen from the figure than the increase through the openings is significant but does not exceed 0.75m/s. The decrease downstream of the barrier ranges from 0.4m/s to 0.8m/s.

Figure 44: Difference in velocity versus baseline on the ebb tide



7.5.2 Maximum Velocity Plots

The maximum velocities for the baseline and Barrier Option 2 scenarios are presented on the following two figures for the flood and ebb tide. It can be seen from the figures that the change in maximum values follows a very similar pattern to when the time at which velocities reached their maximum – on the flood tide the maximum velocity through the navigational gate is circa 1.6m/s. On the ebb tide they are marginally less at circa 1.45m/s.

Figure 45: Maximum velocities over the entire flood tide

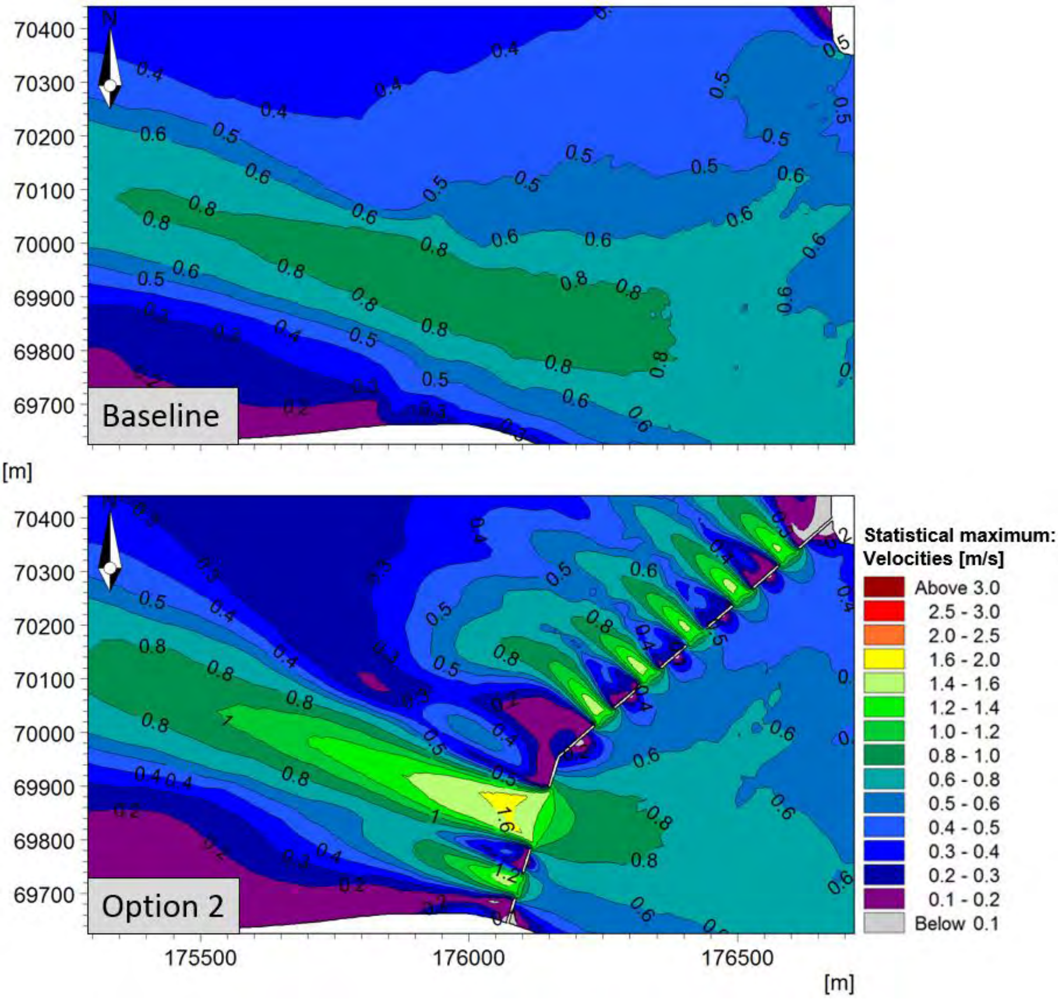
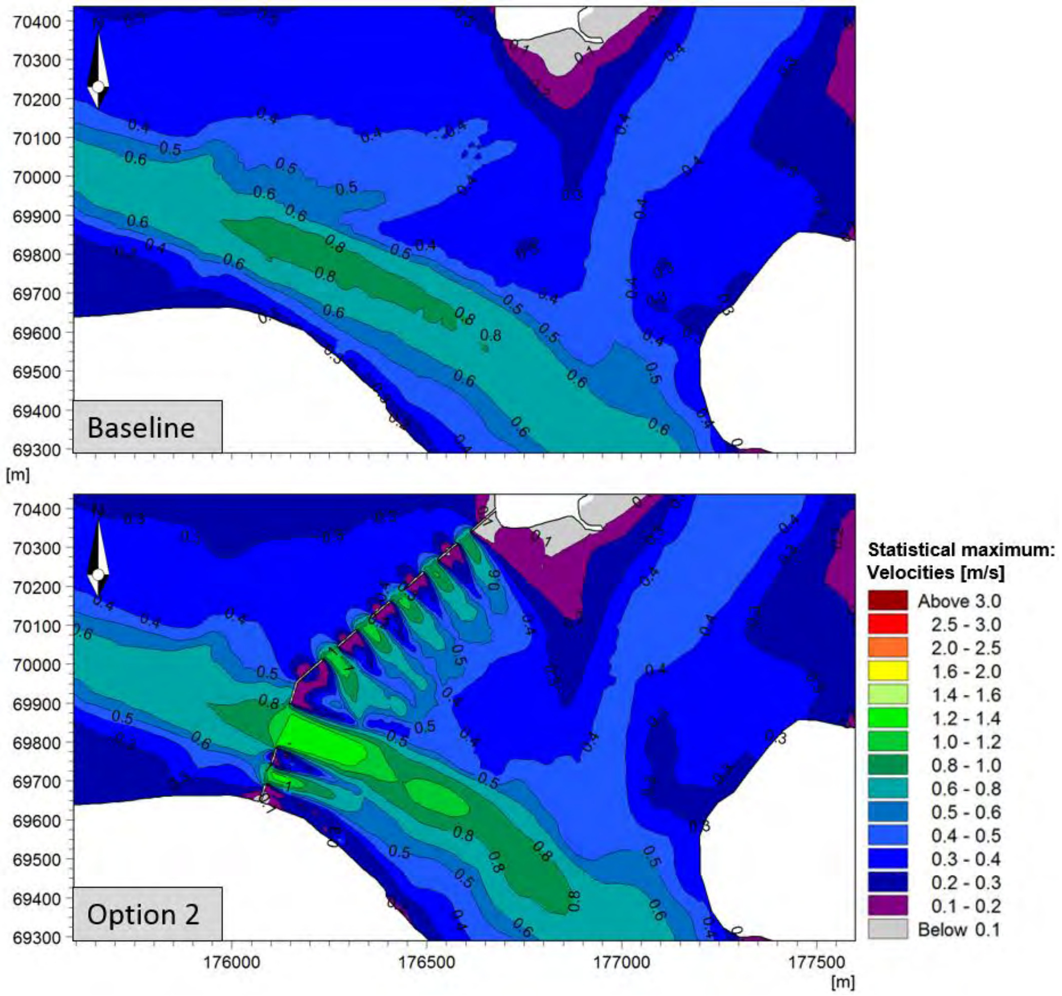


Figure 46: Maximum velocities over the entire ebb tide



7.6 Model Results for Great Island Barrier (Option 3)

The results of the hydrodynamic models which simulated the impact of constructing tidal barriers at Monkstown and Marlogue Point are presented in this section of the report.

The barrier at Monkstown consists of two 60m navigation gates separated by a 10m wide pier and four additional flow gates, each 35m wide. The barrier at Marlogue Point consists of one 60m navigation opening and six additional flow gates, each between 25 - 30m wide and separated by 10m piers.

We note that given the forces that would be exerted on the gates for this scenario, the piers of the barrier would likely be longer than indicated in our model. Any increase in length of the pier would only have minor localized impacts as the increase in dimension would be made in the direction of flow. Our representation of the piers is therefore appropriate for this assessment.

7.6.1 Monkstown

Figure 47 presents the velocities for the time at which they reach their maximum value on the flood tide for Monkstown. Figure 48 presents the equivalent results for the ebb tide. In both cases it can be seen that the gates are having localised effect on the hydrodynamics with areas of slack water forming immediately downstream of each of the concrete piers.

While the velocities through the openings are increased as a result of the reduction of available cross section flow area, the increase is relatively minor as the reduction in available cross sectional area is relatively minor. On the flood tide the peak velocity is increased from circa 1.1m/s to 1.2m/s while on the ebb tide the increase is from circa 0.9m/s to 1.0m/s.

Figure 47: Velocity vectors and velocity plot for the flood tide

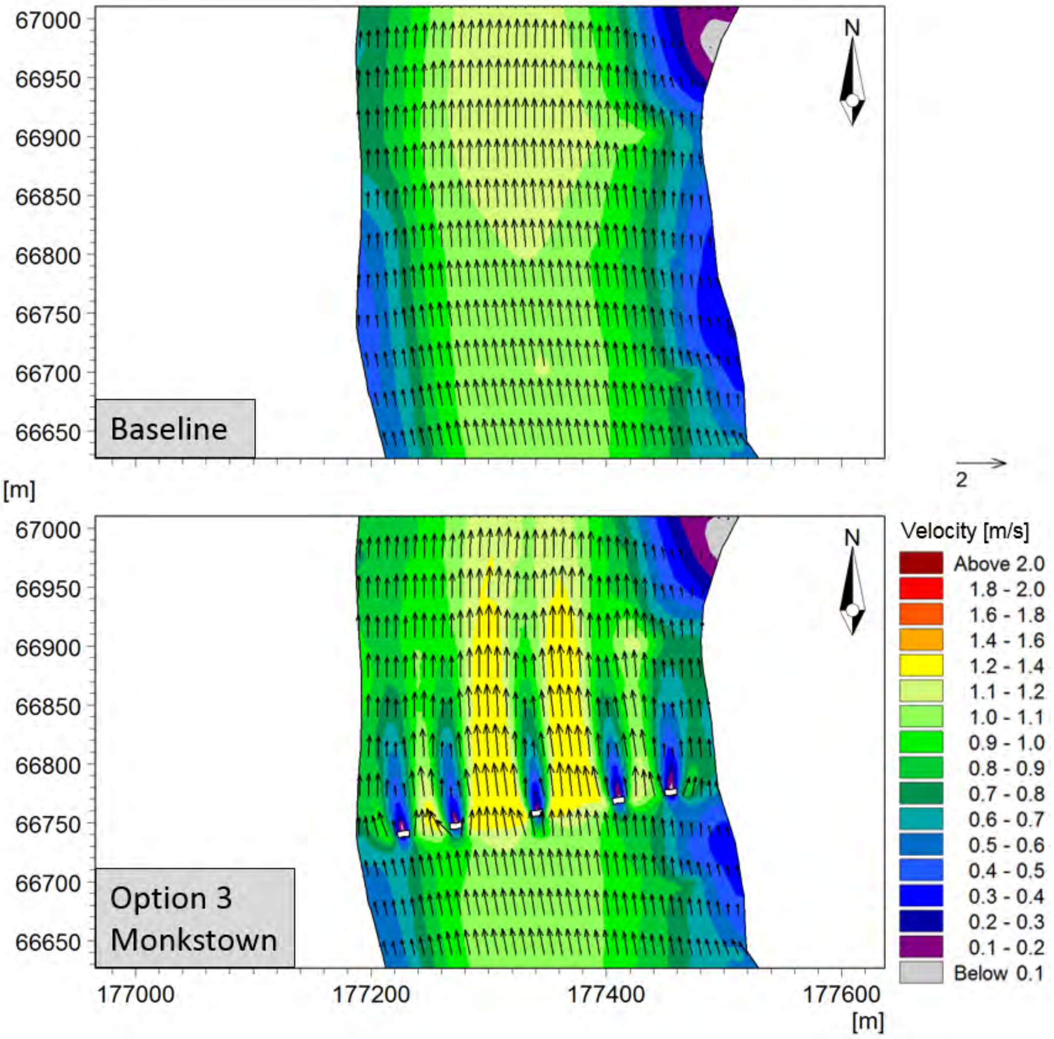
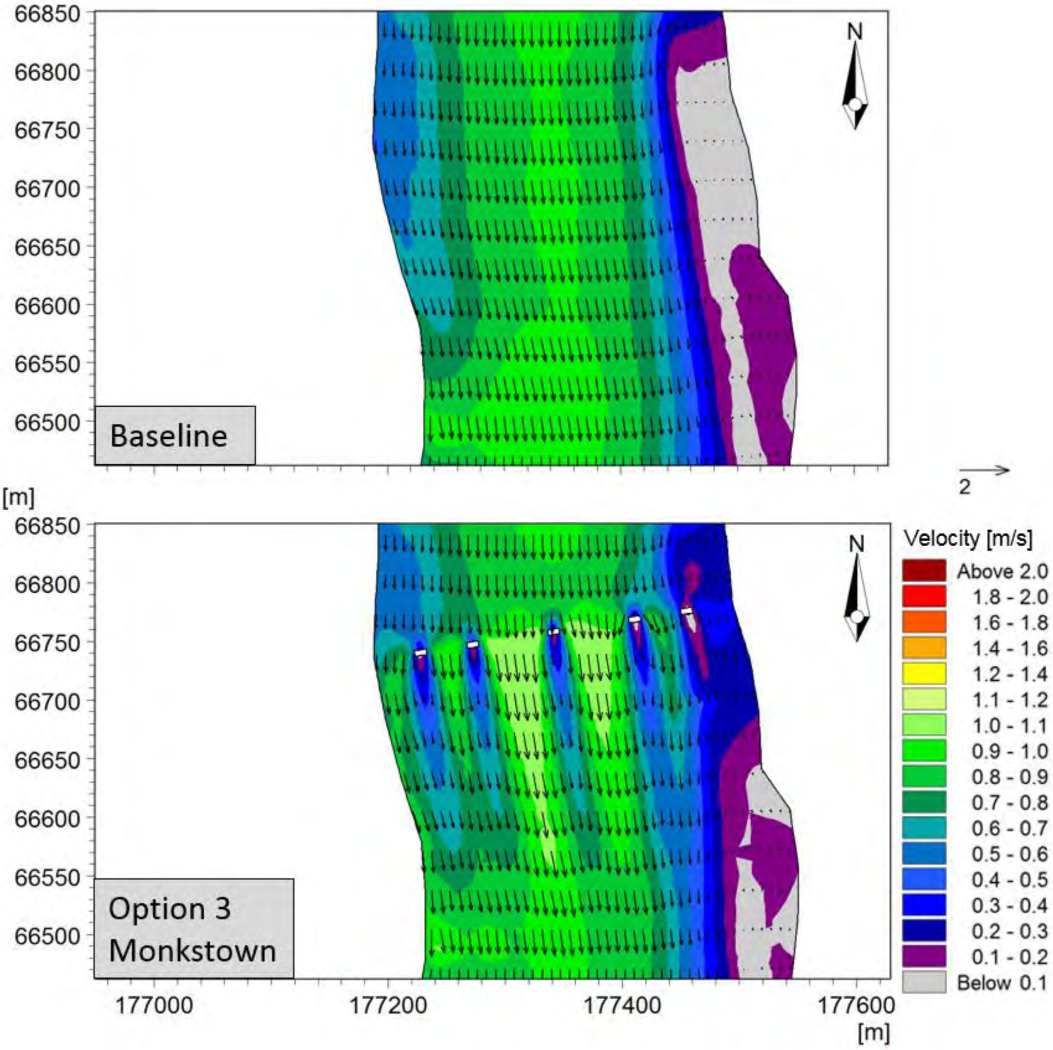


Figure 48: Velocity vectors and velocity plot for the ebb tide



7.6.2 Marlogue Point

Figure 49 presents the velocities for the time at which they reach their maximum on the flood tide for Marlogue Point. Figure 50 presents the equivalent for the ebb tide.

In both cases it can be seen that the gates are having localised effect on the hydrodynamics with areas of slack water forming immediately downstream of each of the concrete piers on the ebb tide, and upstream of the piers on the flood tide.

The increase in velocity is again relatively minor as the reduction in cross sectional area with the pier in place is relatively minor. On the flood tide the peak velocity is increased from circa 1.2m/s to 1.4m/s while on the ebb tide the increase is from circa 1m/s to 1.2m/s.

Figure 49: Velocity plot for the flood tide

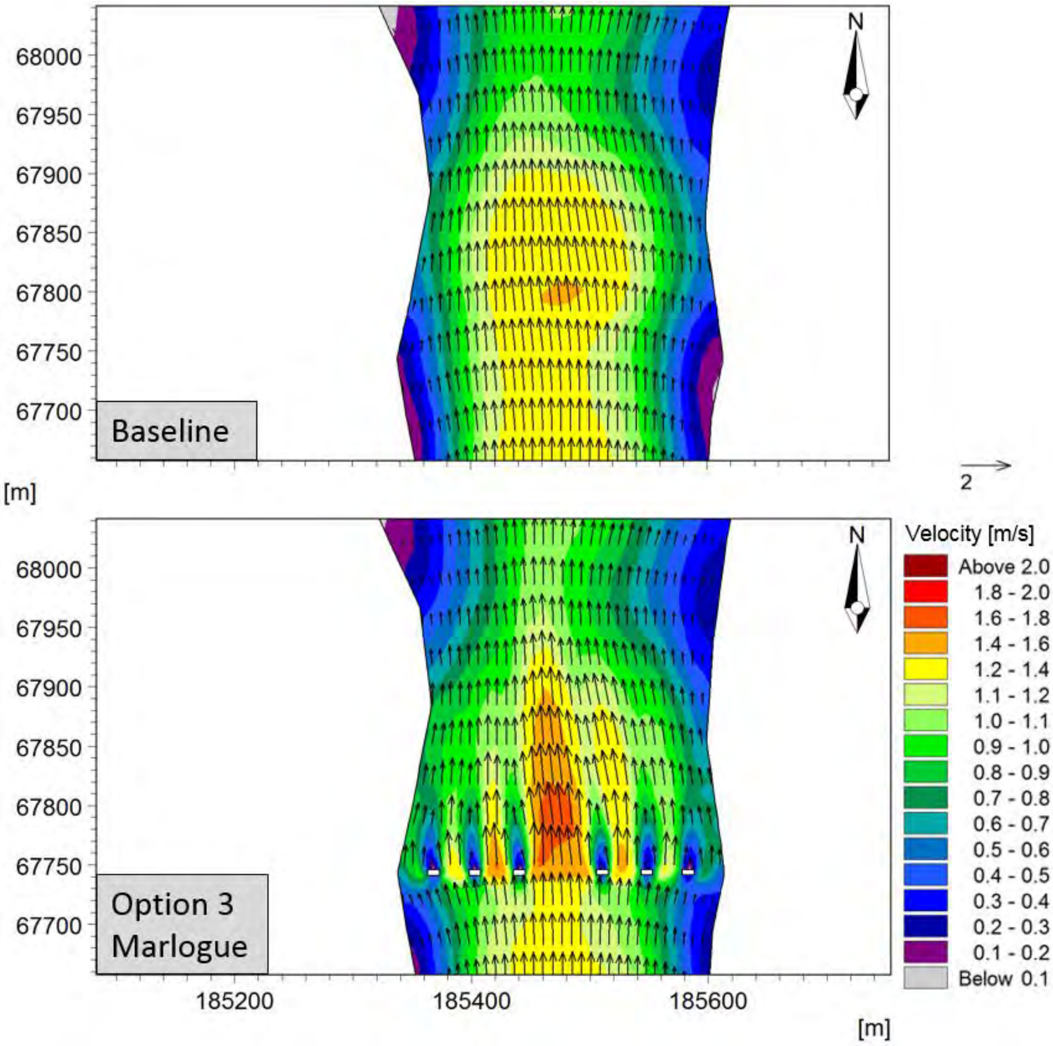
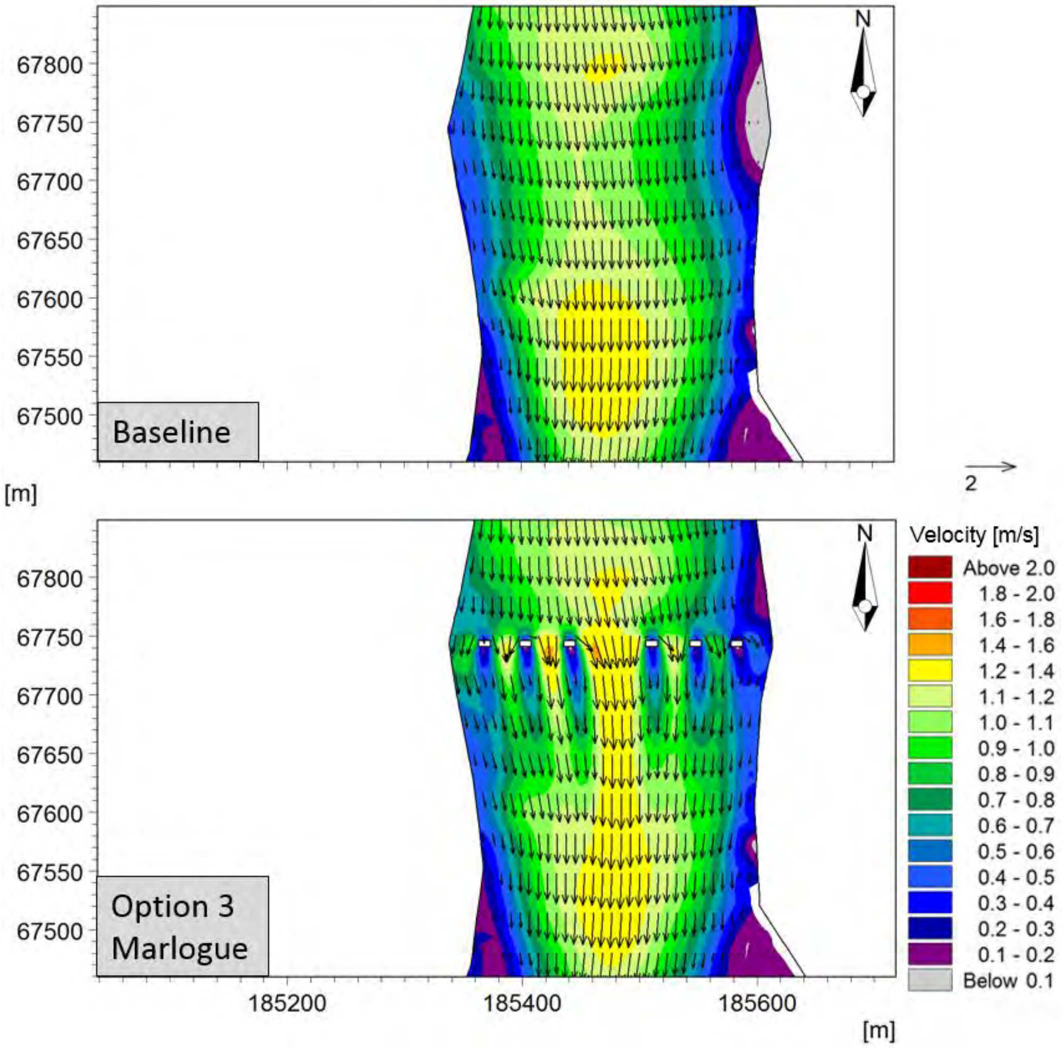


Figure 50: Velocity plot for the ebb tide



8 Technical Assessment of Potential Barrier at Little Island (as per Stakeholder Group's Concept)

8.1 Introduction

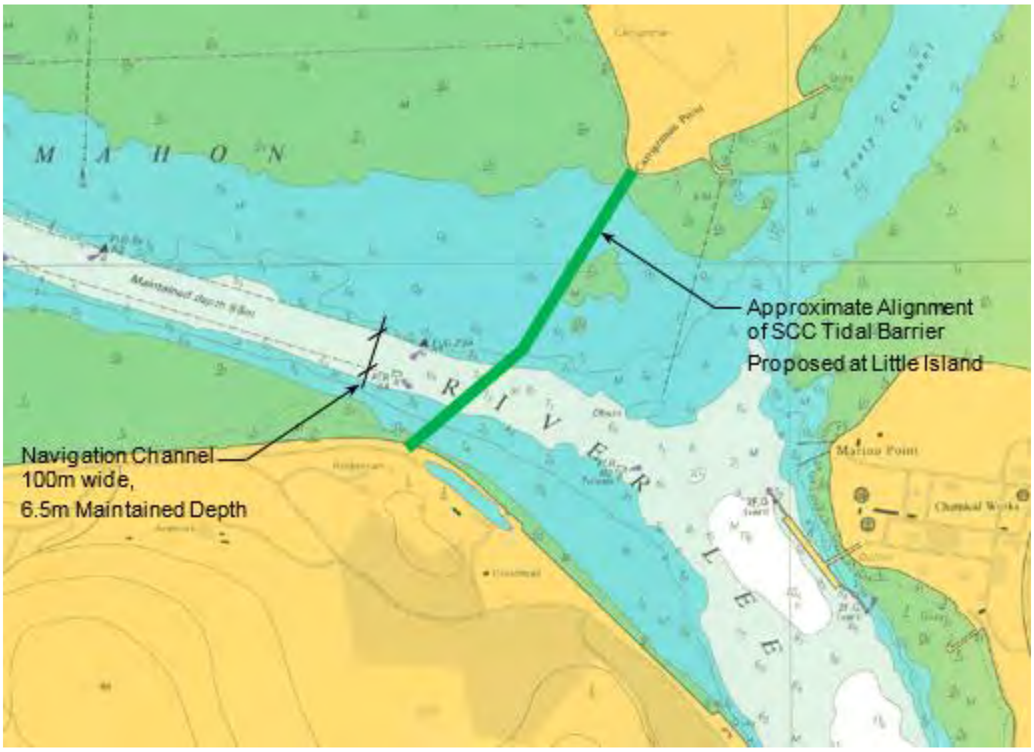
The stakeholder group's proposal is for a barrier at the downstream end of Lough Mahon consisting of the following:

- A total barrier length of approximately 950m.
- A 60m navigation channel with a sector gate and flushing gate structure to prevent silting.
- 3 flow gate complexes, 30m each, for flow.
- 900m of embankment dams in a water depth of 1 to 8 metres. It proposes that the embankment will be a causeway of simple construction made up of earthen/sand protected from erosion by rock armour.
- Ancillary flow control measures for the potential bypass to the north.

The admiralty chart for the Upper Harbour details the water depths in metres to Chart Datum (CD) at the Little Island location

As can be seen from the extract below (with an approximate overlay of the Little Island barrier proposed), the navigation channel is dredged to maintain a depth of 6.5mCD. The width of the dredged channel is 100m between the buoys.

Figure 51: Navigation Channel in Lough Mahon (Admiralty Chart Extract 1773)



8.2 Alignment, Geometry and Configuration

8.2.1 Overview

Page 5 of the stakeholder group's submission shows an aerial image annotated with their proposed location for the barrier at Little Island.

It can be seen that the barrier alignment is not perpendicular to the navigation channel. This is not an appropriate orientation as it would increase the required width of the navigation gate and would result in ships approaching the barrier at an angle. Its proximity to the 90degree bend in the navigation channel will mean that ships will be beginning to turn at this location, further increasing the required width of opening.

The barrier will need to extend far enough onto land so that bypass of the barrier does not occur during a high tide event in the harbour. Based on the alignment and the 910m length of barrier proposed by the stakeholder group, the barrier would only extend to approximately the high water mark north and south of the channel leaving the barrier vulnerable to bypass.

8.2.2 Potential Bypass

The tidal barrier proposed by the stakeholder group on its own will not prevent tidal waters flooding the city, as there is potential for water to bypass the barrier via a number of low lying routes to the north.

Figure 52 below shows ground levels above and below 3.33mOD, based on LiDAR. This is the level of protection required by a barrier in the current scenario including a 0.5m freeboard. Levels that are below 3.33mOD are shown in blue and it can be seen (yellow arrows) that high tides can bypass the barrier at two points under the N25. This water can then flow along the railway line to the north of Little Island. It is unclear from the LiDAR data whether water would be able to continue along the railway line past Burys bridge, east of North Esk Business Park. However, it is likely that the water would be able to enter Lough Mahon through groundwater routes or pipe networks. To stop this possible flow route and to protect the railway line from flooding, it would be necessary to construct two flood gates at these points underneath the N25.

Figure 52: LiDAR Cut Section at 3.33m

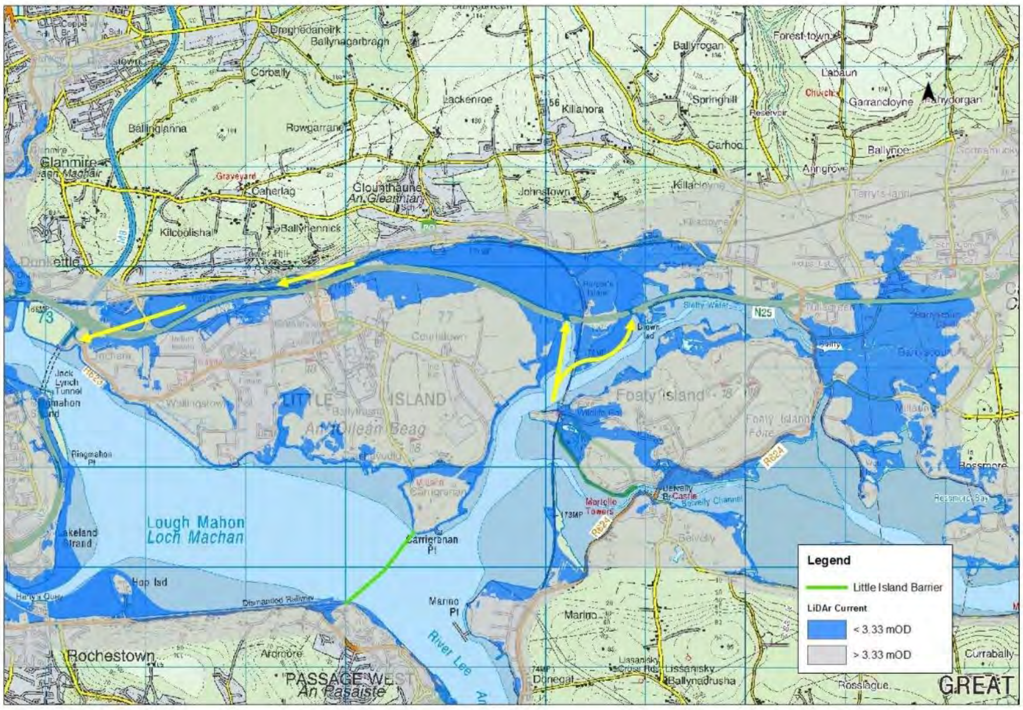
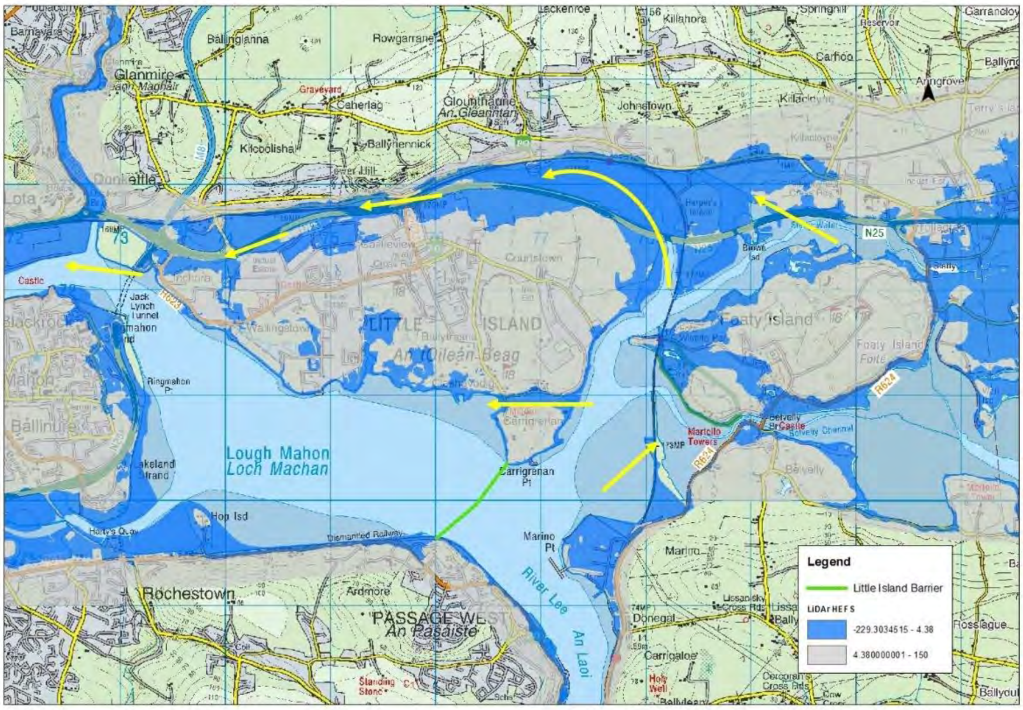


Figure 53 below illustrates ground levels above and below 4.38mOD, based on LiDAR. This is the level of protection required in the future (HEFS) scenario. Levels that are below 4.38mOD are shown in blue and it can be seen (yellow arrows) that high tides can bypass the barrier via a number of additional routes and have a clear route back into Lough Mahon, upstream of the tidal barrier. Therefore, in addition to the flood gates mentioned above, embankments and road raising would be required to protect the city from flooding. These measures could be constructed at a later date if required based on the amount of sea level rise that occurs. They are not included in the final estimated costs.

Figure 53: LiDAR Cut Section at 4.38m



8.2.3 Navigation Gates

The navigational gate component of the barrier is that part of the barrier that opens and closes to allow safe passage of ships and maritime vessels between the inner (City Quays) and outer harbour (Ringaskiddy). The stakeholder group has proposed a singular navigation opening of 60m. The depth of the gates has not advised, but it is assumed that they would need to extend to the existing bed level to allow passage of large ships at the existing low tide levels.

8.2.4 Flow Gates

The other gated component of the barrier will be flow gates that in conjunction with the navigation gates, provide sufficient cross sectional area between low and high tide to allow passage of flow at appropriate velocities which facilitate safe navigation and minimise changes is sedimentation to acceptable levels.

The stakeholder group has not defined the length of its proposed flow gates. But we note that in a cost estimate prepared by HRW on behalf of the group, 90m of flow gates have been assumed.

8.2.5 Impounding Embankments

The embankment is the solid structural component of the barrier that connects the gates to the adjoining land. Where feasible, by using an embankment, the length of the more expensive and complicated gate structures can be reduced.

8.3 Technical Feasibility

8.3.1 Hydrodynamic Assessment

Refer to Section 7.4 of this report for details.

8.3.2 Total length of Barrier

The total length of the barrier at Little Island as proposed by the stakeholder group is 950m. However, it would need to be 1020m in length so that it is appropriately orientated in relation to the Navigation channel and meets high ground to avoid water bypassing at the ends of the barrier.

8.3.3 Width, number and depth of Navigation Gates

The navigation channel is 100m at the barrier location but narrows down to about 70m further upstream. Generally, channels need to be wider where vessels are turning.

Ships passing upstream of this location require a min soft bed level of 8.8m below CD. The sill level for the gate should be no higher than the existing dredged channel plus extra safety margin of at least 0.5m, because it is much more serious for ships to hit a sill structure than run aground in the soft bed of the channel.

Consideration needs be given to the redundancy requirements of the gates in the event that the gates failed to open following a closure. If this happened the navigation lane would need to be closed.

Therefore, with a single gate opening as proposed by the stakeholder group, no vessels would be able to pass and all upstream quays would have to stop operations. This would likely be commercially unacceptable to Port of Cork as well as other recreation users.

A single 60m wide gate as proposed is therefore likely to be insufficient as this would provide no redundancy in the event of a fault and would not allow for ship movement in both directions at the same time. In almost all international tidal barriers, there is a second navigable gate or alternative navigation route. Those that do not, have gate widths significantly larger than 60m. For example, the Maeslant Barrier has a single gate width of 360m. Therefore, ship movement in both directions simultaneously is possible.

Therefore, we would recommend that redundancy be included in the system by providing a second navigable gate

8.3.4 Required Area of Flow/Flushing Gates

Based on our preliminary analysis detailed in Chapter 7, the proposed area of flow gates (including navigation gates) as proposed by the stakeholder group is too small in the context of generating unacceptably high velocities for navigation as well as fundamentally altering the sedimentation patterns in the adjoining

SAC/SPA areas. It would also likely result in increased ongoing dredging costs which could undermine the commercially viability of port activities.

We would recommend that at least 300m length of flow gates be assumed for concept design and budgeting purposes.

8.3.5 Operation of the Hydraulic Gates

The velocity though the main navigational gate opening in the stakeholder group's proposal would be in excess of 3m/s on the flood tide and marginally less on the ebb tide. Velocities of this magnitude will impart significant forces on the various piers enclosing the openings.

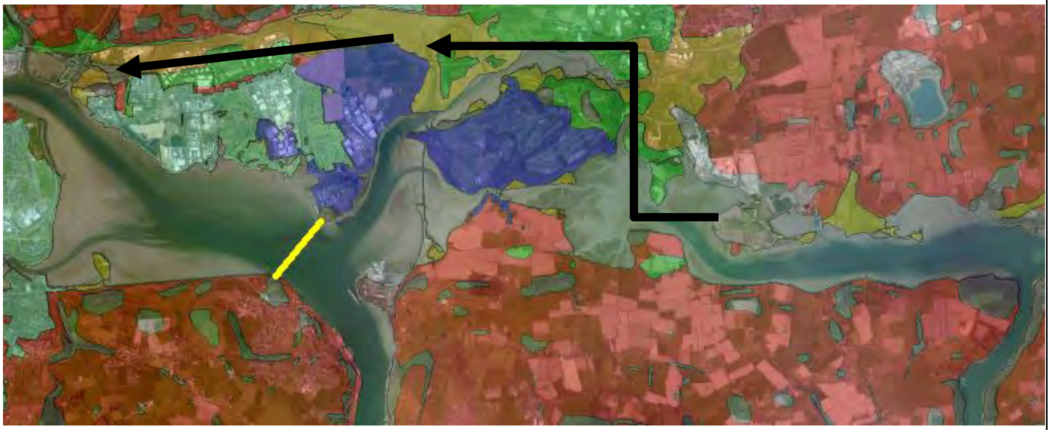
This can lead to the various mechanical and electrical equipment being subject to vibrations which can greatly compromise their long term operation and functioning. Such a mechanism is known to have incurred on the Eastern Scheldt barrier which proved very problematic for the operation of the structure and required significant remedial works.

8.3.6 Geotechnical and Hydrogeological Considerations

Similar to the Jack Lynch Tunnel, from a geotechnical and hydrogeological perspective, this option would not be recommended for the following reasons;

- This barrier is located in the limestone syncline and is expected to be underlain by deep sand and gravel deposits and limestone which may allow water to bypass under the barrier.
- The depths to bedrock in this area may be considerable so cut off of the groundwater routes through sand and gravel could be difficult.
- Tidal water may flow around barrier into Lee valley via north side of Little Island through the high permeability sand and gravel aquifer (see subsoil map with arrow below).

Figure 54: Little Island option: maps showing subsoil, bedrock and groundwater vulnerability



Subsoil – bedrock either side but located in syncline – assume sand & gravel deposits along river bed. S&G deposits to the north (in green and yellow) could act as conduit for tidal flow around north Little Island

Located on predominantly on limestone/mudstone, higher hydraulic conductivity and potential karst bypass

Vulnerability map indicates rock close/ or at surface on either side of bank

8.3.7 Upstream Storage Capacity

In considering the technical viability of a tidal barrier, it is imperative that a location is chosen which will provide sufficient upstream storage for river inflows during the period of closure.

This needs to be considered both for the current scenario but also for future climate change scenarios to ensure that the barrier location chosen is appropriate in the long term given the significant investment involved.

As described earlier in this report, the critical case when considering storage will be the fluvially dominated case when inflow is greatest. In the current scenario, the critical parameters have been defined as follows:

- Barrier Closed at -0.74mOD (low tide)
- Barrier Reopened at 2.4mOD (on ebb tide)

- Barrier Closure time is 8.5 hours
- Storage available between -0.74mOD and 2.4mOD
- Design inflow: 1 in 50 year return period event

At the Little Island location, the storage volume available between -0.74mOD and 2.4mOD is calculated from bathymetry data as 27,569,413m^3. As the barrier will be closed for 8.5 hours, the average inflow that will fill the available storage over the closure period is calculated as 901m^3/s.

The total average design inflow to the barrier at this location is estimated as circa 700m^3/s for the current scenario which is detailed in Appendix B.

This represents circa 78% of the available storage. It is evident therefore that there is sufficient storage upstream of the proposed barrier location for the current scenario, but that it will struggle in the face of climate change, which is examined further below.

As described earlier in this report, in the future climate change scenario (HEFS), the critical parameters have been defined as follows:

- Barrier Closed at 0.261mOD (low tide)
- Barrier Reopened at 2.4mOD (on ebb tide)
- Barrier Closure time is 10 hours
- Storage available between 0.261mOD and 2.4mOD
- Design inflow: 1 in 50 year return period event plus 20% increase due to climate change

At the Little Island location, the storage volume available between 0.261mOD and 2.4mOD is calculated from bathymetry data as 19,164,683m^3. As the barrier will be closed for 10 hours, the average inflow that will fill the available storage over the closure period is calculated as 532m^3/s.

As set out in the Lower Lee FRS Options Report, if no further modifications are made to the dams, or alternative upstream measures put in place, the peak flow at waterworks weir would increase by circa 40% for a 20% increase in inflow to the reservoirs. The increase will be even greater for the 30% increase in inflows for the HEFS.

Even if a conservative 30% increase is applied to the average catchment inflow of 700m^3/s estimate above, this would equate to an average inflow of circa 910m^3/s. This is significantly in excess of the available storage, and so it is evident that the tidal barrier location at Little Island is unlikely to be suitable for the HEFS and in all probability is unlikely to be viable in the MRFS. However, detailed modelling would be required to accurately identify the point at which it would become non-viable.

8.3.8 Conclusion

In conclusion, we consider that the stakeholder group's proposal as submitted is not technically viable for the following reasons:

- It would result in unacceptably high velocities with consequent unacceptable risks to navigational safety.
- Lacks sufficient redundancy and would result in significant maintenance risks due to single navigation opening and high velocities.
- Would likely have unacceptable impacts of geomorphology and the environment.
- Has limited adaptability for climate change.

8.4 Likely Impacts of Stakeholder Group's Proposal

8.4.1 Hydrodynamics, Navigation and Navigational Safety

The stakeholder group's barrier concept as proposed will concentrate the tidal flows through a very narrow channel at the navigation opening. Flow gates, normally left open, will spread the tidal flows over a somewhat wider area and reduce the concentrated flows at the navigation opening. The hydraulic impacts have been assessed earlier in the report.

The option provides a 60m wide navigation gate. However, the gate is not perpendicular to the navigation channel and therefore the effective width for shipping would be reduced.

The barrier is at a location where incoming vessels are swinging from a northerly to west-north-west direction.

Inbound vessels travel northbound up Passage West, then swing west to approach the dredged navigation channel. The barrier, located at the beginning of the channel would restrict the current available channel width from approximately 200m wide to effectively 50m at the barrier.

The hydraulic modelling shows that on the flood tide, the peak velocities are expected to be approximately 3m/s. The vessels would need to maintain an additional 1 - 2m/s minimum over and above the tidal flow in order to maintain control of direction, taking account of the prevailing south westerly winds which would provide a lateral load on the vessels.

On the downstream side of the opening the conditions would be very turbulent. The velocity contours are very close, which means that a small deviation in direction would lead to large change in velocity.

For inbound vessels on the ebb tide, the vessels will be challenged by a head velocity of approximately 3m/s. This of itself need not be a problem, provided the vessel is powerful enough to make headway against the current. The main challenge will be the associated turbulence and cross currents in combination with cross winds.

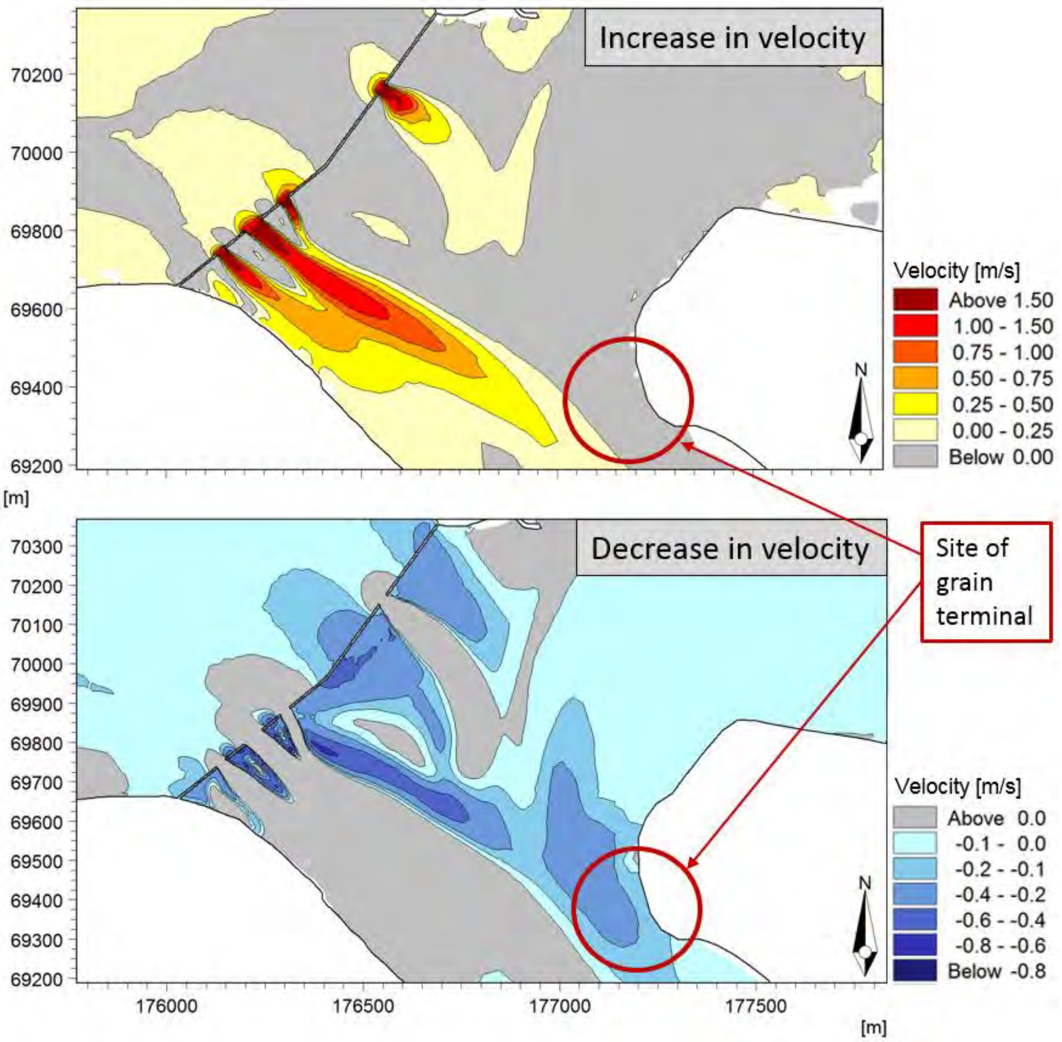
In consequence, inbound vessels will find the barrier very challenging to navigate. The challenges are similar for outbound vessels.

For new structures impacting on navigation it is common to test the navigational impact and to train pilots using simulators. This would be appropriate at a later stage of the design.

In our opinion however, the proposed tidal barrier option as submitted by the stakeholder group is highly unlikely to offer safe hydrodynamic conditions for navigation. It will be especially hazardous for smaller leisure craft.

The stakeholder group's barrier would also have a significant effect on navigation for the Passage West grain terminal at Marino Point (Figure 55) as the findings of the hydraulic model indicates that velocities potentially decrease alongside the jetty which could possibly lead to sediment build up. Conversely, manoeuvring of vessels off the jetty may also be affected by greater turbulence in the water column associated with the changes in velocities.

Figure 55: Change in velocities at Marino Point



8.4.2 Sediment Transport

The stakeholder group's barrier as proposed is likely to have a very significant impact on the transport of sediment and rates of sedimentation in the Lough Mahon due to the change exerted on the hydrodynamics by the structure. This change can be assessed by considering the increases and decreases in velocity:

- The significant increase in velocities resulting from flow being squeezed through the various gate openings will increase the shear stresses acting on the bed which in turn will lead to extensive scouring and erosion of the bed in the vicinity of the openings. High turbulence in the water column will also impact on the mobilisation of sediment in the vicinity of the opening. While we have not estimated the depth and extent of scour that would likely occur, it is very reasonable to expect that the scour depth would be in the order of metres at the structure (where the velocities will be highest) and the scour extent would extend from the structure for a distance greater than circa 100m – 150m both upstream and downstream of the structure. Extensive bed scour protection measures in the form of rock armour and/or concrete units would therefore be required in order to mitigate the scour risk. The area requiring these measures is very large, which will incur additional capital costs as well as on-going maintenance costs as the scour measures would need to be maintained and replaced periodically as they are very likely to have a short design life given the velocities that would be acting on them.
- The reduction in velocities will lead to an increase in sedimentation in certain areas. This process will be most pronounced in the immediate vicinity of the barrier where the embankments of the barrier are acting as an obstacle to the flow and the reduction in velocities are very high. Furthermore, it is also likely that increased sedimentation will also occur further away from the barrier in both the navigation channel and in the environmentally sensitive areas due to overall changes in the hydrodynamics. Bed levels in these areas will therefore have to be artificially maintained through dredging in order to ensure a minimum navigational depth in the channel. In the absence of detailed sediment modelling, it is very difficult to predict the increase in bed levels associated with the increased sedimentation and hence the amount of dredging required in order to maintain levels given the huge uncertainty over the behaviour of the sediment in the water column and the temporal variation of sediment loads entering Lough Mahon. In the baseline scenario however we note that Port of Cork undertake dredging operations once every two or three years to maintain bed levels in Lough Mahon to ensure safe navigation to the quays in Tivoli. It is therefore reasonable to assume that the frequency at which dredging operations would be required with the barrier in place would be increased, therefore incurring additional cost as part of the ongoing maintenance of the barrage structure.

8.4.3 Environmental Impacts

The proposed location lies within or is immediately adjacent to both the SAC and SPA. As such, it is considered an undesirable location from an environmental perspective. The construction period of the barrier will be relatively significant. The stakeholder group's proposal suggests a 2 year construction period which equates to 8 seasons. In practice, it is likely to be at least twice this period. During this time, there would be considerable disturbance to environment near the site.

As discussed above, there will be a requirement to undertaken dredging operations more frequently which could also have a negative environmental impact on the environmentally sensitive sites.

8.4.3.1 Ecology

With regards to the SACs, the structure and functioning of mudflats and sandflats is dependent on the tidal cycle. Construction of tidal barriers outside the SAC but in proximity to it could have the potential to impact on the structure and function of the SAC by changes in accretion of sediment, flow and velocities within the tidal zone. The changes to the velocity at this location can be seen in Figure 56 and Figure 57. While the habitat is likely to tolerate infrequent use of tidal barriers, frequent closing of the barriers is likely to have a significant impact on the structure and function of the Annex I habitat mudflats and sandflats. Disturbance of these habitats could lead to the displacement of waterbirds and any heavy or on-going disturbance could result in habitat loss.

A more extensive investigation, data gathering and analysis would be required to carry out a meaningful assessment of the potential impact of the works on the SPA. However as is shown in the below figures, the impact of the structure would extend outside the footprint of the barrier, and into the SPA. There would be changes to sediment accretion as a result of a new structure within the bay. Regular closing of the barrier could alter the environment and function of the site to the extent that it would no longer be preferable for overwintering birds. SPA listed birds include Shelduck, and Blackheaded gull both foraging and roosting; Little grebe, bar tailed godwit (in small numbers), Oystercatcher and Dunlin Roosting; and Wigeon and Grey crested grebe (in small numbers), curlew, teal and redhshank foraging.

Data gathering requirements here would likely include at least 2 years of new overwintering bird surveys. Site visits would include assessment of roosting/ foraging patterns and the significance of the bathymetry/ sediment profiles/ tide levels.

Figure 56: Increases in velocity for both the ebb and flood tide – Little Island Stakeholder Group Proposal

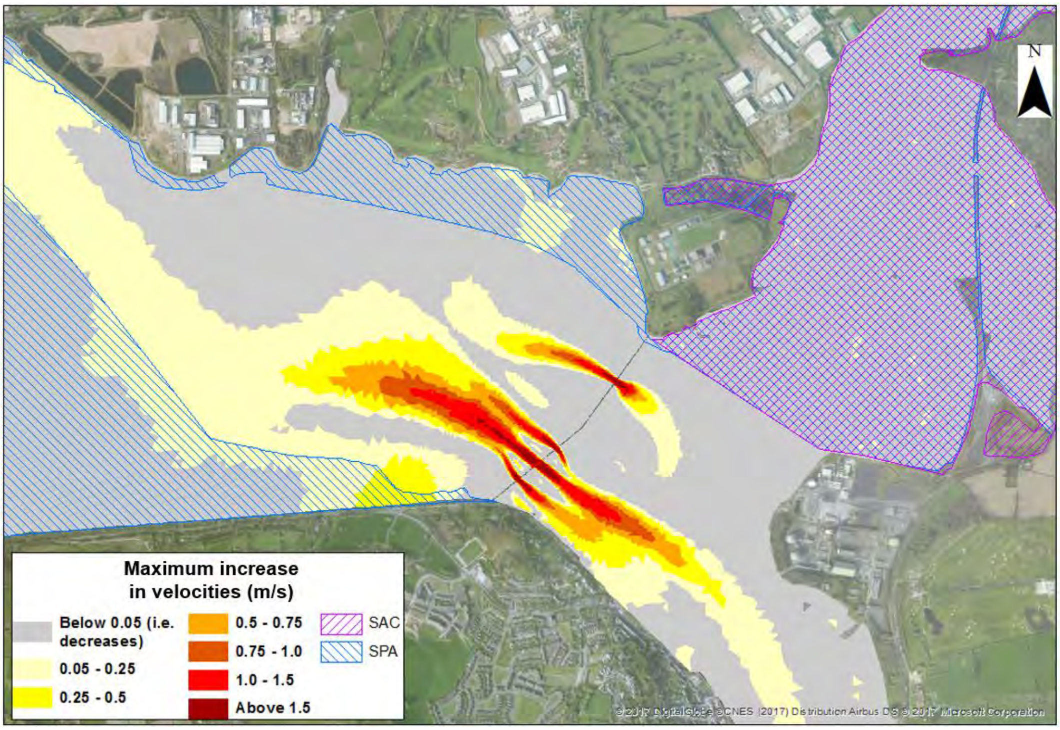
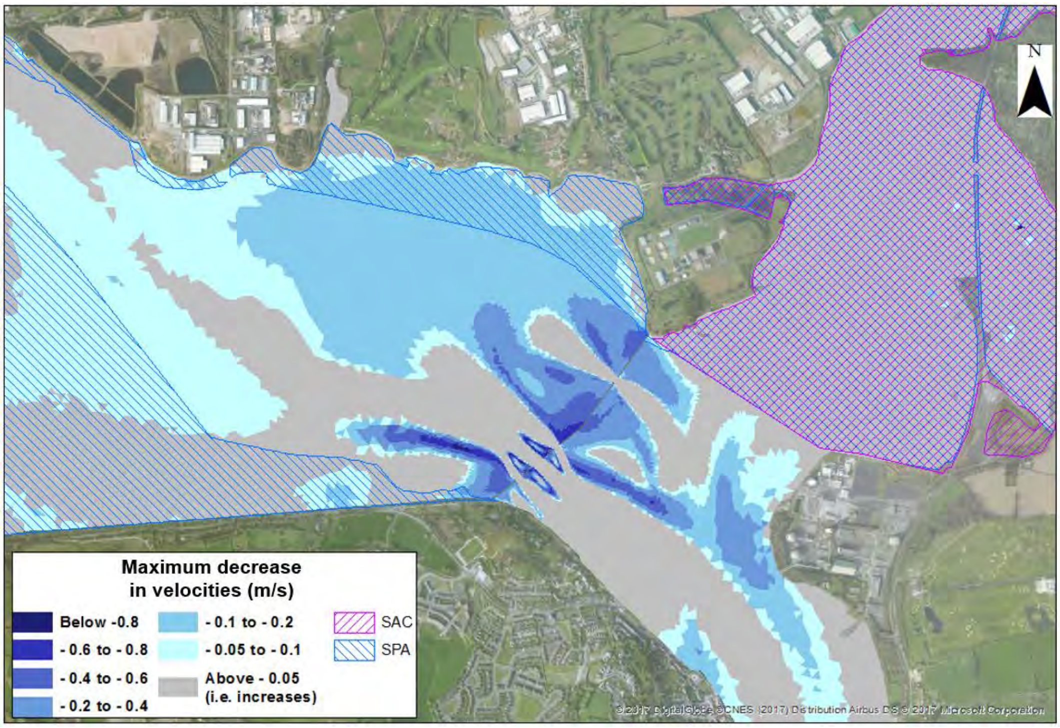


Figure 57: Decreases in velocity for both the ebb and flood tide – Little Island Stakeholder Group Proposal



In summary, the potential impacts on the SPA appear more significant than the potential impacts on the SAC, however our understanding of the potential impacts is limited by the information currently available/ unavailable on the proposal (information currently not available includes construction methodologies and programme durations, potential hydro morphological impacts - losses or gains of sand spits and roosting sites may result from a new structure in the harbour, etc.) and the lack of detailed survey data on the sites themselves.

Further detail on the ecological impacts can be found in the Ecological Report in Appendix C.

8.4.3.2 Landscape and Visual Amenity Impacts

The proposed location lies within Cork Harbour, and is located between Little Island and Passage West. To the north, land uses at Little Island include an Industrial Estate/Business Parks and a Golf Course. To the south lies the environs of Passage West where there is a coastal walkway on a dismantled railway line. To the east, across Lough Mahon, lies Marino Point and to the northeast lies Fota Island.

It is located on the edge of the rural areas and close to industrial land uses which may be more compatible with a structure such as this and where viewers may be less sensitive to changes of this nature in this context.

This location lies within the City Harbour and Estuary Landscape Character Area as defined by the Cork County Draft Landscape Strategy 2007. This Landscape Character Type comprises the city and the harbour as far as Roche's Point as well as the ridge to the north of the city.

The Strategy classifies this Landscape Character Type as Very High Value, Very High Sensitivity and Normal Importance.

The Cork County Development Plan lists several scenic routes in the vicinity:

- S53 lies to the east and runs along the R624 from Marino to Cobh
- S54 lies to the south of the proposed barrier and runs along the R610 south of Passage West to south of Monkstown to Ringaskiddy.

In this location, the proposed barrier is located where the river is relatively wide, almost 1020 metres in width. The barrier is likely to be visible from parts of the scenic route S53 on Great Island, and may be visible from sections of Fota Island. It may also be visible from Scenic Route S54, as well as from the R610 from Rochestown to Passage West. To the north, there are fewer visual receptors on Little Island but visibility will occur, in particular near Carrigrennan Point. It is within an area of High Value Landscape.

To the east, the landscape is designated as High Value Landscape in the Cork County Development Plan 2015-2021.

8.4.3.3 Construction Effects

The construction of a tidal barrier may have some negative construction effects namely construction traffic, noise and vibration, dust and sedimentation as well as ecological and hydrodynamic effects.

The construction period of the barrier will be relatively significant. The stakeholder group mention a 2-year construction period (8 seasons), but in reality it is likely to be significantly greater than this. During this time there would be considerable disturbance to overwintering birds in the vicinity of the site and also upstream of it. Typical restrictions on working in SPAs often include limits on working during the overwintering period, which in this case may be an impractical constraint on construction works but would otherwise further prolong the construction period. Whether bird populations are likely to recover after this extended disturbance would need further consideration.

8.4.3.4 Operational Noise

Following the construction of a barrier, it is expected that there will be some noise resulting from the operation of the barrier.

This would be intermittent while the barrier is either opening or closing, and would only occur occasionally when a storm is expected. This noise is likely to be minimal, therefore having minor adverse amenity effects on surrounding residential landowners.

8.4.3.5 Operational Traffic

It is proposed that only operation vehicles will have access to the barrier and therefore it is not expected that the barrier will have a major impact on traffic in the area when the construction phase is completed.

9 Technical Assessment of Potential Barrier at Little Island (potentially technically viable amended version)

9.1 Amended Pre-Feasibility Concept

In order to assess the effectiveness, costs and impacts of a tidal barrier at this location, an amended version of the stakeholder group's concept has been developed that would more likely be technically feasible based on the limited investigations carried out to date. This amended barrier concept would consist of the following;

- A crest level for the barrier of 4.38mOD which allows for 1/200 year tide level, with a 1.05m sea level rise in the HEFS and 0.5m freeboard. Given that the majority of surge gates are extremely difficult to adapt in the future, and given that construction of a tidal barrier will only become cost beneficial in the case of a significant increase in sea level, it is prudent that both the location and design of a barrier be assessed for a reasonable assumption of sea level rise.
- 2 No. navigation gates totalling 120m in width, to allow for redundancy during operation and maintenance procedures and in the event of gate opening/closing failure, and to allow for continued navigation during construction. The gates would be located in the deepest part of the channel.
- A concrete sill level for navigation gates at 0.5m below existing bed level in the deepest part of the channel at approximately -10.17mOD. This would mean the gates would be 14.55m high.
- Supplementary flow gates with a combined effective cross sectional area of 750m^2, 300m in length, 6m high set at or near existing bed level.
- Piers approximately 10m wide separating gates.
- An impermeable embankment approximately 480m in length, with a 5m wide crest.
- Access roads to north and south sides of the barrier

To address bypass of the Little Island barrier through the North Channel and flooding of the railway line in the short term, the following infrastructure is proposed;

- 2 No. flood gates at the N25 bridges over the north channel

The following components would only become necessary in the future climate change scenario (HEFS). Therefore, they could be constructed at a later date if necessary.

- Embankments at Carrigrennan and a number of locations along the N25
- Road raising of the N25 at two locations

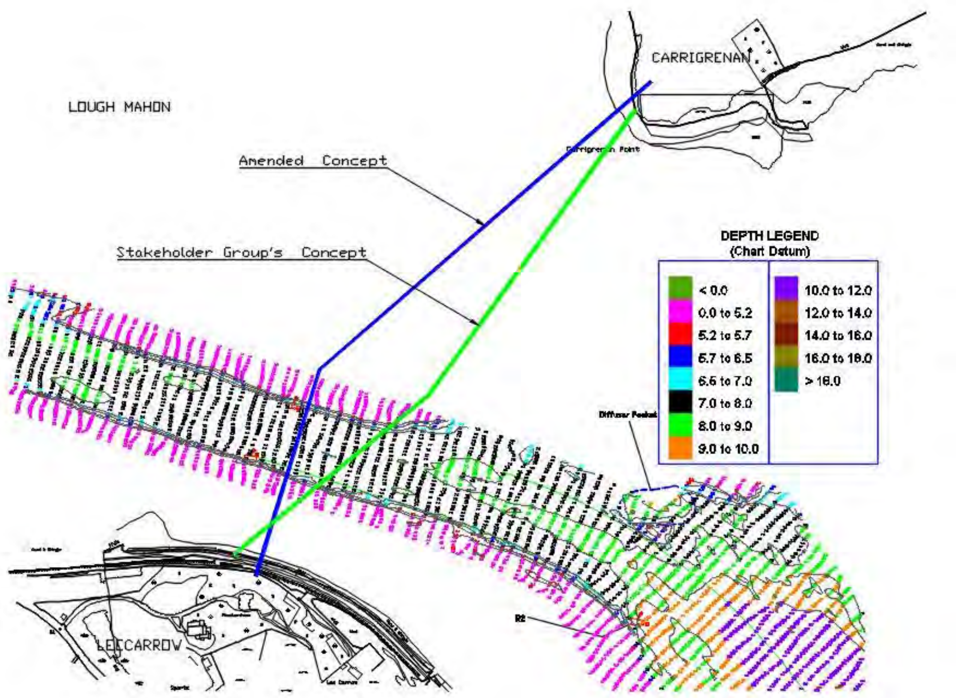
These components are considered further below.

9.1.1 Alignment, Geometry and Configuration

As noted earlier, the stakeholder group's submission shows an aerial image annotated with a proposed location for the barrier at Little Island. Its proposed alignment is not perpendicular to the navigation channel as it should be.

We have therefore developed an amended concept alignment that is more appropriate in terms of navigation requirements. This is shown in blue in Figure 58 below. The green line in Figure 58 below shows the approximate location of this barrier as proposed by the stakeholder group.

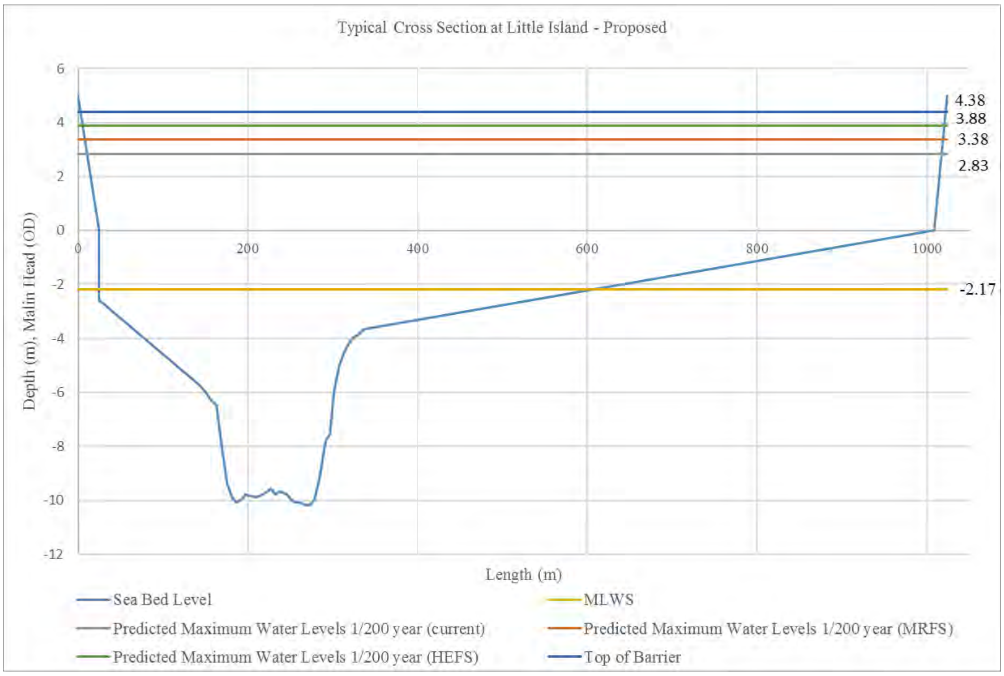
Figure 58: Little Island Barrier Alignment Alternatives



The revised alignment requires a total barrier length of 1020m, together with 470m of new access road required on land to the south side and a connection to the central road at the WWTP on the north side.

Figure 59 below shows a typical cross section of the channel bed at Little Island for this barrier alignment. For the purposes of this assessment, the required level of the top of the barrier is assumed to be approximately 4.38mOD allowing for 1/200 tide level with HEFS sea level rise and a freeboard of 0.5m. Therefore, any proposed barrier would need to extend inland to meet the 4.38mOD contour.

Figure 59: Typical Cross Section of the Little Island Channel



9.1.2 North Channel Bypass

We have examined the issue of potential bypass in detail and we have assessed how the issue of bypass of the barrier could be resolved.

As can be seen below in Figure 60, there are two bridges on the N25 over the estuary, east and west of Harper's Island and it is proposed that two flood gates could be installed at the bridges as part of the solution to the issue. This would likely be sufficient to address the issue for the current scenario.

However, should the future climate change scenario (HEFS) be realised, there is also the potential for water to pass overland and bypass these two flood gates on the N25. As can be seen from the LiDAR sections, defences would therefore also be required at a number of other locations, including:

- North east of Carrigrennan point
- Along the railway line south of the N25
- South of the N25 on north side of Little Island
- At the N25, west of railway line
- At the N25, north of Fota Island
- North of the N25, near Tullagreen intersection

A mix of engineering solutions could resolve these bypass issues, as can be seen in Figure 60 below.

It is proposed that two sections of road on the N25 could be raised with embankments installed at Carrigrennan Point, at the railway line (south of the N25) and at different locations along the N25.

However, these ancillary measures are within the Great Island SAC. This would be a significant consideration with regards to the environmental mitigation and cost of the works.

For the purposes of the cost estimate in Chapter 11, only the cost of the two flood gates at the N25 have been included. The other measures could be constructed at a later date if required based on the amount of sea level rise that occurs.

Figure 60: Potential Tidal Barrier Solution for Little Island

9.1.3 Navigation Gates

The navigational gate component of the barrier is that part of the barrier that opens and closes to allow safe passage of ships and maritime vessels between the inner (City Quays) and outer harbour (Ringaskiddy). The gates would be located in the deepest part of the channel in order to maintain the existing flow and sediment transport regime as much as possible, to meet the navigational requirements of passing ships and to minimise bed level disturbance during the construction stage.

The gates would need to extend to the existing bed level to allow passage of large ships at the existing low tide levels. The gates will also extend approximately 3m above the existing MHWS tide level in order to provide protection (when closed) against a 1/200 tide event with a 1m sea level rise scenario (HEFS).

2 No. 60m gates are proposed to allow for redundancy and meet POCC's likely requirements.

9.1.4 Flow Gates

The other gated component of the barrier will be flow gates, which in conjunction with the navigation gates, provide sufficient cross sectional area between low and high tide to allow passage of flow at appropriate velocities which facilitate safe navigation and minimise changes in sedimentation to acceptable levels. A minimum of 300m of supplementary flow gates are proposed.

9.1.5 Impounding Embankments

The embankment is the solid structural component of the barrier that connects the gates to the adjoining land. By using an embankment, the length of the expensive and complicated gate structures can be reduced. The embankment would be situated on the bed level of the existing estuary bed level. The crest will need to be constructed to approximately 3m above the existing MHWS tide level in order to stop water inflow under a 1/200 tide event with a 1 m sea level rise scenario (HEFS).

The embankment would likely include a small road on the crest to facilitate operation and maintenance activities. This would complicate the adaptability of the embankment and significantly increase the cost of raising the embankment in the future, if it became necessary. Any construction activities on the embankment would also present a risk to the successful operation and maintenance of the barrier gates, as access to them may become restricted. Therefore, it is deemed prudent to construct the embankment to the same defence level as the barrier gates which accounts for the HEFS.

9.2 Technical Feasibility

9.2.1 Hydrodynamic Assessment

Refer to Section 7.5 of this report for details.

9.2.2 Geotechnical and Hydrogeological Considerations

As per Section 8.3.6 above.

9.2.3 Upstream Storage Capacity

As per Section 8.3.7 above.

9.2.4 Conclusion

By making the amendments outlined in Section 9.1. above, the option of a tidal barrier at Little Island could become technically viable, albeit only up to about the MRFS, at which point it would become technically unviable as a result of insufficient storage upstream.

9.3 Likely Impacts of Amended Barrier at Little Island

It can be assumed that the following impacts will be similar for this amended Little Island barrier as for the stakeholder group's version as outlined above, for the following elements:

- Ecology
- Landscape and Visual Amenity
- Construction
- Operational Noise
- Operational Traffic

The amended version will however have a significantly reduced impact on Hydrodynamics, navigational safety and geomorphology as outlined below.

9.3.1 Hydrodynamics, Navigation and Navigational Safety

The proposed amended version of the barrier will still have a significant impact on the hydrodynamics and geomorphology of Lough Mahon, albeit to a lesser scale than the stakeholder group's proposal. The barrier will act as an obstacle to the flow in the estuary and force water to divert around the various components of the barrier and through its openings on both the flood and ebb tide.

However, versus the stakeholder group's proposal, the negative impacts on navigation are mitigated by:

- Increasing the width of navigation span to 120m and increasing the width of flow gates at either side to 300m.
- Aligning the navigation gate perpendicular to channel and therefore ensuring that the full width is effective.
- Setting the navigation span further west on the straight section of navigation channel.

The indirect benefit of these changes is that the maximum flow velocities are reduced substantially through the opening. Peak velocity in the hydraulic modelling indicates approximately 1.6m/s on the flood tide and 1.4m/s on the ebb tide, less than half that of the stakeholder group's proposal. The turbulence would also be proportionately less compared to the stakeholder group's version.

As part of the detailed design, an assessment would need to be made of varying widths of navigation gate in combination with the number of flow gates, to arrive at an acceptable balance of cost and navigation safety.

This version will also still have an effect on navigation for the Passage West grain terminal at Marino Point, but it will not be as pronounced as from Option 1.

The peak velocities through the main navigational gate opening and the additional flow gate openings for this amended option are not likely to compromise the long term operation and viability of the mechanical and electrical equipment of the barrier as the forces acting on the piers from hydrodynamics are not likely to be significantly problematic.

9.3.2 Sediment Transport

The impact of this version of the Little Island barrier on the transport of sediment in Lough Mahon and the wider harbour area would follow a similar pattern to the impact of the stakeholder group's proposal as outlined in Section 8.4.2. The degree of the impact however would be much less given that the change in velocities associated with the barrier are much less.

In the absence of detailed sediment modelling, it is difficult to quantify the reduced impact on sediment transport of this barrier against the previous barrier. It is very likely however that scouring of the bed in vicinity of the openings would remain a serious issue as the velocities through the openings are still in excess of 1.5m/s. This would need to be addressed through the implementation of scour protection measures.

Furthermore, deposition of sediment in the vicinity of the barrier would also be significantly increased which will have adverse consequences for maintaining bed levels and the environment.

There would also likely to be increased deposition in the main navigational channel and in the environmentally sensitive areas which although less than the impact of the stakeholder group's proposal, may still be significant and require on-going maintenance.

9.3.3 Environmental Impact

Generally, as per section 8.4.3 above. However, with regards to the ecology, as can be seen in Figure 61 and Figure 62 below, the change in velocities around the tidal barrier are less severe with this option than the stakeholder group's proposal. This is due to the addition of extra flow gates and having a wider navigation span. Therefore, the changes in accretion of sediment, flow and velocities within the tidal zone will have less of an impact on the mudflats and sandflat habitats than the stakeholder group's proposal.

Further detail on the ecological impacts can be found in the Ecological Report in Appendix C.

Figure 61: Increases in velocity for both the ebb and flood tide – Amended Little Island Option

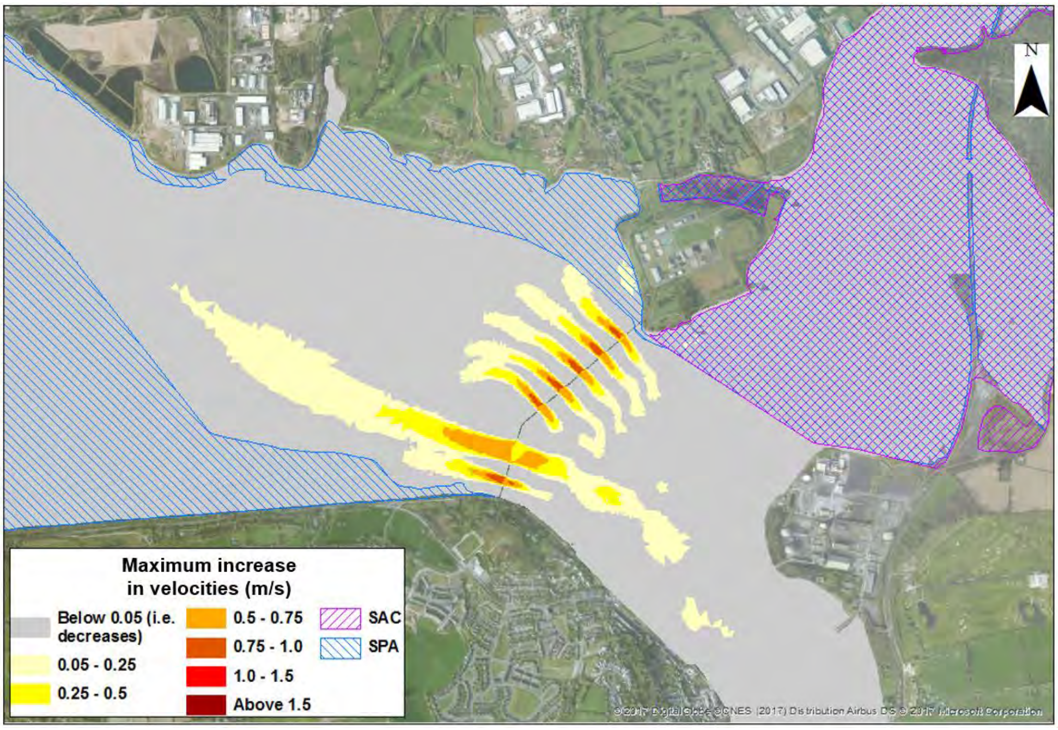
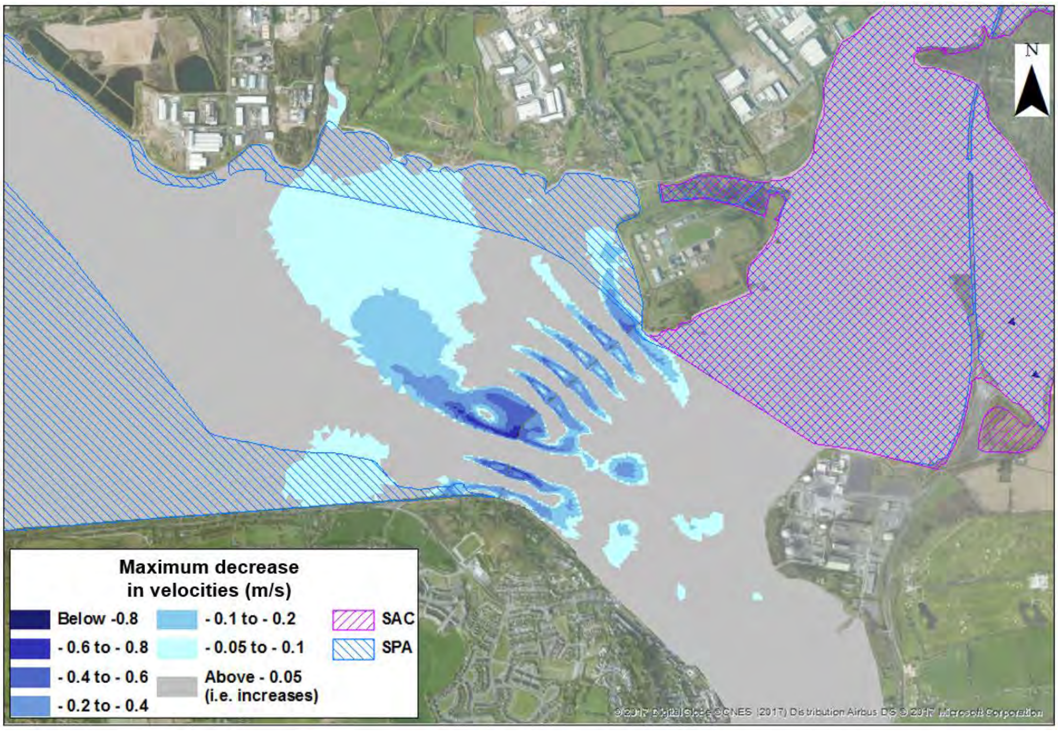


Figure 62: Decreases in velocity for both the ebb and flood tide – Amended Little Island Option



10 Technical Assessment of Potential Barriers at Great Island (Monkstown and Marlogue)

10.1 Pre-Feasibility Concept

10.1.1 Introduction

The location of the proposed barriers at Monkstown and Marlogue is as set out in the Lee CFRAM Study. As established earlier, it is considered that the full width of each opening would need to be gated to maintain velocities at a level as close as possible to existing. Therefore, the following is proposed as a possible solution for the barriers at Monkstown and Marlogue.

2 No. 60 navigation gates and circa 140m of flow gates are proposed at the Monkstown side. A single 60m navigation gate and approximately 165m of flow gates are proposed at the Marlogue side.

At Monkstown:

- A crest level for the barrier of 4.23mOD which allows for 1/200 year tide level, with a 1.05m sea level rise in the HEFS and 0.5m freeboard.
- 2 No. navigation gates, each 60m wide, to allow for redundancy during operation and maintenance procedures and in the event of gate opening/closing failure, and to allow for continued navigation during construction. The gates would be located in the deepest part of the channel.
- A concrete sill level for navigation gates at 0.5m below existing bed level in the deepest part of the channel at approximately -20.47mOD. This would mean the gates would be 24.7m high.
- Supplementary flow gates to span the rest of the channel width, approximately 140m excluding piers. These would also be set to the bed level, with varying heights. On average the flow gates would have a height of approximately 12m.

Figure 63 below presents a schematic representation of a potential tidal barrier at Monkstown.

At Marlogue:

- A crest level for the barrier of 4.23mOD which allows for 1/200 year tide level, with a 1.05m sea level rise in the HEFS and 0.5m freeboard.
- 1 No. navigation gate, 60m wide. The gate would be located in the deepest part of the channel.
- A concrete sill level for navigation gates at 0.5m below existing bed level in the deepest part of the channel at approximately -9.2mOD. This would mean the gate would be 13.43m high.
- Supplementary flow gates to span the rest of the channel width, approximately 165m excluding piers. These would also be set to the bed level, with varying heights. On average the flow gates would have a height of approximately 8m.

Figure 63: Schematic image of potential barrier at Monkstown

10.1.2 Alignment, Geometry and Configuration

Typical cross sections of the existing channel at both locations are shown below in Figure 64 and Figure 65 below.

Figure 64: Typical Cross section at Monkstown.

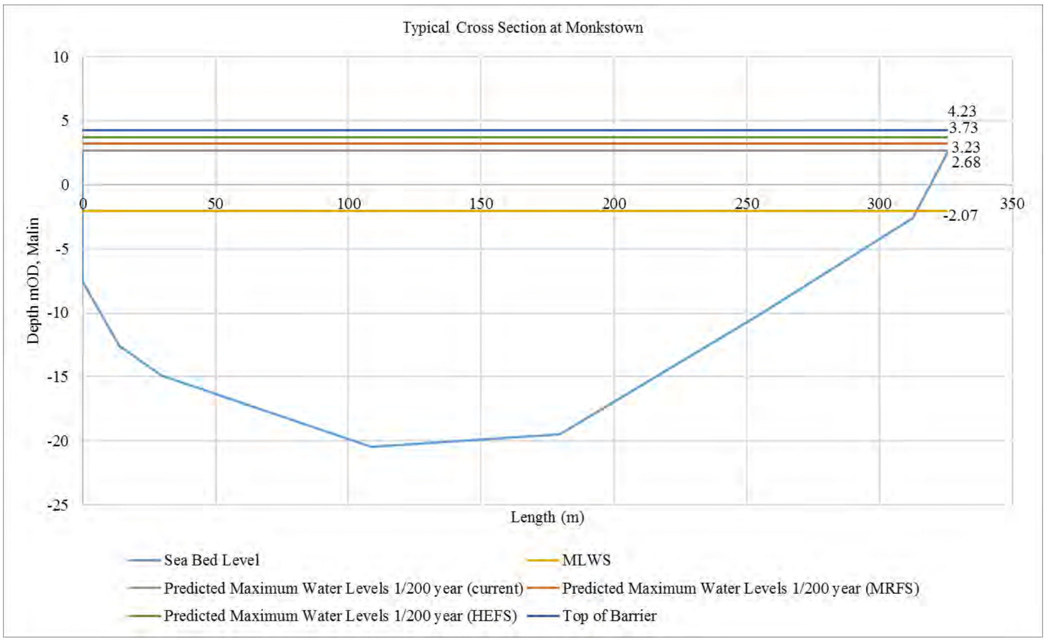
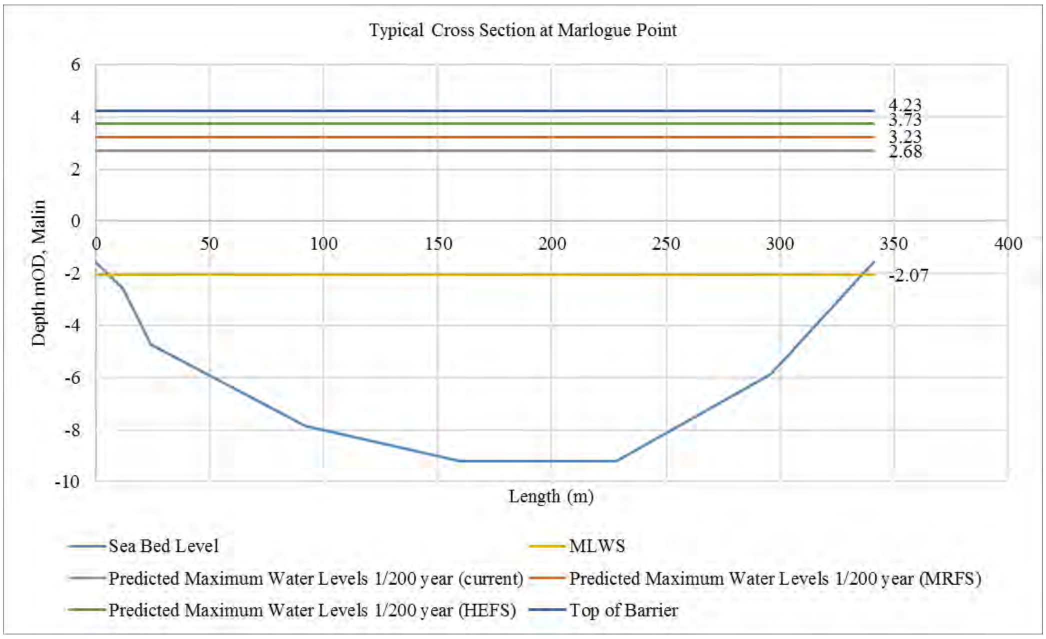


Figure 65: Typical Cross section at Marlogue



10.1.3 Navigation Gates

The gates would be located in the deepest part of the channel in order to maintain the existing flow and sediment transport regime as much as possible, to meet the navigational requirements of passing ships and to minimise bed level disturbance during the construction stage.

The gates would need to extend to the existing bed level to allow passage of large ships at the existing low tide levels. The gates will also extend circa 3m above the existing MHWS tide level in order to provide protection (when closed) against a 1/200 tide event with a 1m sea level rise scenario (HEFS).

10.1.4 Flow Gates

As has been discussed previously, the channels are extremely narrow for the peak tidal flows conveyed at these locations. Average velocities at these locations are already approaching 1m/s and therefore any reduction in flow area would have a detrimental effect. Therefore, at these locations, it is recommended that flow gates be included across the full width of the channel such that the reduction in cross sectional flow area is limited to the area taken up by the piers for the navigation and flow gates.

10.2 Technical Feasibility

10.2.1 Hydrodynamic Assessment

Refer to Section 7.6 of this report for details.

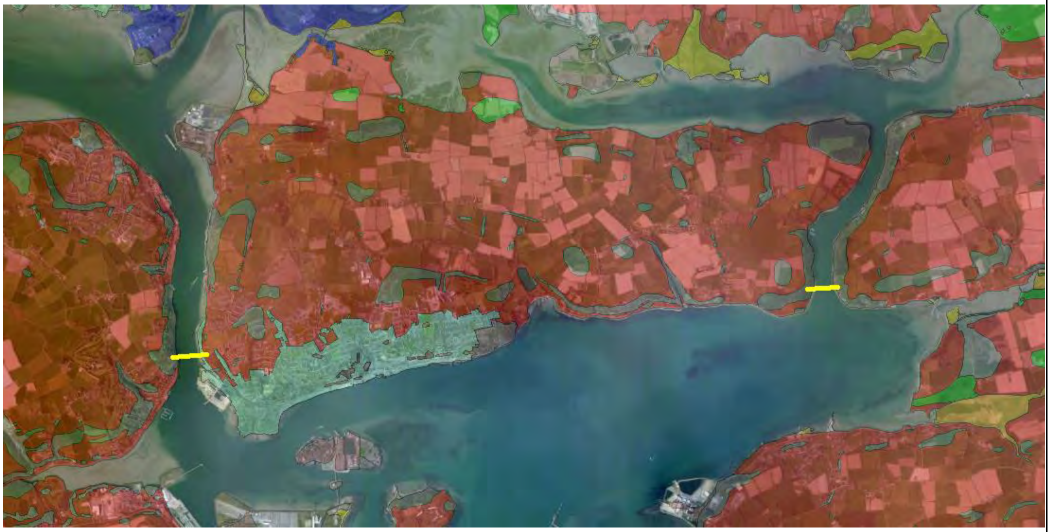
10.2.2 Operation of the Hydraulic Gates

The peak velocities through the main navigational gate opening and the additional flow gate openings are not likely to compromise the long term operation and viability of the mechanical and electrical equipment of the barriers at these locations.

10.2.3 Geotechnical and Hydrogeological Considerations

From a geotechnical and hydrogeology perspective, there are no major issues as it is located on sandstone/mudstone anticline which is preferable. Rock outcrops on either side of barrier would prevent water bypass along the sides of barrier via overburden.

Figure 66: Great Island – includes two barriers off Great Island – east and west: map of subsoil, bedrock and groundwater vulnerability



Subsoil – bedrock either side & shallower depth to bedrock so less risk of bypass

Sandstone mudstone – low hydraulic conductivity so little risk of bypass

Vulnerability map indicates rock close (pink area)/ or at surface (red) on either side of bank. Generally, rock close to surface on anticline.

10.2.4 Upstream Storage Capacity

In considering the technical viability of a tidal barrier, it is imperative that a location is chosen which will provide sufficient upstream storage for river inflows during the period of closure.

This needs to be considered both for the current scenario but also for future climate change scenarios to ensure that the barrier location chosen is appropriate in the long term given the significant investment involved.

As described earlier in this report, the critical case when considering storage will be the fluvially dominated case when inflow is greatest. In the current scenario, the critical parameters have been defined as follows:

- Barrier Closed at -0.74mOD (low tide)
- Barrier Reopened at 2.4mOD (on ebb tide)
- Barrier Closure time is 8.5 hours
- Storage available between -0.74mOD and 2.4mOD
- Design inflow: 1 in 50 year return period event

At the Great Island location, the storage volume available between -0.74mOD and 2.4mOD is calculated (using a complete bathymetric dataset of the harbour) as 73,000,469m^3 (circa 265% of volume available at Little Island). Over the 8.5 hour closure duration, it would require a steady inflow of 2,386m^3/s to fill the available storage.

As detailed in Appendix B, the total average design inflow is estimated as circa 830m^3/s.

This is only circa 35% of the available inflow and therefore, it is evident that there is sufficient storage upstream of the proposed barrier location for the current scenario.

As described earlier in this report, in the future climate change scenario (HEFS), the critical parameters have been defined as follows:

- Barrier Closed at 0.261mOD (low tide)
- Barrier Reopened at 2.4mOD (on ebb tide)
- Barrier Closure time is 10 hours
- Storage available between 0.261mOD and 2.4mOD
- Design inflow: 1 in 50 year return period event plus 20% increase due to climate change

At the Great Island location, the storage volume available between 0.261mOD and 2.4mOD is calculated from bathymetry data as 52,335,882m^3. Over the 10 hour closure duration, the average inflow that will fill the available storage over the closure period is calculated as 1,454m^3/s.

As set out in the Lower Lee FRS Options Report, if no further modifications are made to the dams, or alternative upstream measures put in place, the peak flow at waterworks weir would increase by circa 40% for a 20% increase in inflow to the reservoirs. The increase will be even greater for the 30% increase in inflows for the HEFS.

Even if a conservative 30% increase is applied to the average catchment inflow of $830m^3/s$ estimate above, this would equate to an average inflow of circa $1080m^3/s$. This is still only 74% of the available storage, and so it is evident that the tidal barrier location at Great Island is likely to be suitable for the HEFS and beyond. It is noted that the Lee CFRAMS (Halcrow, 2014) undertook more detailed modelling and arrived at a similar conclusion.

10.3 Assessment of Impacts

10.3.1 Hydrodynamics, Navigation and Navigational Safety

The proposed barrier could have a very significant impact on the hydrodynamics in both the West and East Passage as the barrier will act as an obstacle to the flow in the estuary and force water to divert around the various components of the barrier and through its openings on both the flood and ebb tide. It is proposed to minimise this impact by incorporating navigation or flow gates across the entire opening so that any obstruction is limited to the discrete piers at the ends of each gate.

Only the western barrier at Monkstown is pertinent to the larger vessels using Cork Harbour. Both barriers would need to accommodate smaller leisure craft.

The hydraulic modelling shows an increase in peak velocities on ebb and flow tides at the Monkstown Barrier. On the flood tide the peak velocity increases from 1.2m/s approximately to 1.4m/s approximately. These flows are moderate compared to Barrier Options 1 and 2 at Little Island.

10.3.2 Sediment Transport

The impact of Tidal Barrier Option 3 (the barriers at Monkstown and Marlogue Point) are not likely to have a significant impact on the transport of sediment in the harbour as they are not having a significant impact on the hydrodynamics. As indicated in the results in the previous section, the impact of these barriers are localised to a reduction in velocity on the upstream of the barriers on the flood tide and a reduction in velocity on the downstream of the barriers on the ebb tide. Sediment is therefore likely to be deposited at these locations which may need to be artificially controlled through dredging.

The increase in velocity associated with the barriers is not significant and is not likely to have a significant influence on the erosion of material from the bed. There is still however likely to be a need for scour protection measures around the base of the piers to mitigate the risk of localised scour.

10.3.3 Environmental Impact

10.3.3.1 Ecology

Both barriers and Monkstown and Marlogue Point are outside of the designated Natura 2000 sites. Should construction be carried out with appropriate mitigation to avoid disturbance of the adjoining sites there is potentially no direct impact.

However, it is noted that any barrier within or in close proximity to the SAC or SPA will have an impact on the Conservation Targets for those sites, namely the requirement for the permanent habitat area to be stable or increasing, subject to natural processes. In the case of any tidal barrier being progressed detailed assessment on bird populations and behaviour would be required to allow the project to rule out potential impact on the Natura 2000 Sites.

As the barriers are located in existing narrow channels, the majority of the existing channel width will need to have barrier openings for navigation and flow. Therefore, in the absence of lengthy impounding embankments, a significantly lesser change in velocities and sedimentation patterns will arise as can be seen in the figures below. This combined with the with the locations being remote from any SAC or SPA designations, mean that the environmental impacts would be significantly less than at the Little Island locations for example.

Figure 67: Increases in velocity for both the ebb and flood tide – Great Island, Monkstown

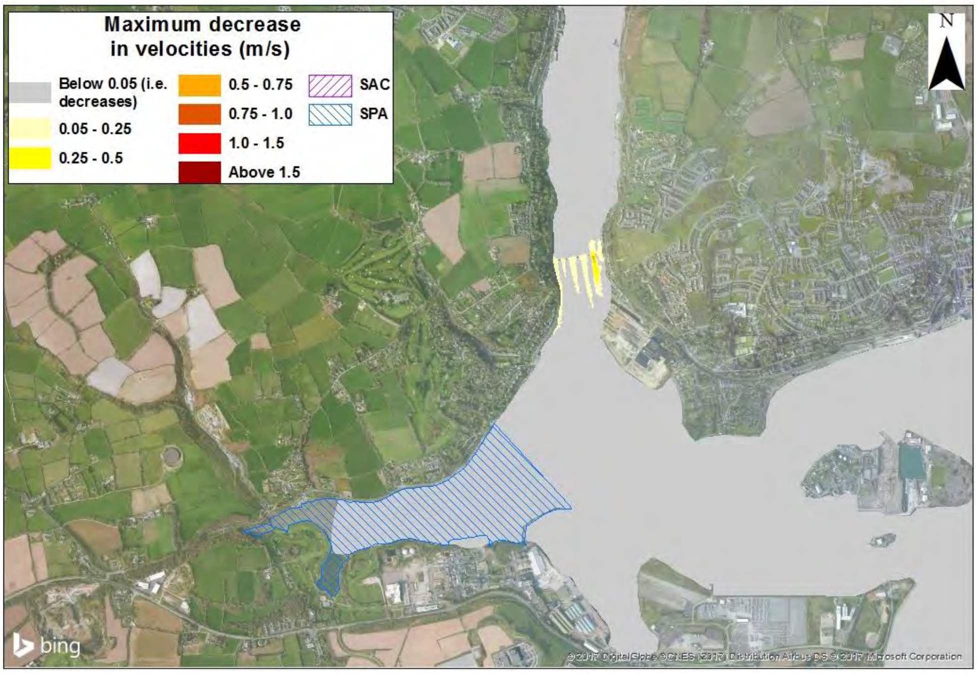


Figure 68: Decreases in velocity for both the ebb and flood tide – Great Island, Monkstown

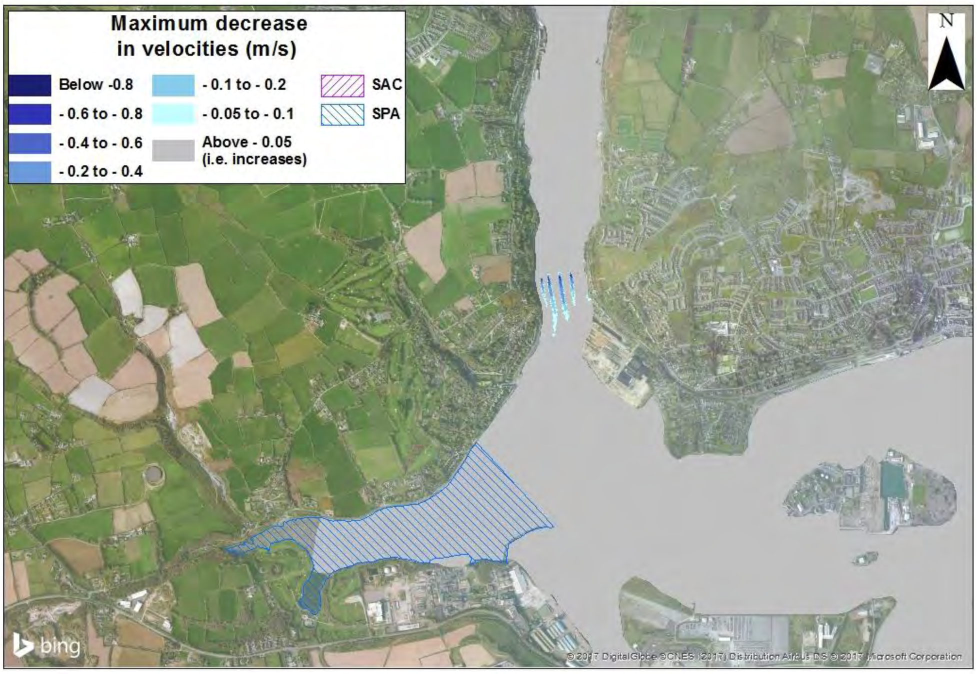


Figure 69: Increases in velocity for both the ebb and flood tide – Great Island, Marlogue

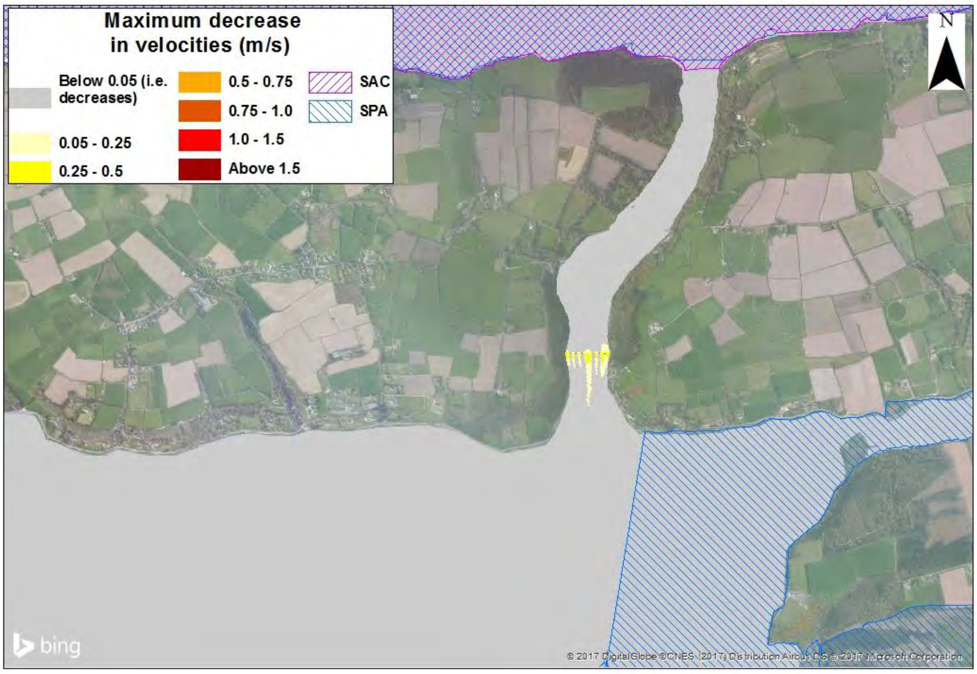


Figure 70: Decreases in velocity for both the ebb and flood tide – Great Island, Marlogue

Further detail on the ecological impacts can be found in the Ecological Report in Appendix C.

10.3.3.2 Landscape and Visual Amenity Impacts

The proposed location consists of two relatively narrow tidal barriers, either side of Great Island within Cork Harbour. One barrier lies within a narrow passage between Monkstown and Rushbrooke, while the other barrier is located between Marlogue Point and the land opposite, across the Ballynacorra River. Land uses around Monkstown include open space, and residential development on both sides of the channel and the Rushbrooke docks and Commercial Park are located south of the proposed barrier on Great Island. The area has a partly rural character. The proposed barrier location at Marlogue lies in a rural context, with woodlands, agricultural lands and scattered buildings.

From a landscape and visual perspective, this location lies within the City Harbour and Estuary Landscape Character Area as defined by the Cork County Draft Landscape Strategy 2007. This Landscape Character Type comprises the city and the harbour as far as Roche's Point as well as the ridge to the north of the city. The Strategy classifies this Landscape Character Type as Very High Value, Very High Sensitivity and Normal Importance. This proposed barrier location is designated as High Value Landscape in the Cork County Development Plan 2015-2021. The barrier at Monkstown is not within this designation but is in close proximity to the designation.

The two barriers are located at narrow channels in the harbour, on either side of Great Island. The barriers are relatively narrow in extent, with lengths of 310 metres at Monkstown and 285 metres at Marlogue, and are the shortest of all the barrier options when considered separately.

The proposed barrier at Monkstown will be visible from the Scenic Routes S53 and 54, both of which run along the coast. Visibility will be concentrated in the narrow channel and views are likely to form visual receptors located in the Monkstown area as well as across the river. Views are also possible from the Ringaskiddy port to the south. This is an active port however so views would not be considered highly sensitive.

There will also be visibility of the Marlogue barrier from the scenic route 51, and again views will be concentrated along the narrow channel, which has more of a rural character. There are less visual receptors – fewer residents and there is a road on one side (east) of the channel only. More distant views are also likely from parts of the coast road at Aghada to the south.

10.3.3.3 Construction Effects

The construction of a tidal barrier may have some negative construction effects namely construction traffic, noise and vibration, dust and sedimentation as well as ecological and hydrodynamic effects.

10.3.3.4 Operational Noise

Following the construction of a barrier, it is expected that there will be some noise resulting from the operation of the barrier. This would be intermittent while the barrier is either opening or closing, and would only occur occasionally when a storm is expected. This noise is likely to be minimal, therefore having minor adverse amenity effects on surrounding residential landowners.

10.3.3.5 Operational Traffic

It is proposed that only operation vehicles will have access to the barrier and therefore it is not expected that the barrier will have a major impact on traffic in the area when the construction phase is completed.

11 Preliminary Cost Estimate

11.1 Introduction

When considering the feasibility of a tidal barrier in Cork Harbour, one of the key considerations is cost and Benefit Cost Ratio (BCR). In this section a number of different methods have been used to estimate the potential costs for a number of potential barriers.

Firstly, the value of the construction project cost has been calculated based on recommendations from a selection of academic papers.

Secondly a unit rate has been derived that more accurately represents the potential cost of a barrier in Cork Harbour specifically.

Finally, consideration has been taken of the possible whole life costs of a barrier, including operation and maintenance costs and any other ancillary work that need to be undertaken to facilitate the construction, maintenance and operation of a barrier.

The purpose of this assessment is to establish an approximate order of magnitude cost for the potential barriers and allows a comparison to be made between the various flood risk management options.

In Chapter 5 above, the potential barrier locations were discussed and it was shown that the option with the greatest technical viability was at Great Island.

However, it was acknowledged that a barrier at Little Island may represent a less expensive option due to the river's lower depth at this point. Therefore, options at both these locations have been assessed in this report. These options are:

1. Little Island Option 1 – Concept as proposed by a stakeholder group, with further information from a cost estimation prepared on behalf of the group by HR Wallingford.
2. Little Island Option 2 – similar to the above but with larger navigation and flow gates which are considered more likely to represent the minimum needed in terms of safe navigation and minimising environmental impact.
3. Great Island – Two tidal barriers working in tandem at Monkstown and Marlogue.

The concept design for these options is summarised in Section 11.3 below.

11.2 Cost Estimation Methodology

A top-down approach has been used in this report to estimate the approximate order of magnitude of the construction costs using a number of different methods. International examples of similar structures have been used to generate unit costs or relationships. These can then be applied to the Cork barrier options to estimate the potential project costs. These methods are summarised below:

1. Method 1 – Jonkman Method (Jonkman, Hillen, Nicholls, Kanning, & van Ledden, 2013)

   The Jonkman paper was progressed in two more papers that defined further the data used in the study (Mooyaart L. , Jonkman, de Vries, van der Toorn, & van Ledden, 2014) (Mooyaart & Jonkman, 2017). All these studies looked at international examples of tidal barriers and derived a unit cost based on the length of only the gated elements of a barrier. The calculation does not include an allowance for any embankment and therefore should be combined with a separate costing for the earthen element.

2. Method 2 – Aerts Method (Aerts, Botzen, Moel, & Bowman, 2013).

   In this method, unit costs for both the gated and earthen elements have been derived based on international tidal barrier data. The purpose of this paper was to assess the feasibility of a tidal storm surge barrier for the city of New York.

3. Method 3 – Unit Rate Development

   Data from previous studies noted above, and other freely available sources were used to develop unit costs for the construction of a barrier in Cork based on a number of different criteria as follows:

   1. Depth
   2. Area of gated elements
   3. Separation of navigation gates, flow gates and embankment rates.

The values of these gated elements were then combined with an estimation for the earthen elements. The rate for the embankment was calculated by looking at available international information and previous Arup projects.

To allow for a comparison to be made between the different methods, the relative standard deviation, also called the coefficient of variation (Cv) is calculated. This value is a ratio of the difference between the actual costs and the calculated costs and will be presented as a %. This is presented to compare the accuracy of each method. The lower the % value of Cv, the lower the level of uncertainty associated with the method.

Where necessary, cost data has been converted to 2017 rates. To do this, Purchasing Power Parities (PPP) were used to convert the project cost from the source country to the Irish equivalent, using the PPPs from the year the structure was completed. This value was then inflated using the Irish Consumer Price Indices (CPI) to give a euro value for 2017. The PPP rates were taken from the Organisation for Economic Development (OECD) and the CPI data was taken from the Irish Central Statistics Office. This conversion was undertaken to ensure consistency and to allow for direct comparisons to be made between the various methods and options.

The data sources used in this study have made general assumptions about what has and has not been included in the published international project costs. Following on from the guidance in these papers, an assumption has been made that the cost includes the design, materials, construction, land acquisition, taxes, fees, site investigations and environmental mitigation. It is understood that the published costs do not include operation and maintenance costs and do not include the costs of any ancillary work that are required to compliment the tidal barrier construction i.e. upstream fluvial defences.

At the Little Island location, as previously discussed in this report, there is the potential for a storm surge to bypass the barrier using a number of overland routes to the North. Due to the inadaptability of tidal barriers, it is prudent to design the main tidal barrier gates to account for sea level rise. However, some of the ancillary work could be completed at a later date when there is a clearer view on the amount of sea level rise. Therefore, only the cost of floodgates required at the N25 have been included in the final cost estimate, as these are the only elements required in the current scenario. Estimates for this ancillary work has been made in Section 11.5 using the gate unit rates derived in Method 3.3.

Whilst a tidal barrier will provide protection to the east of Cork City, fluvial defences will still be required further west. An estimate for these defences has been made in Section 11.6 based on the costs of the relevant elements of the exhibited scheme.

Considering the whole life cycle of the structure is also a critical factor in cost estimation and this is assessed in Section 11.7. Generally operation and maintenance (O&M) costs can be related back as a function of the capital cost of the project. An assessment has been made of rates suggested in academic journals, examples from existing similar structures and also examples from previous cost estimate studies for other potential barriers.

Mega projects of this nature are susceptible to high levels of risk and uncertainty due to a number of factors. These include works duration, the use of new techniques leading to unexpected costs and substantial environmental requirements. Therefore, it is important to provide a significant allowance for contingency. "The Green Book: appraisal and evaluation in central government" published by the UK government suggests a rate of between 6% and 66% for large scale, non-standard civil engineering projects. During the construction of the Eastern Scheldt storm surge barrier, a report advised to budget at least for an additional 30% contingencies at the start of the new (similar) projects (Goemans & Smits, 1994).

It is proposed to use a figure of 20% in this study. This figure will be added in the final cost comparison summary in Section 11.8.

11.3 Cork Tidal Barrier Options

The concept design is considered to represent an appropriate barrier based on the limited Bathymetric information, Ground Investigation information and limited input from key stakeholders at this stage.

Detailed design may lead to a variation of the concept design but is unlikely to change the primary findings of this study in terms of scale of structure, navigation requirements, potential impacts and the approximate order of magnitude costs.

The barrier is envisaged to consist of navigation gates, flow gates and embankments as outlined below in Table 11 below. Ancillary components are outlined in Section 11.5.

Table 11: Concept Cork Barrier Configurations

	Little Island Option 1	**Little Island Option 2**	**Great Island**	
Overall Length	1020	1020	595	
Navigation Gates			Monkstown	Marlogue
Type	Sector	Rotary Seg.	Rotary Seg.	Rotary Seg.
Number	1	2	2	1
Span (excl. piers) (m)	60	60	60	60
Cumulative Span (m)	60	120	120	60
Gate Height (m)	14.55	14.55	24.7	13.43
Flow Gates				
Type	Vertical lift	Vertical lift	Vertical lift	Vertical lift
Number	6	6	4	6
Span (excl. piers) (m)	15	50	35	27.5
Cumulative Span (m)	90	300	140	165
Gate Height (m)	6	6	12	8
Embankment				
Length (m)	810	600	0	

The barrier configuration options at the various locations and the reasoning for selecting the chosen gate types have been discussed in Chapter 6.

The cumulative spans listed above do not include the length of the piers or the area required for dry dock housing of the gates. Therefore, the overall length of the whole barrier structure is longer than the cumulative spans plus the embankment length. The cost of the piers and housing are assumed to be incorporated into the cost of the actual gates.

The modelling done in Chapter 7 assumed the height of all the gates to be the full depth of the channel across the entire length of the barrier. Similarly, in this cost analysis, the chosen heights for the navigation gates at both locations is the maximum depth of the river. However, in an effort to minimise cost and following an analysis of the tide variations and flow requirements in Section 6.2.1, a flow gate height of 6m was deemed to be sufficient at Little Island. 6m flow gates have also been assumed for the stakeholder group's option.

At Great Island, as discussed in Section 6.2.2, the channels are narrower and any reduction in flow area would have a significant negative impact on navigation and navigational safety.

Therefore, the height of the flow gates should be set to the maximum depth possible. An approximate average of the flow gate heights required at Monkstown would be 12m and at Marlogue, 8m.

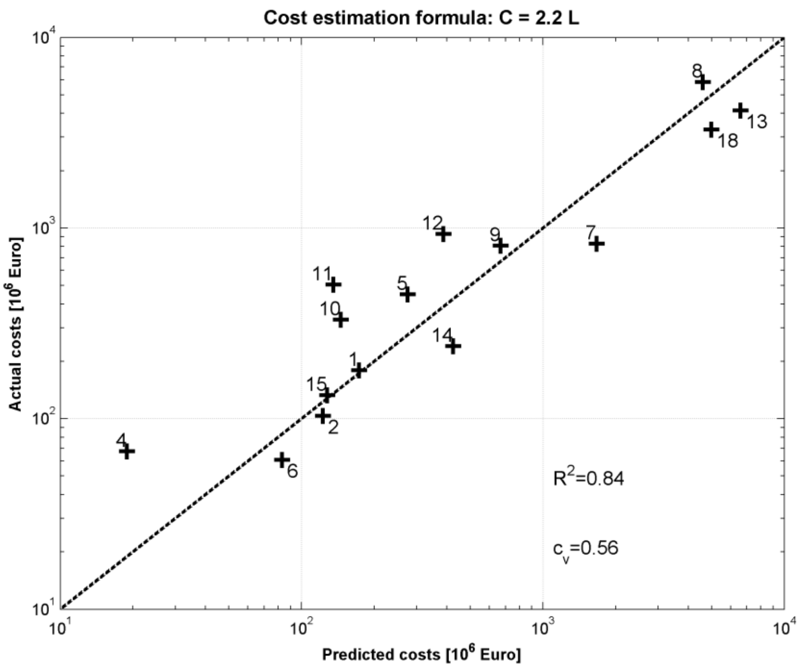
11.4 Construction Cost Estimate

11.4.1 Method 1 – Jonkman Method

An Investigation from the Journal of Coastal Research was used as an initial pass at a top-down exercise (Jonkman, Hillen, Nicholls, Kanning, & van Ledden, 2013). On average, the unit cost for a storm surge barrier was found to be 2.2 million euros per metre of span (Mooyaart L. , Jonkman, de Vries, van der Toorn, & van Ledden, 2014). The paper uses the length of just the gated sections of the barrier in its calculation.

Figure 71 below is an extract from (Mooyaart & Jonkman, 2017) which plots the actual cost of 15 international tidal barriers against a cost calculated based on a rate of €2.2m per lin.m derived by the Jonkman study.

Figure 71: Cost Estimation Formula (Mooyaart & Jonkman, 2017)



A good correlation is evident, though it should be noted that a significant variation of 56% was still found. This method does not differentiate in terms of depth or hydraulic head and it does not account for differentiation between types of gates or the gate function (navigation or flow). All of these factors could be a critical in the design of any potential barrier. Also as this method is only applicable to the length of the gated section of the barriers, the cost of the impounding embankment and other supplementary items would need to be added to the total cost.

Nonetheless, it provides a good starting point to estimate the potential range of costs.

Applying this rate to only the gated elements of the potential barriers chosen in this study yields the following results:

Table 12: Cost Estimate Method 1 - Cork Results

	Little Island Option 1	Little Island Option 2	Great Island
Cumulative Span (m) (excludes piers)	150	420	485
Rate	€2,200,000	€2,200,000	€2,200,000
Rate (2017)	€2,256,119	€2,256,119	€2,256,119
Estimated Cost (2017)	€338,417,802	€947,569,847	€1,094,217,561

Adding an approximate value for the cost of the embankment element yields the following results. This value was calculated based on international studies and previous Arup experience.

Table 13: Cost Estimate Method 1 Plus Embankment - Cork Results

	Little Island Option 1	Little Island Option 2	Great Island
Embankment cost	€38,235,416	€28,322,530	€0
Total Estimated Cost	**€376,653,218**	**€975,892,377**	**€1,094,217,561**

11.4.2 Method 2 – Aerts Method

A report investigating the feasibility of a tidal barrier for the city of New York also evaluated historical data on international tidal barriers using a top-down approach. For cost estimation they calculated a rate of $2.37m – $3.53m per metre of movable barrier parts (Aerts, Botzen, Moel, & Bowman, 2013). This rate is used for more complex structures, especially those that incorporate sector gates. Therefore, it is the appropriate rate to use when looking at the Cork Harbour options. For the purposes of this estimation, only the lower bound figure has been used. The application of a contingency later in Section 11.8, in the cost comparison summary, will account for the variation between the lower bound and upper bound rates. In the study, the authors applied a rate of $10m per km of levee(bund) for structures built before 1990 and $85m per km of levee(bund) for structures built after based on estimates in another scientific paper. This is discussed further in the next section.

A significant variation of 64% was found with this method.

Converting to euros and applying these rates to the potential barriers chosen in this study yields the following results.

Table 14: Cost Estimate Method 2 - Cork Results

	Little Island Option 1	Little Island Option 2	Great Island
Cumulative Span (m)	150	420	485
Rate Lower 2017 (per m)	€1,934,187	€1,934,187	€1,934,187

	Little Island Option 1	Little Island Option 2	Great Island
Gate Cost (per m)	€290,128,059	€812,358,565	€938,080,724
Embankment length (m)	810	600	0
Rate 2017 (per m)	€69,370	€69,370	€69,370
Embankment Cost	€56,189,358	€41,621,747	€0
Total Estimated Cost	**€346,317,417**	**€853,980,312**	**€938,080,724**

One of the key limitations of this study was its focus primarily on rates and evidence from structures in the United States of America. This makes sense in the context for which it was created, but does not necessarily represent a rate that could be used accurately worldwide.

11.4.3 Method 3 – Unit Rate Development

Data from 15 international barriers was gathered to allow further methods of cost estimation to be assessed. The 15 barriers used were:

Table 15: International Barriers used in Cost Estimation

	Country	Year Completed
Thames Barrier	UK	1984
Venice	Italy	2011
IHNC Lake Borgne	USA	2011
St Petersburg	Russia	2010
Ems	Germany	2002
Hartel	The Netherlands	1997
Hollandsche Ijssel	The Netherlands	1956
Maeslant	The Netherlands	1997
Ramspol	The Netherlands	2002
Seabrook	USA	2011
New Bedford	USA	1966
Hull Barrier	UK	1980
Stamford	USA	1969
Eastern Scheldt	The Netherlands	1986
Eider	Germany	1973

Method 3.1 and 3.2 below have established that depth, and therefore area, is a key driver in the cost of any potential barrier.

A number of different prices for various types of dikes, embankments and flood walls were found. When applying these rates to the selected barriers, an effort was made to use the rate that best suited the structure that was built and took into account the age of the structure and where it was built. For example, the cost of constructing a modern dike in the USA or the Netherlands is estimated to cost $46,700 per m (Dijkman, 2007).

However, for barriers built before 1990 a rate of $10,000 is appropriate (Aerts, Botzen, Moel, & Bowman, 2013). A significant reason for this variation is the level of protection that is now provided by newer structures. A distinction between types of flood walls was also made. Due to its high strength and very large height, the cost of the flood walls for the IHNC barrier are over 20 times more than that of a typical flood wall.

A summary of these rates is as follows:

Table 16: Summary of Bund Rates

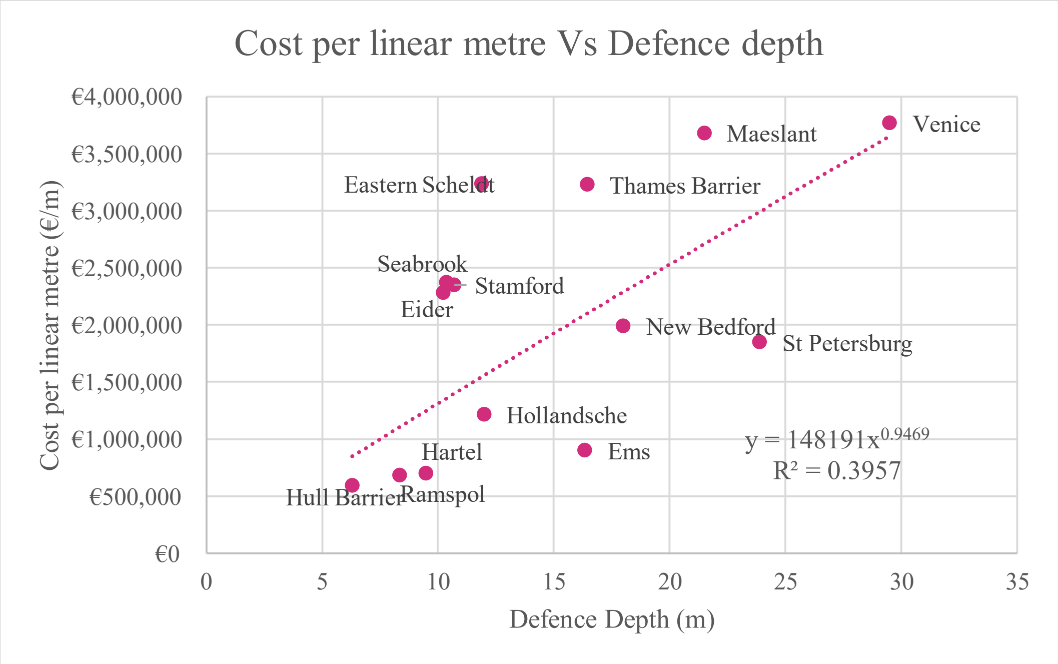
Bund Rates	
New Embankments (per m)	€44,355
Old Embankments – pre 1990 (per m)	€8,161
IHNC Flood Walls (per m)	€95,256
Typical Flood Wall (per m2)	€3,936

11.4.3.1 Method 3.1 – Unit Rate – Depth per Linear Metre

The first method selected was to analyse the total cost per lin.m of barrier against the maximum depth of the barrier. For this method the IHNC Lake Borgne Surge Barrier was excluded as a significant amount of the cost of the project can be attributed to a very large, high strength flood wall.

Figure 72 below is a graph showing the results of these findings.

Figure 72: Graph of total cost/lin.m vs depth for international barriers



Notwithstanding the significant variation, it is evident that the cost per lin.m increases significantly with depth and confirms that depth is a key driver of cost.

This is a function of the exponential scale of barrier required with depth and the increased construction cost associated with working at greater depths (temporary works etc.).

A power trendline resulted in the most positive correlation. Applying the above rates/trend to the potential Cork barriers yields the following results:

Table 17: Cost Estimate Method 3.1 - Cork Results

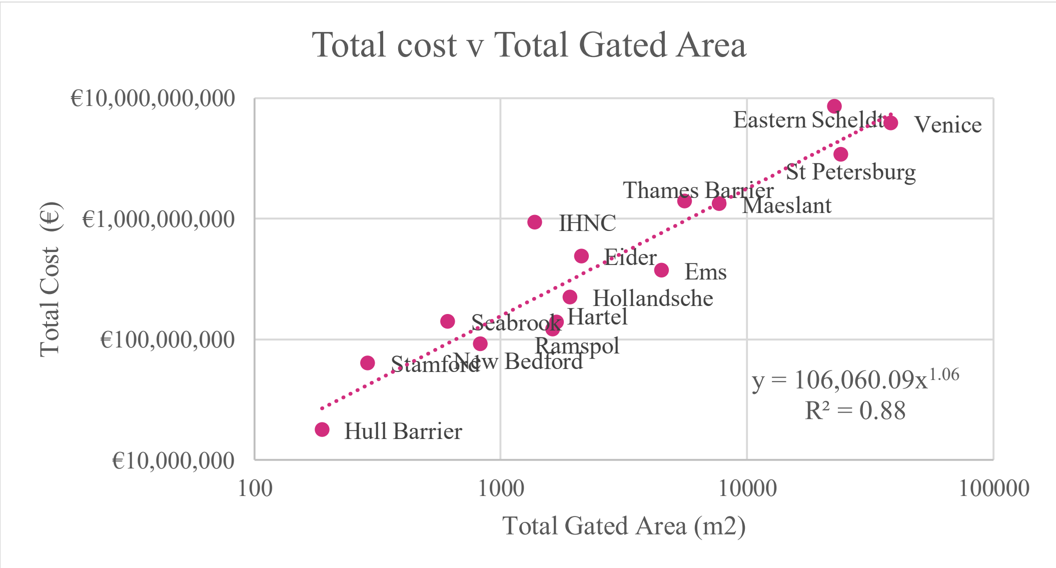
	Little Island Option 1	**Little Island Option 2**	**Great Island**
Cumulative Span (m)	150	420	485
Defence Depth	14.55	14.55	24.7
Cost per linear metre	€1,870,410	€1,870,410	€3,087,213
Total Estimated Cost	**€280,561,488**	**€785,572,166**	**€1,497,298,234**

This method was applied only to the gated elements of the potential Cork barriers.

11.4.3.2 Method 3.2 – Unit Rate – Area of Gated Elements

Figure 73 below is a graph showing the cost per m^2 (gated section area) against the project costs.

Figure 73: Graph of Total Cost Vs Total Gated Area for International Barriers



The graph indicates that there is, in general, a relationship between the area of gates and cost, and thus that this is a reliable barometer of likely cost.

Again, a power trendline resulted in the most favourable correlation. Applying the above rates/trend to the potential Cork barriers yields the following results:

Table 18: Cost Estimate Method 3.2 - Cork Results

	Little Island Option 1	**Little Island Option 2**	**Great Island**
Total Gated Area (m^2)	1,413.00	3546.00	6769.8
Total Estimated Cost	**€231,580,674**	**€614,150,314**	**€1,218,882,977**

This method was applied only to the gated elements of the potential Cork barriers.

11.4.3.3 Method 3.3 – Unit Rate - Separation of Navigation Gates, Flow Gates and Embankment Rates

Jonkman et al., (2013) derived a formula which could be applied to the linear length of a notional barrier and determine an approximate construction cost for any given tidal barrier defence.

However, it was identified that there was a substantial variation between the actual costs and the predicated costs using this method (Variation = 56%). Method 3.1 and 3.2 demonstrated that a significant factor in the cost of a barrier would be the depth, and therefore the area of the gated elements. It was decided that deriving a price per m^2 of flood gate and a separate price per m^3 for the impounding embankment would therefore be a better approach. This method would take into account deeper structures and the potential for having a long embankment and thus better predict costs. This was seen as a more suitable approach in the context of deep harbours such as Cork Harbour.

Firstly, to achieve the most accurate result possible, the cost of the impounding embankments, dikes and flood walls was removed from costs of the assessed international barriers. Next, the navigation and flow gate rates were back calculated from the remaining costs. Therefore, it was possible to derive a rate per m^2 for a number of various gate types (sector gates, vertical lift gates, flap gates etc.).

Then, the volume of any notional tidal barrier embankment was calculated based on an assumed crest width and typical slope angles in line with international guidance. The derived cost of typical embankments per m^3 was developed based on international research and previous experience constructing similar tidal/storm surge barriers/barrages and storm defences.

Once the rates were derived, it was possible to calculate an estimated cost for each of the storm surge barriers and compare this estimate against the known actual costs to test the validity of the formula.

The formula established to represent the above method could be written as follows:

$$ax + by + cz = Barrier\ cost$$

$where$

$a = Volume\ of\ impounding\ embankment\ structure\ (m^3)$

$$x = Derived\ \ cost\ of\ typical\ bund\ per\ m^3$$

$$b = Cross\ Sectional\ Area\ of\ Naviatgtion\ gate\ (m^2)$$

$$y = Derived\ Cost\ per\ m^2\ of\ Navatigation\ Gate\ (m^2)$$

$$c = Cross\ Sectional\ Area\ of\ Flow\ gate\ (m^2)$$

$$z = Derived\ Cost\ per\ (m^2)\ of\ Flow\ gate\ (m^2)$$

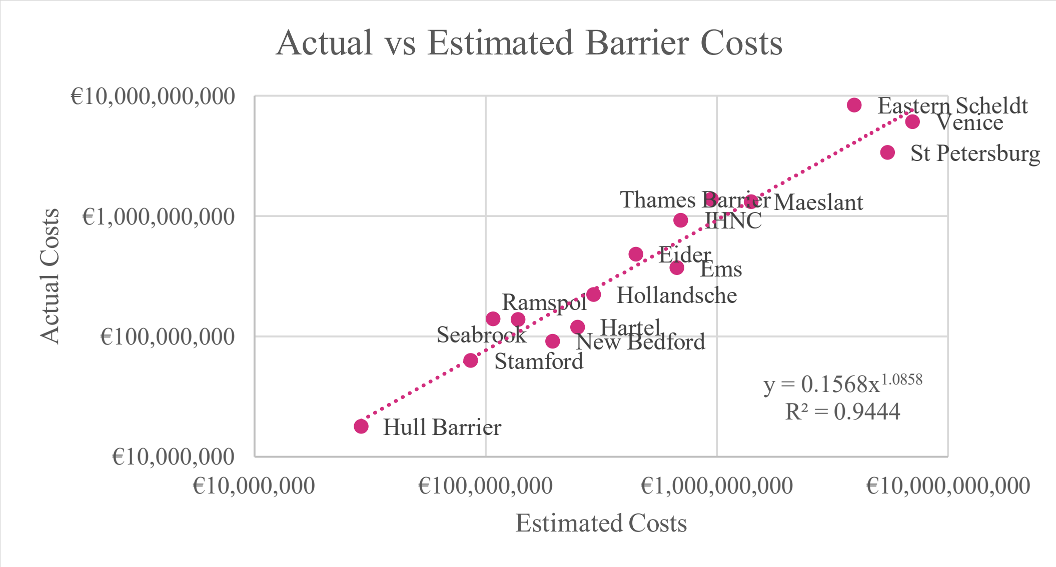
Table 19 shows the summary of information used in the calculation of costs for the various tidal barriers/storm surge barriers.

Table 19: Summary of International Barrier Data

	Total Gate Area (m^2)	**Bund Length (m)**	**Wall Length/ Area**	**Total Cost**	**Estimated Total Cost**
Thames Barrier	5591.15	0	0	€1,391,661,737	€948,824,602
Venice	38510.00	0	0	€6,141,187,896	€7,013,704,662
IHNC Lake Borgne	1381.32	0	2791m	€933,035,384	€697,721,630
St Petersburg	24193.40	23554	0	€3,411,846,815	€5,484,872,813
Ems	4509.50	0	0	€373,201,552	€672,769,241
Hartel	1627.35	0	0	€120,473,595	€249,986,191
Hollandsche Ijssel	1920.00	0	0	€224,107,260	€294,941,768
Maeslant	7740.00	0	0	€1,325,209,547	€1,407,707,750
Ramspol	1686.70	0	0	€138,418,802	€138,418,802
Seabrook	612.42	0	0	€139,955,308	€107,965,943
New Bedford	828.00	5486.4	0	€91,627,426	€195,367,198
Hull Barrier	189.00	0	0	€17,827,372	€29,033,330
Stamford	288.90	3109	1,646m^2	€63,500,089	€86,637,739
Eastern Scheldt	22759.60	6380	0	€8,473,646,290	€3,946,634,734
Eider	2134.00	4686	0	€488,413,121	€447,565,587

The findings of this analysis can be seen in Figure 74 below.

Figure 74: Actual Vs Estimated International Barrier Costs



Please note this graph shows a power trendline equation and the scales are logarithmic.

The variation was found to be 40%, indicating that the per m^2 approach to calculating the actual/predicated cost relationship was more accurate than the per lin.m approach (Method 1), but of more relevance is the fact that it is more likely to provide a more robust estimate for the particulars at Cork.

This method was then used to estimate a cost for a barrier in Cork. The embankment rate used in the formula is derived from international data and from previous cost estimates undertaken by Arup. Assuming that for Little Island Option 1, the navigation gate is a sector gate and the flow gate is a vertical lifting gate the formula we have used is as below:

$$(Volume\ of\ Bund * €78/m^3) + (Area\ of\ Nav\ Gate * €181{,}874/m^2) + (Area\ of\ Flow\ Gate * €170{,}900/m^2) = Barrier\ cost$$

For Little Island Option 2 and Great Island, the navigation gate selected is a rotary segment gate and the flow gate is also a vertical lifting gate. This gives the following formula:

$$(Volume\ of\ Bund * €78/m^3) + (Area\ of\ Nav\ Gate * €165{,}832/m^2) + (Area\ of\ Flow\ Gate * €170{,}900/m^2) = Barrier\ cost$$

The above formulae were then applied to the potential Cork barriers and the following results were calculated:

Table 20: Cost Estimate Method 3.3 - Cork Results

	Little Island Option 1	Little Island Option 2	Great Island
Volume of Embankment (m^3)	487,625	361,204	0
Rate per m^3	78	78	78
Embankment Cost	€38,235,416	€28,322,530	€0
Area of Nav Gate (m^2)	873	1,746	3,770
Rate per m^2	181,874	165,832	165,832
Navigation Gates Cost	€158,776,339	€289,542,102	€625,152,243
Area of Flow Gate (m^2)	540	1,800	3,000
Rate per m^2	170,900	170,900	170,900
Flow Gates Cost	€92,285,748	€307,619,162	€512,698,603
Calculated Total	**€289,297,503**	**€625,483,794**	**€1,137,850,846**

11.4.4 Comparison of Tidal Barrier Construction Cost Estimates

Table 21: Cost Estimate Results Comparison

Approach	Little Island Option 1	Little Island Option 2	Great Island
Method 1 – Jonkman	€376,653,218	€975,892,377	€1,094,217,561
Method 2 – Aerts	€346,317,417	€853,980,312	€938,080,724
Method 3.1 - Depth	€280,561,488	€785,572,166	€1,497,298,234
Method 3.2 – Area	€231,580,674	€614,150,314	€1,218,882,977
Method 3.3 – Unit Rate	€289,297,503	€625,483,794	€1,137,850,846
Median	**€289,297,503**	**€785,572,166**	**€1,137,850,846**
Mean	**€304,882,060**	**€771,015,792**	**€1,177,266,068**

11.4.5 Discussion of Methodologies

As mentioned in the introduction, we have generally used a top down approach in this analysis. This allows us only to produce a value that represents an approximate order of magnitude cost, however a significant level of contingency must also be allowed for.

A bottom up approach could also be used. However, this approach would be very difficult to calculate in this instance for a number of reasons. Firstly, it requires a high level of definition of the various elements of the structure. As a result, a significant detailed design would need to be undertaken. This is particularly difficult to achieve at prefeasibility stage, where there is insufficient information to propose a definitive scheme design. Secondly, there would be great uncertainty in terms of appropriate rates in the Irish context, given the absence of comparable projects nationally. Finally, large scale, non-standard, civil engineering projects of this kind are very sensitive to many assumptions which cannot be evaluated accurately at this level of study.

A number of methods to convert the historical costs of international barriers and rates were considered.

Using the Purchasing Power Parities (PPP) resulted in a greater level of accuracy overall. Construction Cost indices could have been used instead of Consumer Price Index (CPI) to account for inflation. However, the data set for the construction cost indices was much smaller, so using the CPI allowed for greater consistency across all calculations. In general, the rate of inflation using the construction cost indices was found to be higher than the CPI.

11.4.6 Discussion of Results

It can be seen that the Little Island Barrier proposed by a stakeholder group (option 1) is significantly less expensive than the Great Island Barriers Option. It was found that the depth of the harbour at Monkstown is a significant factor in the cost of the Great Island Barrier.

However, it is again very important to note that the Little Island Option 1 as per the stakeholder group's concept is not likely to be technically feasible. The design is premised on the assumption that only 150m of the total length of the channel would be gated. It is likely that navigation requirements, navigational safety, sedimentation patterns, dredging costs, compensation, environmental impacts and/or mitigation would require a barrier at Little Island to have a significantly larger gated area. Therefore, the cost estimate for the Little Island Option 2 is considered likely to be a more realistic estimate for a potential tidal barrier in this location.

To further analyse the relevant costs associated with the construction of a tidal barrier, the cost estimates from Method 3.3 (Unit Rate method) will be used from this point onwards. This figure represents the best estimate for Cork due to its consideration of the depth in the channel. Also the method yielded the most favourable variation value at 40%.

11.5 Ancillary Costs to Prevent Bypass

As noted earlier, the tidal barrier proposed at Little Island will not, on its own, be sufficient to prevent tidal waters inundating the city. It could be possible for flood waters to bypass the barrier via a number of low lying routes to the north.

Therefore, it was necessary to carry out a cost estimate for the additional ancillary items to the North of the Little Island Barrier.

There are two bridges over the estuary on the N25, east and west of Harper's Island and it is proposed that two flood gates could be installed at the bridges as part of the solution. For the purposes of this cost estimate, it is suggested that one gate would be 20m long x 6m high. The other gate, through the narrower path would be 5m long x 6m high. This is based on the basic bathymetric data available at these points. The rate used to calculate the cost is the price derived in method 3.3 for a vertical lift gate. A lot of further study would be needed to refine this proposal for future use. In particular, the fact these gates reside within the Great Island SAC could result in the estimated cost being much higher.

The costs for these gates are shown below in Table 22.

Table 22: Cost Estimate for Ancillary Defences

Barrier Element	Size	Estimated Construction Cost
Little Island Bypass		
Gate Barrier 1:	20m x 6m high	€20,952,283
Gate Barrier 2:	5m x 6m high	€4,810,822
Total		**€25,763,105**

In the future climate change scenario (HEFS), there is also the potential for water to pass overland and bypass these two flood gates on the N25. Defences would therefore be required at a number of other locations. It is proposed that two sections of road on the N25 be raised with embankments installed at Carrigrennen Point, at the railway line (south of the N25) and at different locations along the N25.

The associated costs for these items are noted in Table 23 below. These figures are based on established industry rates. They will not be included in the final total cost estimate as they may be built as required at a later date when the amount of sea level rise becomes apparent.

Table 23: Cost Estimate for extra defences – Future Climate Scenario (HEFS)

Barrier Element	Size	Estimated Construction Cost
Railway Embankment		
West Section:	472m x 4.2m high	€758,991
East Section:	469m x 3.0m high	€452,930
Motorway Embankment		
Section 1:	44m x 2.0m high	€24,468
Section 2:	880m x 4.0m high	€1,310,304
Section 3:	27m x 2.0m high	€6,389
Carrigrennan Embankment	275m x 2.0m high	€211,778
Road Raising - N25		
West on N25	235m	€233,437
East on N25	240m	€255,420
Total		**€3,253,719**

11.6 Cost of Residual Fluvial Defences on Scheme

A tidal barrier will provide protection against both tidal events and fluvial events to the east of Cork City. However, fluvial defences will still be required further west in the city and as far as Inniscarra in locations where the capacity of the channel (including the presence of weirs) drives flood levels rather than the downstream tidal boundary.

In the exhibited scheme, the design case 1 in 100year fluvial event assumes a 1 year tidal boundary of circa 2.4mOD. With a tidal barrier in place, this downstream boundary will decrease significantly. For this event, the barrier would be closed at a level of circa -1mOD. However, due to the inflow, water levels in the east of the city could rise up to between 1mOD to 2mOD depending on the scale of the event (and thus inflow) and location of the tidal barrier. (Levels would rise higher in the climate change scenario).

We have undertaken a number of hydraulic model runs with downstream boundaries of 1mOD and 0.5mOD as these are considered reasonable boundaries for this type of event.

In these scenarios, because of the presence of the flow control structure, no defences would be required on the South Channel.

Our analysis has shown that defences will still be required on the North Channel from upstream of the Tyndall Institute. At this location, there is only circa 100mm in difference between flood levels from the runs with the 0.5mOD and 1mOD tidal boundary confirming that flood levels upstream are less sensitive to the downstream boundary.

From Grenville Place to Salmon Weir, defence levels will be somewhat lower than the exhibited scheme, whereas upstream of Salmon Weir, defence heights will be unchanged as they are not affected at all by the tidal boundary.

To allow for the reduced height of defences between Salmon Weir and Tyndall, we have assumed a rate of 80% of the cost of the exhibited scheme in this reach.

The baseline construction cost for these fluvial defence elements is therefore estimated to be €20.7million.

11.7 Operations and Maintenance Costs of Tidal Barrier

The whole life cycle cost should be considered in the development of any major project. These costs will include operation and maintenance costs. This is especially important when designing and constructing anything which can put the public’s safety at risk. A lack of maintenance and the consequences of such can have catastrophic effects.

Both navigation and flow gates have structural, electrical and mechanical components that require periodic upkeep. The structural components will generally only require attention every 15 years with coatings being replaced etc. Annual inspections will be required for structural elements while mechanical elements may need to be tested at much more regular intervals.

Annual costs for maintenance can generally be related back to the capital cost of the project. A number of publications have provided estimates of appropriate rates that should be applied to calculate the likely annual operation and maintenance costs. Similar ranges have been used or determined when creating the cost estimates for the operation and maintenance costs for tidal barriers at feasibility/option development stage.

Examples include the Avon Heathcote Estuary Tidal Barrier, New Zealand and the Bridgwater Tidal Barrier Scheme, UK. These rates are summarised in the below table.

Table 24: International O&M rates

(Jonkman, Hillen, Nicholls, Kanning, & van Ledden, 2013)	1.00%
(Aerts, Botzen, Moel, & Bowman, 2013) Lower	0.50%
(Aerts, Botzen, Moel, & Bowman, 2013) Upper	2.00%
Avon Heathcote Lower	1.00%
Avon Heathcote Upper	5.00%
Bridgwater Tidal Lower	1.00%
Bridgwater Tidal Upper	2.00%
(Nicholls, Cooper, & Townend, 2007) Lower	5.00%
(Nicholls, Cooper, & Townend, 2007)Upper	10.00%

Excluding all the values above 2% and getting the average, results in a rate of 1.25%. Applying this to the total construction cost for the Cork Barrier options (baseline construction cost plus contingency) results in the following costs for Operation and Maintenance:

Table 25: Estimated O&M Costs for proposed solutions based on average rate

Approach	Rate	Little Island Option 1	Little Island Option 2	Great Island
Average	**1.25%**	**€5,036,027**	**€10,078,821**	**€17,377,880**
For 50 years		€251,801,339	€503,941,057	€868,894,017
NPV 50 years (4 % discount rate)		€108,173,855	€216,493,078	€373,276,870

11.7.1 Operations and Maintenance Costs of an Comparable Tidal Barrier, the Thames Barrier

An example of the operation and maintenance costs for a constructed tidal barrier that is comparable, is the Thames Barrier in London, England.

The barrier is a series of rising sector gates, the four largest spanning 61.5m and the two smaller spanning 31m, standing 20 metres tall and stretching 520 metres across the River Thames. There are also four smaller non-navigable channels between nine concrete piers and two abutments.

The construction cost for building the Thames Barrier and associated works came to £564 million in 1982, valued at €1.4 billion at 2017 prices. The operation and maintenance cost for the Thames Barrier and associated defences is approximately

£8 million per annum which includes the current cost of £16,000 to close the barrier on each occasion. It should be noted that additional capital improvements to the defences are not considered as part of the operation and maintenance costs.

Utilising the known costs of the Thames Barrier, the operation and maintenance is found to be 0.64% per annum of the capital cost. This corresponds to the indicative cost of 0.5% - 2% per annum for all types of tidal barriers mentioned in publications such as Aerts et al. (2013).

Breaking down the costs further and converting to euros, an annual operation and maintenance cost of €1,602 per gated m^2 can be determined using the Thames example.

Using this rate, we can estimate the annual cost of operation and maintenance and the percentage of same compared to the capital cost for the proposed solutions at Little Island and Great Island as shown in Table 26.

Table 26: Estimated Annual O&M Costs for the proposed solutions based on Thames Barrier calculated rate

	Little Island Option 1	**Little Island Option 2**	**Great Island**
Total Gated Area (m^2)	1413.00	3546.00	6769.80
Annual Cost	€2,263,940	€5,681,481	€10,846,725
As a % of estimated Total Construction Cost	0.56%	0.70%	0.78%

The estimated annual operation and maintenance costs for the proposed solutions using the Thames Barrier calculated costs remains within the 0.5% - 2% per annum range, further verifying its applicability.

11.7.2 Minimum, Maximum and Average Annual Operation and Maintenance Costs

This range is to be used to determine the minimum, maximum and average annual operation and maintenance costs for the proposed solutions. The Lee CFRAMS used 1.5% of the basic construction costs to estimate the NPV of the maintenance costs during the consideration of the tidal barrier. While 1.5% is within the proposed range, we propose to use an average value of 1.25% which we consider a more representative value. This is higher than the percentage calculated using the Thames example but takes account the increasing frequency of operation that will occur and is the average of all the rates suggested in the publications listed above in Table (excluding upper bound rates).

Table 27 details the estimated minimum, maximum and average annual operation and maintenance costs within the 0.5% - 2% of the capital costs per annum range.

Table 27: Estimated Annual Operation and Maintenance Costs based on 0.5% - 2% of the Capital Cost

	Little Island Option 1	**Little Island Option 2**	**Great Island**
Annual O&M Cost - 0.5% of Total Construction Cost	€2,014,411	€4,031,528	€6,951,152
Annual O&M Cost - 2% of Total Construction Cost	€8,057,643	€16,126,114	€27,804,609
Annual O&M Cost - 1.25% of Total Construction Cost	€5,036,027	€10,078,821	€17,377,880
1.25% rate - NPV 50 years (4 % discount rate)	**€108,173,855**	**€216,493,078**	**€373,276,870**

The annual cost of the operation and maintenance for a tidal barrier will vary over its design life and will also be dependent on its usage.

A higher usage will involve higher operational cost and increased need for maintenance. The average value of 1.25% of the capital costs will be progressed for the cost comparison.

A detailed cost estimate of the operation and maintenance would need to be undertaken if the tidal barrier is progressed to detailed design stage.

11.8 Cost Comparison Summary

Table 28: Cost Comparison of Exhibited Scheme versus Tidal Barrier Schemes

Cost Item	**Exhibited Scheme (€) ***	**Tidal Barrier at Little Island Option 1 (€)**	**Tidal Barrier at Little Island Option 2 (€)**	**Tidal Barrier at Great Island (€)**	**Comments**
Main Tidal Barrier	N/A	289,297,503	625,483,794	1,137,850,846	Method 3.3 Estimate
Ancillary Costs of localised defenced to prevent bypass	N/A	25,763,105	25,763,105	N/A	
Direct Tidal and Fluvial Defences	67,995,274	N/A	N/A	N/A	
Reduced Fluvial Defences	N/A	20,674,510	20,674,510	20,674,510	
Subtotal Baseline Construction Costs	**€67,995,274**	**€335,735,118**	**€671,921,409**	**€1,158,525,356**	
Archaeology and Environmental Mitigation	6,799,527	0	0	0	Assumed included in Barrier Estimates

Cost Item	Exhibited Scheme (€) *	Tidal Barrier at Little Island Option 1 (€)	Tidal Barrier at Little Island Option 2 (€)	Tidal Barrier at Great Island (€)	Comments
Add Optimism Bias/Contingency	14,958,960	67,147,024	134,384,282	231,705,071	20% of Baseline Construction Cost.
Construction Cost Total	**89,753,761**	**402,882,142**	**806,305,691**	**1,390,230,427**	
Add Surveys/SI /Fees/Supervision	9,277,839	0	0	0	Assumed included in Barrier Estimates
Add Land Acquisition / Compensation	8,975,376	0	0	0	Assumed included in Barrier Estimates
Add Art Allowance	64,000	64,000	64,000	64,000	
Capital Cost Total	**€108,070,976**	**€402,946,142**	**€806,369,691**	**€1,390,294,427**	
Add NPV Maintenance Cost (4% discount rate)	19,279,108	108,173,855	216,493,078	373,276,870	1.25% of Construction Cost total per annum for 50 years. (1% for exhibited scheme as more passive)
Total Project Cost	**€127,350,084**	**€511,119,997**	**€1,022,862,768**	**€1,763,571,297**	
Percentage of Exhibited Scheme	**100%**	**401%**	**803%**	**1385%**	

* All figures on exhibited scheme taken directly from Lower Lee FRS Options Report 2017

Table 29Table 29: Cost Comparison for Tidal Only Defence Scheme below shows the cost comparison between the various tidal barrier schemes as a tidal only defence scheme, i.e. the cost of the fluvial defences has been removed.

Table 29: Cost Comparison for Tidal Only Defence Scheme

Cost Item	Exhibited Scheme (€) *	Tidal Barrier at Little Island Option 1 (€)	Tidal Barrier at Little Island Option 2 (€)	Tidal Barrier at Great Island (€)	Comments
Subtotal Baseline Construction Costs		€315,060,608	€651,246,898	€1,137,850,846	
Construction Cost Total		€378,072,730	€781,496,278	€1,365,421,015	
Capital Cost Total		€378,136,730	€781,560,278	€1,365,485,015	
Total Project Cost		**€479,666,442**	**€991,409,213**	**€1,732,117,741**	

11.9 Cost Benefit Analysis

11.9.1 Calculation of Benefit

The Lee CFRAMS provides the basis for assessing the benefit of a tidal barrier at a number of locations in Cork Harbour. It is not envisaged that any potential scheme that included the construction of a tidal barrier would ignore the fluvial flooding potential in the west of the city. Therefore, the Benefit Cost Ratio is calculated for a combined tidal and fluvial solution. However, the Benefit Cost Ratio for a tidal only defence scheme has also been presented for comparison purposes.

11.9.2 Tidal and Fluvial Benefit

The total benefit of the currently exhibited scheme is €185.5m. However, a scheme incorporating a tidal barrier would provide benefit to more areas outside of the city.

The Lee CFRAMS estimated the Present Value Benefit of a Tidal Barrier at Great Island to be €79.8m (Halcrow, 2014).

A Barrier at Little Island and assuming local measures to protect the Little Island /Glounthaune area, would leave Midleton and Passage West unprotected. The Lee CFRAMS estimated a tidal only benefit of €23.6m and €0.5m respectively for these areas. Therefore. the Little Island Barrier would provide a benefit of €55.7m, approximately 70% of the benefit provided by a barrier at Great Island.

Within these two values, €79.8m at Great Island and €55.7m at Little Island, Cork City accounts for approximately €38m. Therefore, the residual tidal benefit outside of the Cork City area would be approximately €41.8m at Great Island and €17.7m at Little Island.

Combining this with the total benefit of the exhibited scheme gives a total benefit as shown in Table 30 below.

Table 30: Comparison of Benefit of Exhibited Scheme Vs Tidal Barrier options

	Exhibited Scheme	Little Island Option 1	Little Island Option 2	Great Island
Tidal Only Benefit	N/A	€55,700,000	€55,700,000	€79,800,000
Total Fluvial and Tidal Benefit	€185,500,000	€203,200,000	€203,200,000	€227,300,000

11.9.3 BCR for Tidal Only Defence Scheme

Table 31 below indicates the relative BCRs for tidal only at Little Island and Great Island.

Table 31: BCR for a tidal benefit only defence scheme

	Exhibited Scheme	Little Island Option 1	Little Island Option 2	Great Island
NPV Benefit	N/A	€55,700,000	€55,700,000	€79,800,000
NPV Costs	N/A	€479,666,442	€991,409,213	€1,732,117,741
BCR	N/A	0.116	0.056	0.046

11.9.4 BCR for Fluvial and Tidal Defence Scheme

Table 32 below indicates the relative BCRs for combined fluvial/tidal schemes for schemes incorporating tidal barriers at Little Island and Great Island, as well as the exhibited scheme.

Table 32: BCR for combined fluvial and tidal defence schemes

	Exhibited Scheme	Little Island Option 1	Little Island Option 2	Great Island
NPV Benefit	€185,500,000	€203,200,000	€203,200,000	€227,300,000
NPV Costs	€127,350,084	€511,119,997	€1,022,862,768	€1,763,571,297
BCR	1.457	0.398	0.199	0.129

12 Comparison of likely Cork Solution to other Relevant International Barriers

12.1 International Tidal Barriers

A review of international tidal barriers was completed to investigate which structures would be suitable for comparison to the requirements and conditions in Cork Harbour. The barriers selected were on the basis that their gate types are similar to those that have deemed suitable for Cork as per the analysis in Chapter 6. Those chosen also had to facilitate navigation. Their main characteristics, including key dimensions, type of gate structures and construction costs are outlined in Table 33 below.

Table 33: Details of comparable international barriers

Barrier	Thames Barrier	Ems Barrier	Seabrook Floodgate
Country	UK	Germany	USA
Original Cost	£564,000,000	€290,000,000	$165,000,000
2017 Cost	€1,391,661,737	€373,201,552	€139,955,308
Year Completed	1984	2002	2011
Construction Duration	10 years	4 years	4 years
Total Length	530m	476m	130m
Navigation Gate Type	Rotary Segment	Rotary Segment & Radial	Sector
Navigational Span	307m	110m	60m
Nav Gate Max Height	16.45m	16.35	14.35m
Flow Gate Type	Radial	Vertical Lift	Vertical Lift
Flow Gate Span	124m	304m	90m
Flow Gate Max Height	6.7m	10.5m	6m
Bund Length	None	None	None
Alternative Navigation Options	Yes – 6 navigation gates	Yes – 2 navigation gates	Yes – Pontchartrain Causeway

12.2 Comparison to Cork Harbour Proposals

12.2.1 The Thames Barrier

Figure 75: The Thames Barrier (Source: Wikipedia)

It has already been established that a potential barrier at the Great Island location in Cork Harbour would likely require the full width of the river to be gated due to the need to maintain normal flow velocities in the narrow channels. Therefore, the Thames Barrier represents a good example of what barriers at Monkstown and at Marlogue could look like. At the Little Island location, it is envisaged that there will be a substantial bund element and therefore a structure like the Thames Barrier would need to be augmented.

The Thames Barrier was constructed between 1974-1982 and is composed of 6No. rotary segment gates for navigation and 4No. radial gates for flow control at the edges of the river. The total overall length is comparable to the Great Island Option however, the water depth at the Thames is not as deep as at Monkstown. The project cost of the Thames Barrier in 2017 terms is approximately €1.4 billion. Given the similarities between the Thames Barrier and the Great Island Option, the estimate of €1.4 billion for the capital costs of a potential Great Island Barrier appears to be reasonable.

12.2.2 The Ems Barrier

Figure 76: The Ems Barrier (Source: Emden Touristik)

The Ems Barrier in Germany was identified as another barrier which may be suitable within Cork Harbour. The barrier consists of a number of different gate types across the full width of the channel. It was constructed between 1998-2002 and is composed of 1No. rotary segment gate and 1No. segment gate for navigation and 5No. vertical lift gates for flow control. The cumulative span of all the gates is a 414m long, which is very similar to the estimated gate span and gate types that would be required at Little Island, as per Option 2 in the cost estimates above.

However, there are a number of key differences between the barriers that would have a big impact on the cost. The water depth at Little Island is deeper than at the deepest point at the Ems Barrier, resulting in an increase in the required gate height. A potential Barrier at Little Island would require a significant embankment to be constructed, also increasing the cost. Also, it is envisaged that the flow gates at Little Island would have to be spread out across the whole barrier length, therefore the gates would not be adjacent to each other as at the Ems. This would significantly increase cost due to more piers being required, a much larger construction area being needed and also there would be far greater quantities of infrastructure required (access, telemetry, power etc.).

The 2017 construction cost for the Ems barrier has been calculated at €373 million. Despite the key technical differences described, the estimated capital cost of Little Island Option 2 when, compared to the Ems Barrier, seems slightly high at €806 million. However, there are a number of reasons why the project cost of the Ems Barrier should not be viewed as representative of typical barrier construction costs.

There are a number of unknown factors which would influence the final cost of construction. These include site conditions, weather etc. It was constructed in a country with significant previous experience building tidal barriers and this expertise would be highly valuable. The barrier is a very cost efficient project however, in every cost estimation method used in Chapter 11, the Ems Barrier was consistently over estimated. This indicates that it is not a typical example of tidal barrier cost.

12.2.3 The Seabrook Floodgate Complex

Figure 77: The Seabrook Floodgate Complex (HR Wallingford, 2017)

This image was taken from the HR Wallingford Cost Estimate produced for the stakeholder group's tidal barrier at Little Island. In the HRW report, it was used to show an example of sector gates and flow gates, as is proposed by the stakeholder group at Little Island. Therefore, it is a good structure to use as a comparison with the potential solutions in Cork.

The barrier in the photo is the Seabrook Floodgate Complex in New Orleans, USA. The barrier was constructed in 2011 and consists of 1No. 30m Sector gate for navigation and 2No. 15m vertical lift gates for flow. The 2017 cost of this barrier is approximately €154 million.

The barrier suggested by the stakeholder group is over double the size of the Seabrook Floodgate. The sector gate span suggested is 60m (double that of Seabrook) while the total flow gates span is 90m (treble that of Seabrook). Also Cork harbour is much deeper so the gates would have to be substantially higher.

In addition, the Seabrook Floodgate complex does not include any embankment or bund so this would be a further extra cost. Therefore, it would be reasonable to assume that the cost of the stakeholder group's proposal would be over twice the cost of the Seabrook Floodgate Complex. This aligns well with the cost estimate calculated in Chapter 11 for the group's proposal. Removing the costs of the fluvial and ancillary work from the estimate, gave a cost estimate of €347m.

However, it should again be emphasised that, as has been shown earlier in the report, the stakeholder group's proposal is not likely to be technically feasible due to a number of considerations including navigation requirements, navigational safety, sedimentation patterns, dredging costs, compensation, environmental impacts and/or mitigation and that therefore a larger and more expensive structure will likely be required.

12.3 Other Suggested Structures

Barrier (and or barrage) structures at Singapore, Cardiff and Swansea were also mentioned during the Exhibition process.

The Singapore Marina Barrage is a dam built across the 350-metre wide Marina Channel to keep out seawater. It has no navigational function. During fluvial flood events, crest gates are activated to release excess storm water into the sea when the tide is low and in the case of high tide, the water is pumped into the sea. It is therefore not applicable to Cork.

The proposed Cardiff and Swansea tidal barrages are to enclose lagoons and their primary purpose is to generate electrical power from a renewable source. The projects are currently in feasibility/planning stages. It is not proposed that they will facilitate major navigation or contribute to flood control once constructed. Again, they are not directly applicable to Cork.

13 Comparison of Tidal Barrier at Little Island and Great Island

The relative merits of a tidal Barrier at Little Island versus at Great Island are compared in Table 34 below under a number of key criteria. A traffic light system is used to illustrate the relative merits of each solution.

Green represents a positive mark, orange represents significant challenges, and red represents potential 'show stoppers'.

Table 34: Comparison of Location Options

Criteria	**Barrier Location**	
	Little Island (& North Channel)	**Great Island (Monkstown & Marlogue)**
Length	Longer length, 1020m in total	Shorter length - Combined length of 595m, split into two barriers of 310m and 285m.
Depth	Similar in depth to barrier at Marlogue but significantly less than at Monkstown -7.6m CD maximum depth.	Monkstown Barrier would be quite deep in comparison to many international barriers and being located in a narrow channel with high velocities will be more difficult to construct17m CD maximum depth at Monkstown. -6.6m CD maximum depth at Marlogue Point.
Upstream Storage Volume (Present Day)	Sufficient storage volume behind the barrier to store fluvial flows	Sufficient storage volume behind the barrier to store fluvial flows
Upstream Storage Volume (MRFS)	Very marginal storage volume behind the barrier to store fluvial flows in MFRS.	Sufficient storage volume behind the barrier to store fluvial flows for MRFS
Upstream Storage Volume (HEFS)	Insufficient storage volume behind the barrier to store fluvial flows in HEFS	Sufficient storage volume behind the barrier to store fluvial flows for HEFS and beyond
Road Access	New road connections required for south and north access. Total 670m length (490m and 180m, south and north respectively)	Existing west and east road access at Monkstown. Road connection required at west side of Marlogue Point.
Areas defended	Excludes Midleton, Ballinacurra and Passage West	Includes Midleton, Ballinacurra and Passage West
Road Works Required to National Route	505m road raise on N25	None required.
Road Works Required to railway line	Embankment construction required along railway south of N25	None required.
Geotechnical	Larger depths to rock. Risk of karst due to limestone bedrock. Likely more expensive foundations	Shallower sandstone rock. No major concerns

Criteria	Barrier Location	
	Little Island (& North Channel)	**Great Island (Monkstown & Marlogue)**
Hydrogeological	Potential for barrier bypass via deeper deposits of sand and gravel at barrier and via north little island. Cut off not possible due to depths	No major issues identified - Cut off to bedrock maybe required and achievable if gravels line riverbed
Navigation	Similar requirements	Similar requirements
Visual Impact	Obstructs view to horizon from Lough Mahon towards Marino Point. Likely to be more visible because of lower lying surrounding land and longer length of barrier	Obstructs view to horizon from Ferry Point towards Monsktown, and from Ballinacurra River towards East Ferry. Shorter length and higher surrounding ground means that it won't be visible to as large a surrounding area.
Environmental	Partly within the SPA/SAC areas. Significant risk to designated zones.	Both located considerable distance outside of the designated SAC and SPA and provided gates provided across full width of channel, there is significantly less risk to environmental receptors etc.
Construction Issues	Shallower bed will make construction easier as will lower velocities (depending on construction phasing) but geotechnical and hydrogeology constraints mean foundations likely more complicated	Significant depth at Monkstown and higher velocities make construction very challenging. On plus side, foundation requirements likely to be less onerous that Little Island.
Cost	Likely to be cheaper of two locations but subject to confirming shorter gated length	More expensive of the two options
BCR	Very negative BCR.	Very Negative BCR. Despite higher cost, BCR likely to be similar to Little Island due to defending of Midleton, Passage West etc.

As demonstrated earlier in this report, neither barrier is cost beneficial at present and would only become cost beneficial with sea level rise of circa 500mm, i.e. the MRFS. However, in the MRFS, the Little Island Barrier is at its limit is terms of available upstream storage. It therefore will only provide a viable solution for a short window of sea level change. The Great Island barrier however has sufficient upstream storage for the HEFS and beyond, and therefore has a considerably greater period of viability.

The Great Island barrier also has the benefit of protecting the Midleton/Ballinacurra areas, which the Little Island barrier does not.

Furthermore, the Little Island Barrier has a significantly greater likelihood of significantly impacting the SPA and/or SAC and thus potential triggering an IROPI (imperative reasons of overriding public interest) process. Given that there is a viable and significantly less expensive alternative, it is highly unlikely that an IROPI approval would be achievable.

Whilst the currently estimated cost of the Little Island barrier is less that the Great Island barrier, this is premised on the potential for a much shorter gated length.

It is however quite possible that further environmental and navigation studies could result in the required gated length needing to be longer than that assumed in either of two concepts assessed in this report. This would erode the cost differential between the two barriers.

Notwithstanding the above, it is worth noting that the difference in current BCR ratios between the scheme is quite marginal as the lesser cost of the Little Island Barrier is somewhat offset by the greater benefit of the Great Island Barrier.

Following this initial analysis, we consider that the Great Island Barrier is likely to provide a more robust and viable long term solution when and if sea level rise in excess of 500mm arises.

14 Multi Criteria Analysis

Table 35 below is a High Level Multi-Criteria Analysis of relative merits of exhibited scheme versus tidal barrier options at Little Island and Great Island. Each scheme is ranked in terms of its relative merit. A score of 1 represents the top ranking or the most favourable scheme. A traffic light system is again used to differentiate the relative merits of each scheme.

The results of the MCA show that the exhibited scheme ranks highest in comparison to potential tidal barrier schemes located at Little Island and Great Island. In particular, the exhibited scheme performs strongly in the areas of cost, benefit cost ratio, adaptability to climate change and ecology.

While both barrier locations scored very similarly in most areas, the Great Island location is shown to be more favourable due to having sufficient storage to accommodate even the highest predicted rise in sea level due to climate change. Also, the Great Island barrier location is further away from the SPAs and SACs that are in the Cork Harbour area. Therefore, the construction and operation of a barrier at Great Island would have less of an impact on ecology than one at Little Island.

Table 35: Multi Criteria Analysis

Indicator	**Narrative of key Issues**			**Rank**		
	Exhibited Scheme	**Tidal Barrier at Little Island**	**Tidal Barrier at Great Island**	**Exhibited Scheme**	**Little Island Barrier**	**Great Island Barrier**
Technical Robustness – Tidal	Predominantly passive solution with small number of small scale flood gates in city, with majority required for freeboard only. Low risk of mechanical failure	Operational complexity in terms of managing barrier closure in conjunction with dam discharges as well as managing smaller sluice gates in north channel. Higher risk of failure of electrical/mechanical elements. Higher maintenance requirements		1	2	2
H&S	Standard construction techniques with majority of construction on land. Low maintenance requirements so H&S risk is low	Significant H&S risk during construction due to specialised construction techniques, working at depth, in fast flowing water. High maintenance requirement. Moderate to high H&S risk	As Little Island Barrier, but greater risk due larger depth below MSL and higher velocities	1	2	3
Adaptability to Climate Change	Direct defences designed for future raising (temporary or permanent) and are compatible with future tidal barrier and other upstream measures.	Tidal Barriers difficult to adapt so would likely have to be constructed to selected climate change levels. Little Island Barrier Location does not provide sufficient storage for all future climate change scenarios.	Tidal Barriers difficult to adapt so would likely have to be constructed to selected climate change levels. However, Great Island location has sufficient storage for all future climate change scenarios	1	3	2
Reduce Economic Damage	Exhibited Scheme does not protect areas downstream of Custom House.	Little Island Barrier defends additional areas currently at low tidal risk on Tramore and Glashaboy and around Little Island Area	Great Island Barrier also protects Midleton and Passage West areas	3	2	1

Indicator	Narrative of key Issues			Rank		
	Exhibited Scheme	**Tidal Barrier at Little Island**	**Tidal Barrier at Great Island**	**Exhibited Scheme**	**Little Island Barrier**	**Great Island Barrier**
Cost	Circa €130m project costs	Circa €1bn project costs	Circa €1.8bn project costs	1	2	3
BCR	BCR > 1	BCR<<<<1	BCR<<<<1	1	2	3
Ecology	Only local in-channel works with no risk to designated sites. Construction risks only.	Significant in-channel works across Lough Mahon, in or adjoining SAC/SPA, with potential long term as well as construction impacts	Whilst in-channel works are significant, less likely to have long term impacts on SAC/SPA	1	3	2
WFD	Only minor impacts during construction.	Potential to change saline content/exchange in harbour	Potential to change saline content/exchange in harbour	1	3	2
Landscape and Visual	Works are small scale in tidal reach and offer opportunity to enhance riparian zone and river scape.	Tidal barrier will be very significant change to the landscape in a high value landscape	Tidal barrier will be very significant change to the landscape in a high value landscape	1	2	2
Cultural Heritage	Potential for minor impacts during construction but can be mitigated. Positive of Significant investment in repair of historic quay walls	Potential Impact is low and limited to tie in points of barrier	Potential Impact is low and limited to tie in points of barrier	2	1	1

Indicator	**Narrative of key Issues**			**Rank**		
	Exhibited Scheme	**Tidal Barrier at Little Island**	**Tidal Barrier at Great Island**	**Exhibited Scheme**	**Little Island Barrier**	**Great Island Barrier**
River/ Harbour Amenity	No significant impact on river amenity. No impact on harbour.	Potentially significant impact on velocities and sedimentation in Lough Mahon with follow on impacts for amenity. Also restrictions on navigation movements when barrier is closed.	Potentially impact on velocities and sedimentation West Passage. Not as significant as at Little Island. Also restrictions on navigation movements when barrier is closed.	1	3	2
River/ Harbour Navigation/ Industry	No impact	Potential significant impact in harbour on Port of Cork Company, aquaculture, and pleasure craft businesses.	Potential significant impact in harbour on Port of Cork Company, and pleasure craft businesses.	1	3	2
Tourism	Any short term construction impacts localised to quays and minimised by phasing. Significantly offset by improvement in streetscape, access to river, new walkways and plaza areas.	Potential for negative impact due to restrictions on navigation and water tourism.		1	3	2
Overall Score (Applying no weighting)				16	29	27
Overall Ranking				1	3	2

15 Responses to Key Questions raised through Statutory Exhibition Process

Question: What about alternative barrier location at Little Island - Leecarrow proposed by a stakeholder group?

Answer: The stakeholder group's proposal has been reviewed in detail (as set out in this report), in terms of its location, form, suitability, impacts and costs. It is not likely to be technically feasible due to a number of considerations including navigation requirements, navigational safety, sedimentation patterns, dredging costs, compensation, environmental impacts and/or mitigation. The location has many disadvantages such as its proximity to the SPA and SAC in Cork Harbour and the potential to negatively impact same, the fact it doesn't protect Midleton and Passage West, unfavourable geological and hydrogeological location, and mal-adaptability for climate change.

A modified version of the group's proposal that includes more gated elements could be technically feasible and may prove a less expensive option than at Great Island in terms of initial capital cost. However, this is by no means a certainty given the amount of variables involved in a project of this scale. In particular, detailed navigation, ecological and sedimentation studies would need to be undertaken to establish if in fact an even larger gated area is needed. This would reduce any cost differential with the Great Island location.

Notwithstanding the potentially lesser cost than at Great Island, it will probably not offer the best value for money if and when a barrier is needed given that it doesn't protect Midleton and Passage West and has limited storage in the face of climate change. Its estimated whole life cost (NPV) of circa €1bn makes it circa 8 times the cost of the exhibited scheme and it does not come close to having a benefit cost ratio approaching unity. It would only become economically viable when and if sea level rise of circa 500mm arises at which point it would start to become technically unviable. In other words, it would have a very short shelf life.

Question: What about barrier location at entrance of harbour (Camden Fort/Crosshaven area - White Bay/Roche's Point area)?

Answer: Such a barrier would likely cost in excess of €2.7bn and would be the deepest tidal barrier in the world. It would involve new technology which is not tried and tested at such depths, and would involve construction in a hazardous environment at such depths and at high velocities. As it has the maximum storage of all locations in the harbour and would benefit the largest areas, it would represent the most complete solution with greatest adaptability to climate change. However, it is not affordable at the present time, and a barrier at Great Island is likely to represent a more appropriate and affordable solution (in relative terms) in the medium to long term.

Question: What about barrier location at Great Island - Monkstown and Marlogue Point?

Answer: This location was identified in the Lee CFRAMS as being the optimum location for a tidal barrier when and if a barrier became economically viable. The findings of this study would generally validate this position. However, it appears likely that the preliminary estimate included in the Lee CFRAMS (which was undertaken at a very high level) is likely to significantly underestimate the cost of such a barrier. At present it remains economically unviable and this will remain the case if and until sea level rise of circa 500mm occurs.

Question: Has possibility of power generation at the barrier been considered?

Answer: Tidal Hydropower generation is associated with tidal barrages rather than barriers, where water typically is held in rather than kept out of harbours or bays, although they can sometimes provide a secondary flood risk function. They will generally not be viable where there is a requirement for major navigation across the barrier, because for hydropower purposes, maintaining a head differential across the barrier for a large proportion of the time is a key requirement. This is incompatible with major shipping.

Lock gates are generally used at tidal barrages to manage infrequent movement of smaller vessels across the barrage, but this is generally quite expensive. The navigational requirement in Cork means that a barrage is unlikely to prove viable. Furthermore, a tidal barrage will fundamentally alter the regime in the harbour, essentially turning the area inside the barrier into a freshwater impoundment. Given the SAC and SPA designations in Cork Harbour, it is evident that it would be difficult to secure statutory approval for a tidal barrage.

Question: Has possibility of incorporation of road crossing at the barrier been considered?

Answer: Due to the requirement for a clearance height for shipping of circa 45m, a through road is not a reasonable possibility at any barrier location, although access roads will be required from either side to access the navigation gates for maintenance. It is also worth noting that there is not a strong business case for a new roadway at any of the locations considered.

Question: Have other tidal barriers been studied, including Cardiff, Singapore, Swansea, Ramspol, etc.?

Answer: Yes. Cardiff, Swansea and Singapore are in fact tidal barrages rather than tidal barriers, i.e. they are designed to keep water in, not out. Ramspol is very different to Cork in so far as there is no tidal range and limited navigation. As illustrated in this report, circa 15 international tidal barriers have been examined with the Thames Barrier, the Ems Barrier and the Seabrook Floodgate Complex considered to be best for comparison. A study of these barriers have formed a key input into this pre-feasibility assessment of a tidal barrier at Cork

Question: Have the future plans of Port of Cork (relocation of container terminals to Ringaskiddy) been considered?

Answer: Yes. We are very familiar with POCC's plans. In preparing this report, we consulted with Port of Cork Company who confirmed that its current programme is for its container (LoLo) business to be moved to Ringaskiddy by 2020. However, this is only one aspect of its business. It will continue to operate other aspects of its business in the inner harbour both in Tivoli and the City Quays into the foreseeable future for a likely timespan of a further 20 to 25 years. In addition, it is considered likely that for the foreseeable future, there will remain a business case for retaining the ability to allow large vessels travel as far as the city quays, i.e. for tourism, navigational history reasons etc.

Question: Has the EIS considered that a tidal barrier may be acceptable under IROPI (imperative reasons or overriding public interest)?

Answer: The EIS was prepared on the basis of the exhibited scheme, not a tidal barrier scheme and therefore has not considered the question of IROPI with respect to a tidal barrier. It should be noted that the IROPI route arises when a proposed scheme is shown to have a significant negative impact on an environmentally designated site (an SAC or SPA). In such a scenario, it would have to be proven that there isn't a viable alternative, regardless of cost. In this case, there is a viable alternative that will not have a negative effect on the SAC and SPA, and which costs significantly less. This is the exhibited scheme. Therefore, it is considered extremely unlikely that such a scheme would be considered for proposal using the IROPI process and it is even more unlikely that it would succeed under IROPI at the present time. If sea level rise were to occur to the extent that a tidal barrier became the only viable option, then this might change.

16 Conclusions

This report provides details of a pre-feasibility report undertaken on the potential of a Tidal Barrier solution in Cork Harbour. It has been prepared in response to submissions received through the statutory exhibition process for the Lower Lee (Cork City) Drainage Scheme (flood relief scheme), to provide further information to the public explaining why a tidal barrier is not currently viable and why it was accordingly screened out at the options selection stage of the project.

Four locations for a tidal barrier were considered as follows:

- Jack Lynch Tunnel
- Downstream of Lough Mahon at Little Island (as put forward by a stakeholder group)
- Either side of Great Island at Monkstown and Marlogue
- Roche's Point.

The Jack Lynch Tunnel can be ruled out as technically unviable as it has insufficient storage upstream even in the current scenario, a situation which would worsen with climate change.

The Roche's Point location would require a barrier significantly deeper than any barrier in the world in a deep harbour in an area of high velocities. It could cost up to twice that of a barrier either side of Great Island. Whilst it would be imprudent to rule it out as a future solution for Cork, it is probable that it would be a solution of last resort, only in the scenario where climate change impacts were such that a barrier at Great Island became technically unviable.

A suitably designed tidal barrier at the Little Island location as proposed by a stakeholder group may be technically viable in the current scenario, but has limited storage and thus would have a shorter lifespan than the Great Island barrier in the face of climate change.

Whilst potentially technically viable at present, the Little Island site has many challenges in terms of being able to bring the project through a statutory approvals process and construction. It is located immediately adjoining both an SAC and SPA and so there are significant environmental hurdles which would have to be addressed. There is potential for significant changes in geomorphology, navigation and marine amenity.

Whilst the location of the barrier as proposed by the stakeholder group is potentially viable, the barrier components and budget cost as set out by the group are not viable in their current format.

The barrier alignment, geometry, gate sizes etc. as proposed by the stakeholder group are all unsuitable and would require significant modification. A suitably designed barrier at this location (tidal only defence scheme) would likely cost in the order of €990m (Net Present Value cost), significantly greater than the stakeholder group's €165m estimate.

It is also worth noting that there is a significant risk that this cost would increase if a greater width of gates were needed across the 1km stretch of channel, for navigation, environmental or other reasons.

When combined with fluvial defences as proposed in the exhibited Scheme, such a solution at Little Island would have a combined BCR of 0.2, clearly not cost beneficial. It is therefore evident that it is currently not cost beneficial.

Crucially, it is evident that a tidal barrier at the Little Island location only becomes economically viable if sea level rise of circa 500mm arises. However, in this MRFS, its location means that it would start to become technically unviable at a similar point in time due to the limited upstream storage capacity. It therefore does not represent a viable short to medium term option and in all likelihood may well not represent the best medium to long term option.

Tidal barriers at Great Island have also been considered. The Great Island location has sufficient upstream storage to cater for the HEFS and beyond. Technically, it therefore represents a better long term solution in the face of climate change.

However, because of the narrowness of the channels at either side of Great Island, any barrier at this location would need to maintain flow across the full width of the existing channel to ensure continued safe navigation, reasonable velocities, and minimise changes in geomorphology.

Gates across the full width have the negative effect of significantly increasing cost but has the positive of minimising the risk of negative impacts on the SAC and SPA which are located a reasonable distance from the barrier locations. A barrier at Great Island (tidal only defence scheme) is estimated to have a NPV cost of circa €1.73bn.

It is also worth noting that at present, the Mean High Water Spring Tide is circa 1.9mOD. With 1m of sea level rise, this would increase to circa 2.9mOD which is above the current threshold of flooding in the city. A tidal barrier would therefore be required to close over 400 times a year to prevent flooding of the City by spring tides in the HEFS. Even in the MRFS the barrier would need to be closed approximately 100 times a year to protect the city. These closures would be in addition to any closures required to defend the city against storm surge events that present a risk of tidal flooding. Such a high frequency of closures would have a dramatic impact on navigation and the environment and would significantly increase the operational cost of such a barrier. Increasing the threshold of flooding in Cork from 2.5mOD to 3.4mOD by low level direct defences (as proposed in the exhibited scheme) would have the benefit of increasing storage upstream of a barrier, reducing the frequency (and cost) of operation of the barrier and minimising the impact on navigation and on the environment. It is therefore evident that a viable tidal barrier solution (if and when the need arises) will require to be undertaken in conjunction with low level direct defences in Cork city.

As well has having a very negative BCR, multi-criteria assessments carried out as part of the Lee CFRAMS and this study have both established that the exhibited scheme scores better than a tidal barrier scheme across all the criteria of technical, social, environment and economic.

The following can therefore be concluded:

- Low level Direct Defences in Cork (as per the exhibited Scheme) are the optimum solution for Cork to meet the short and medium term needs of the city.
- Such defences are the first step in a climate change strategy to manage flood risk in Cork and will form a key component of any future tidal barrier system. This is similar to the tidal defences for London where raised riverside walls were first enforced in 1898 followed by legislation for a Barrier in 1970, and also in Venice where river side “insular walls” were built and raised in increments before the significantly more expensive tidal barrier commenced as a longer term option. In both London and Venice, the barrier closure operations are assisted by the earlier riverside raised defences which were already in place.
- A tidal barrier is not currently viable and will not likely become viable for approximately 50 years or more. This eventuality is so far in the future and the timing so uncertain that it should not unduly influence decision making at this time
- If and when a tidal barrier becomes viable, the optimum location is likely to be at Great Island, but a full and detailed feasibility study of the options would have to be undertaken at that point in time.

Glossary

BCR	Benefit Cost Ratio
CD	Chart Datum
CFRAMS	Catchment Flood Risk Assessment and Management Study
CFRMP	Catchment Flood Risk Management Plan
HEFS	High End Future Scenario
HRW	HR Wallingford
LiDAR	Light Detection and Ranging
LLFRS	Lower Lee Flood Relief Scheme
MCA	Multi Criteria Analysis
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
mOD	Metres above Ordnance Datum
MRFS	Mid-Range Future Scenario
NPV	Net Present Value
OPW	Office of Public Works
SAC	Special Area of Conservation
SPA	Special Protection Areas
Velocity	Current Speed in a given direction
Astronomical tide	The tidal signal that results from gravitational effects only without any atmospheric influences
Storm Surge	An abnormal rise in the tidal elevation above the predicted astronomical tide. Surges are caused by either a storm event and/or low atmospheric pressure

Appendix A

Hydrodynamic Model Build and Calibration

A1 Hydrodynamic Model Build and Calibration – Introduction

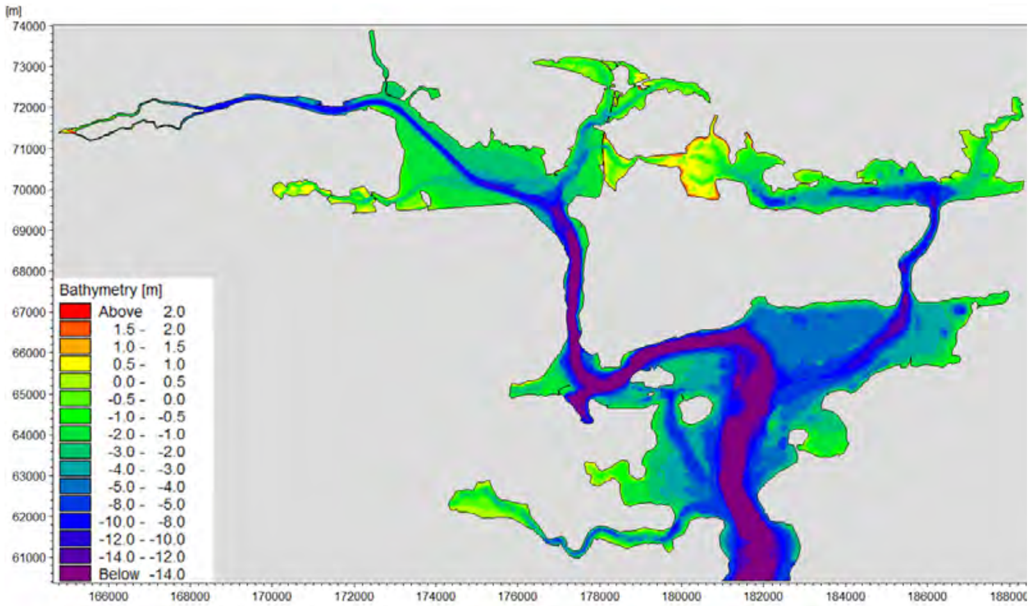
The section presents information on the development can calibration of the hydrodynamic model. The findings of the model were presented in Section 7 of the report.

A2 Data Collection

In order to develop a hydrodynamic model a number of datasets are required. The datasets used in this study include:

- Bathymetric data – The bathymetric data used for the Cork Harbour model was an amalgamation of different survey datasets of the harbour taken over the years. The primary source was a bathymetric survey undertaken by Irish Hydrodata Ltd. in 1992 as part of a study of locations for an outfall from the Cork Main Drainage Scheme. This data is supplemented by a number of smaller more localised recent surveys of the harbour. A plot of the bathymetric data for the harbour is presented in Figure 78.

Figure 78: Cork Harbour Bathymetric plot



- Recorded flow data – As part of the Irish Hydrodata survey in 1992, a number of gauges were placed at locations within Cork Harbour to record water levels, velocities and velocity direction. The gauges were deployed for approximately 3 months during the winter of 1991/1992 and therefore cover a number of spring and neap tidal cycles.

This data was used to drive the hydrodynamics by acting as the boundary condition of the model at Roche's Point model as well to calibrate the model.

- Cork City Tidal Barrier Cost Estimate (HR Wallingford, 2017)
- OSI and Bing maps

A3 Hydrodynamic Model Development

A3.1 Software

The hydrodynamic model has been developed using the flexible mesh (FM) version of MIKE 21 HD. MIKE 21 is developed by the Danish Hydraulic Institute (DHI) and is recognised internationally as being one of the leading edge software in the field of coastal and estuarine modelling.

The model is a depth integrated two-dimensional model i.e. it assumes that the estuary can be represented as a single layer of fluid. Stratification is therefore not accounted for in the model, however a two-dimensional approach is considered a valid approach in modelling the harbour.

The hydrodynamic model calculates the time varying water level and velocities for an irregular grid of points throughout the model domain in response to the oscillation of the tide and river inflow.

A3.2 Model Extent

The extent of the hydrodynamic model is presented in Figure 79 below.

Figure 79: Extent of hydrodynamic model

It can be seen that the model covers the full extent of the harbour from Roche's Point to the Waterworks weir and up into the Owenacurra estuary in Midleton. A single open tidal boundary condition is applied at Roche's Point as per the red line in the figure. Fluvial inflows are applied from the River Lee at the nose of the central island.

A4 Barrier Configurations and Grid Resolution

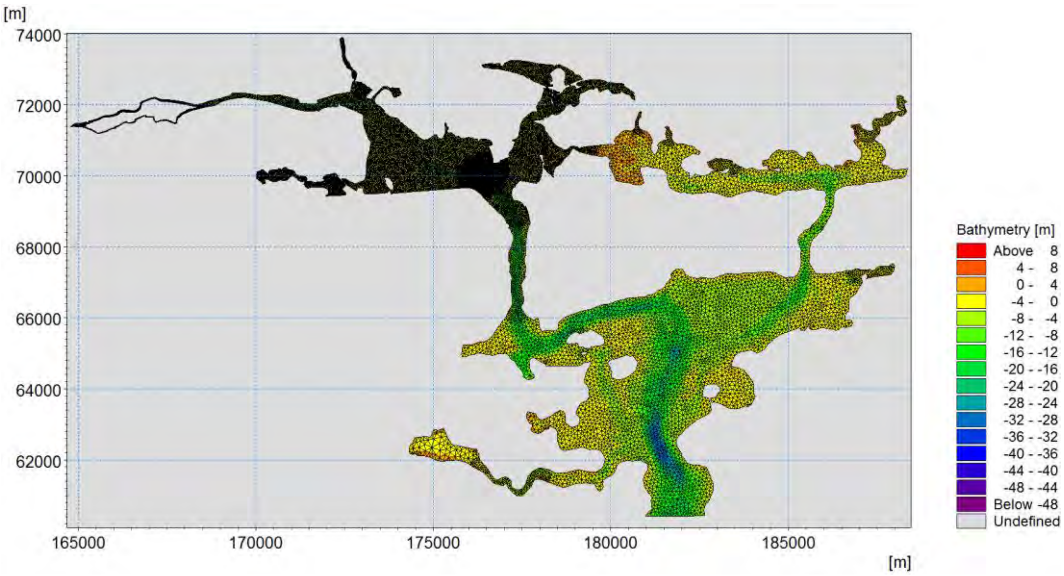
The 2D model resolution is set by the area of the triangular mesh elements of the 2D model grid. As the model is a flexible mesh model the resolution varies throughout the domain.

Defining the model resolution involves a trade-off between utilising a high-resolution mesh to accurately resolve the flow and the computational run time of the model which increases with increasing mesh resolution.

A number of varying computational mesh resolutions were tested during the model build phase of the work in order to find the optimal balance between resolution and model run time.

The finalised mesh can be seen in Figure 80. It can be seen that a very fine mesh resolution was utilised for the areas in the vicinity of the tidal barrier in order to correctly model the flow through the various openings of each of the barrier. This is evident from the plot as the individual grid cells are not distinguishable from each other. Relatively coarser mesh resolutions were used further away from the barriers in the other harbour.

Figure 80: A finalised computational mesh of the model



Four different scenarios were considered in our analysis:

- A baseline scenario i.e. the existing conditions in the harbour with no barrier in place
- Tidal barrier Option 1 – tidal barrier located at Little Island;
- Tidal barrier Option 2 – alternative tidal barrier also located at Little Island;

- Tidal barrier Option 3 – tidal barrier in the outer harbour at Monkstown (West Passage) and Marlogue Point (East Passage)

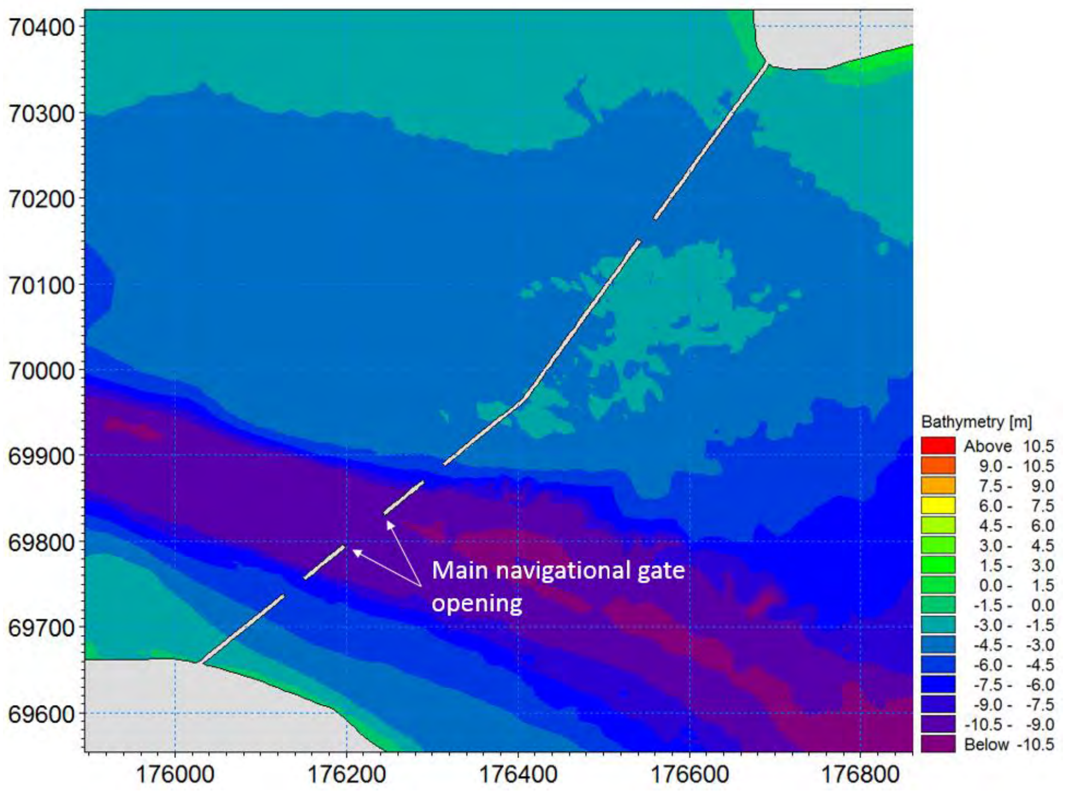
These various barrier configurations are presented in the following section.

A4.1 Tidal barrier Option 1

As outlined earlier in the report, Tidal barrier Option 1 consists of a 60m navigation gate in the deepest part of the channel with three additional 30m wide flow gate openings. While an alignment for this barrier has been proposed by a stakeholder group, the position of the three 30m wide flow gate openings along the alignment have not.

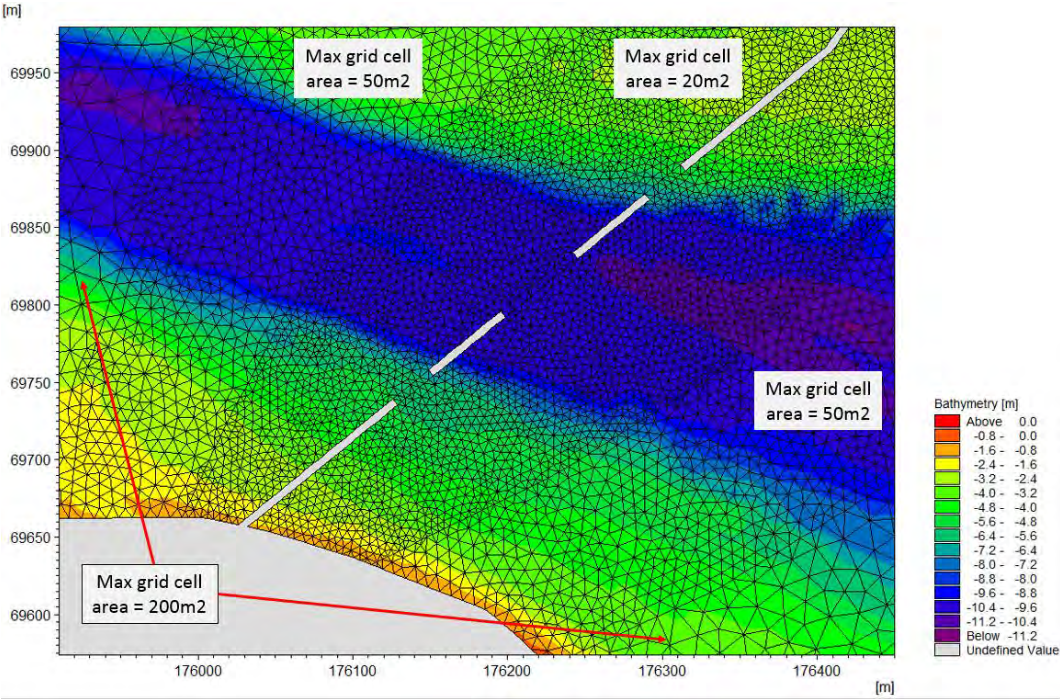
Figure 81 presents the configuration of this barrier in our hydrodynamic model. The main 60m wide navigation gate is located in the centre of the deep channel with a flow gate set at either side set back at an appropriate distance. We have assumed that the third flow gate is positioned on the Northern mudflat in order to allow an exchange of water at this location and to minimise the impact of the barrier on sediment transport. We have assumed in our model that the sill level of all the openings in the barrier are equivalent to the existing bed levels at their respective locations.

Figure 81: Representation of the stakeholder group's barrier in the hydrodynamic model.



The computational mesh in the immediate vicinity of this barrier is presented in Figure 82. The very high resolution of the model in the vicinity of the barrier is evident from the plot.

Figure 82: Computational mesh in the vicinity of Barrier Option 2

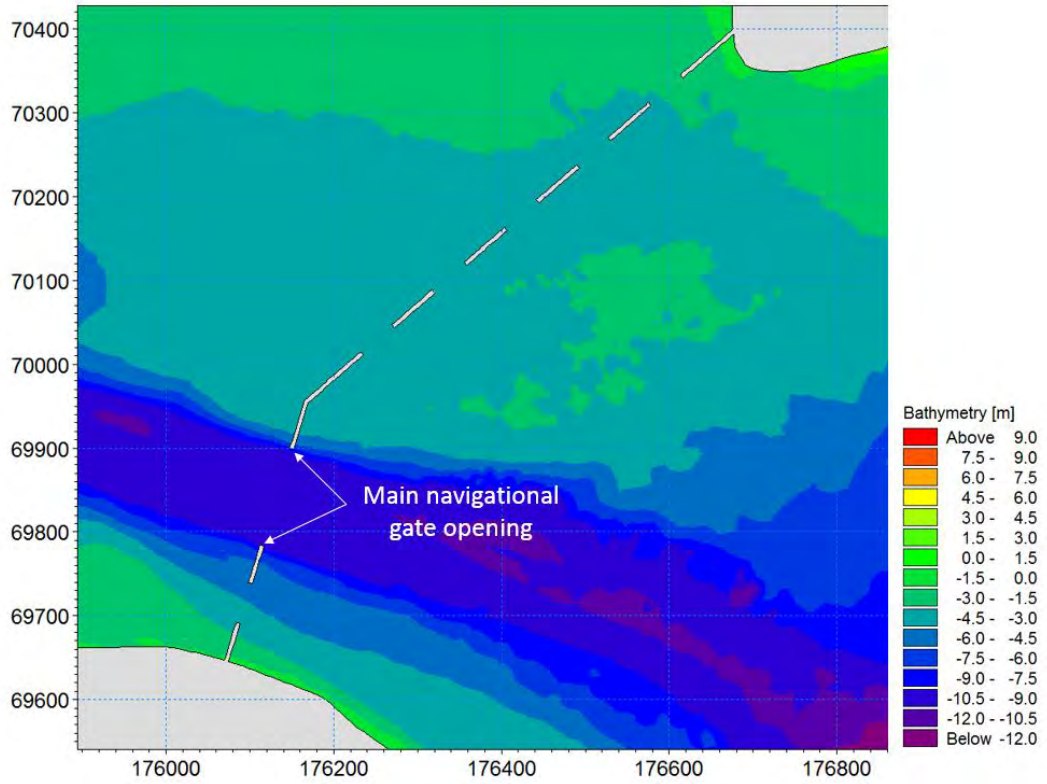


A4.2 Tidal barrier Option 2

Tidal barrier Option 2 consists of a 120m navigation opening with six additional flow gate openings each of 50m width. The configuration of this barrier is presented in Figure 83.

We note that as well as having greater opening widths, Option 2 is also aligned differently to Option 1. In Option 2 the main navigational gate is set perpendicular to the direction of flow in order to streamline the velocities through the opening. This will minimise localised turbulence in the water column and provide a wider effective opening for vessels following the navigation channel.

Figure 83: The Increased Flow Area Barrier at Little Island with background bathymetry



A4.3 Tidal Barriers Option 3: at Monkstown and Marlogue Point

The configuration of the tidal barrier at Monkstown is presented in Figure 84 and at Marlogue Point in Figure 85. The barrier at Monkstown consists of two 60m navigation gates separated by a 10m wide pier and four additional flow gates, each 35m wide. The barrier at Marlogue Point consists of one 60m navigation opening and six additional flow gates, each between 25-30m wide and separated by 10m wide piers. We note that as these piers would have to carry substantial loads, it is likely that they would need to be extended in the direction of flow. For the purpose of this study however the representation of the piers in the model is appropriate and adequate as any increase in dimensions of the piers in the direction of flow would only have minor localised impacts.

Figure 84: Barrier piers with background bathymetry at Monkstown

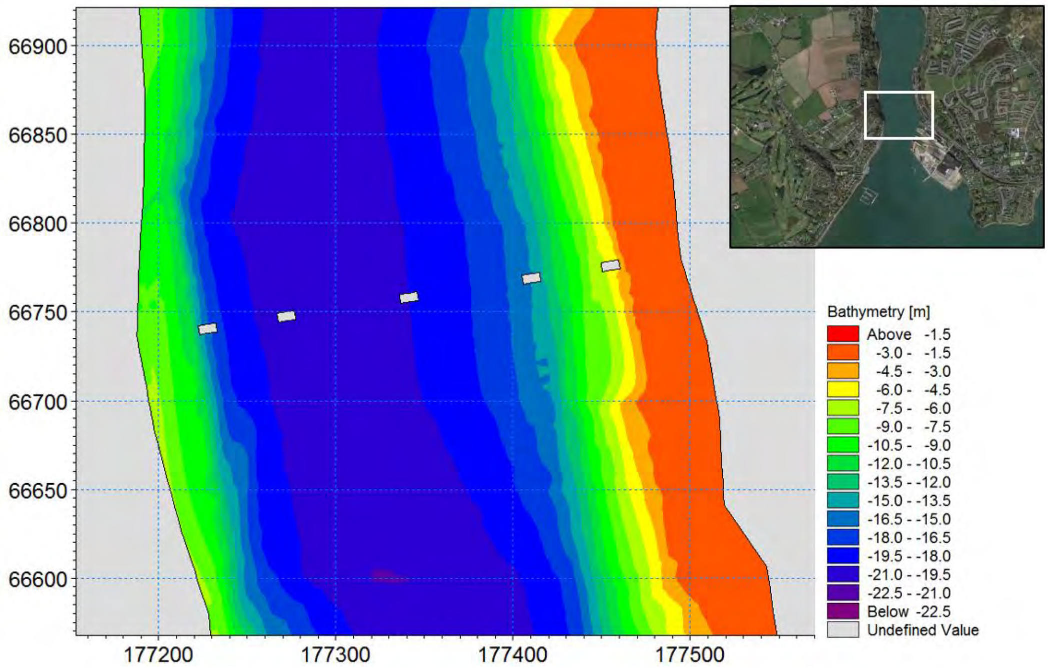
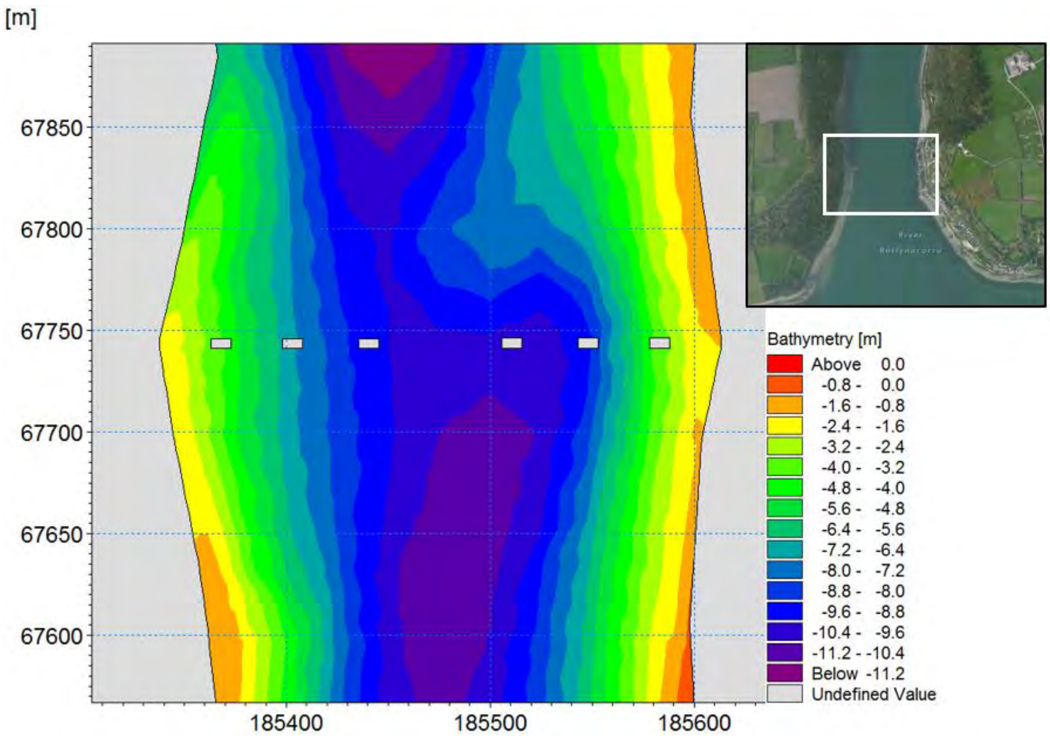


Figure 85: Barrier piers with background bathymetry at Marlogue



A4.4 Model Parameters

An adaptive time step was used in the model. The maximum time step was selected as 5 seconds. The minimum time step was selected as 0.01 seconds. The actual time step used by the model throughout the simulation was determined by the model computations based on the requirements of the mesh.

A number of additional parameters require definition in the model. These are listed below along with the values selected for the model. It is noted that setting of model parameters is guided by both the model calibration process and also by our experience in numerical modelling.

Table 36: Model parameters used in the study

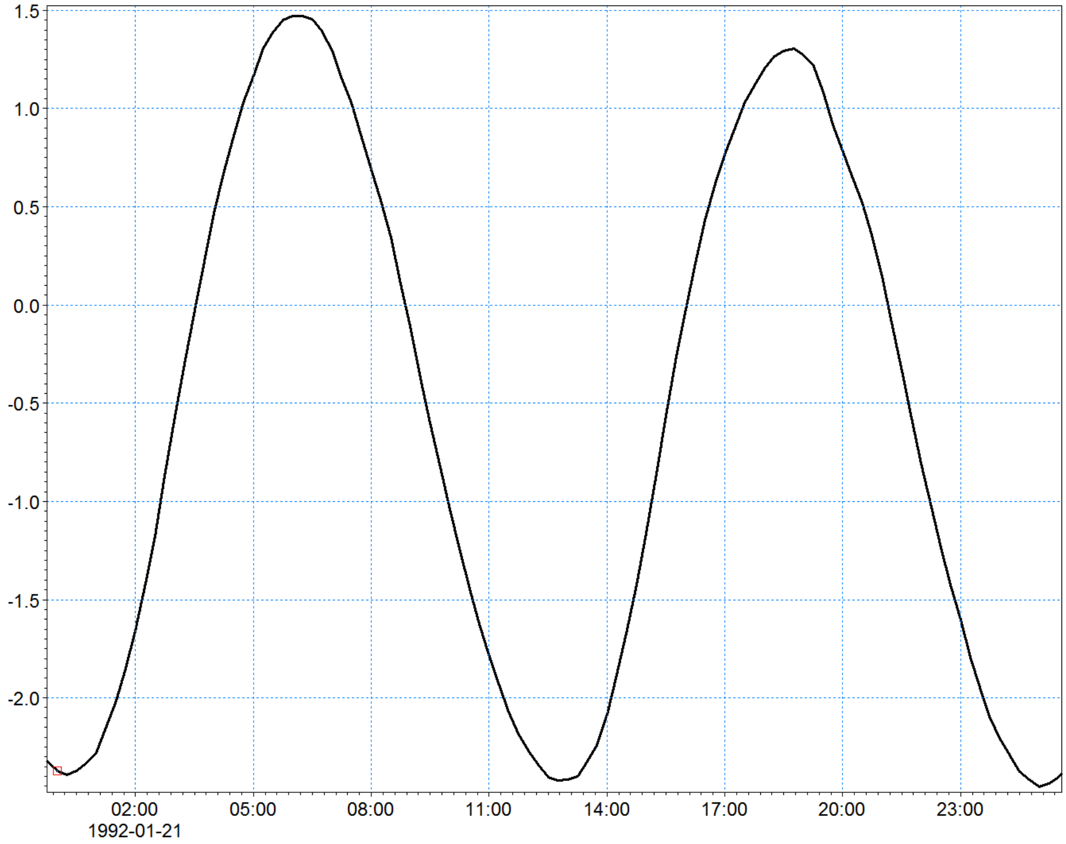
Parameter	Value
Drying depth	0.005m
Flooding depth	0.05m
Wetting Depth	0.1m
Eddy Viscosity	Smagorinsky formulation constant value of 0.5
Bed resistance	A spatially varying Manning's M formulation was used to accurately capture the variation in bed resistance for different areas of the harbour

Coriolis forcing, precipitation, evaporation, wave radiation and ice coverage were all ignored in the model as they were deemed to not have any significance.

A4.5 Boundary Conditions

The models were run with a single tidal open boundary condition at Roche's Point. Recorded tidal data from Roche's Point from the 1992 survey was used as the boundary condition. Figure 86 presents the spring tidal conditions from the Roche's Point data. It can be seen from the figure that the tidal amplitude for spring tides for the harbour is circa 4m.

Figure 86: The spring tidal signals used as a boundary condition for the model



Source discharge points were applied at the appropriate locations in the model in order represent river inflows.

A5 Model Calibration

Model calibration involves comparing recorded data against model results to determine how good the model is at reproducing the hydrodynamics of the harbour. The process of calibration allows some of the parameters of the model to be fine-tuned to achieve the best match between the data and the model.

The 2D hydrodynamic model was calibrated against the recorded water level, velocity and velocity direction data from the 1991/1992 Irish Hydrodata survey of Cork Harbour. This process involved varying various parameters of the model in order to achieve a good match between the measured and modelled datasets.

A5.1 Water Level Calibration

Figure 87 below shows the recorded and modelled water levels for spring tide conditions at Ringaskiddy just offshore from the Pfizer plant.

It can be seen from the plot the modelled water level is a good match to the recorded water level. The model however slightly underestimates the peak water levels.

Figure 87: Recorded water level (red) against modelled (blue) at a point near Ringaskiddy

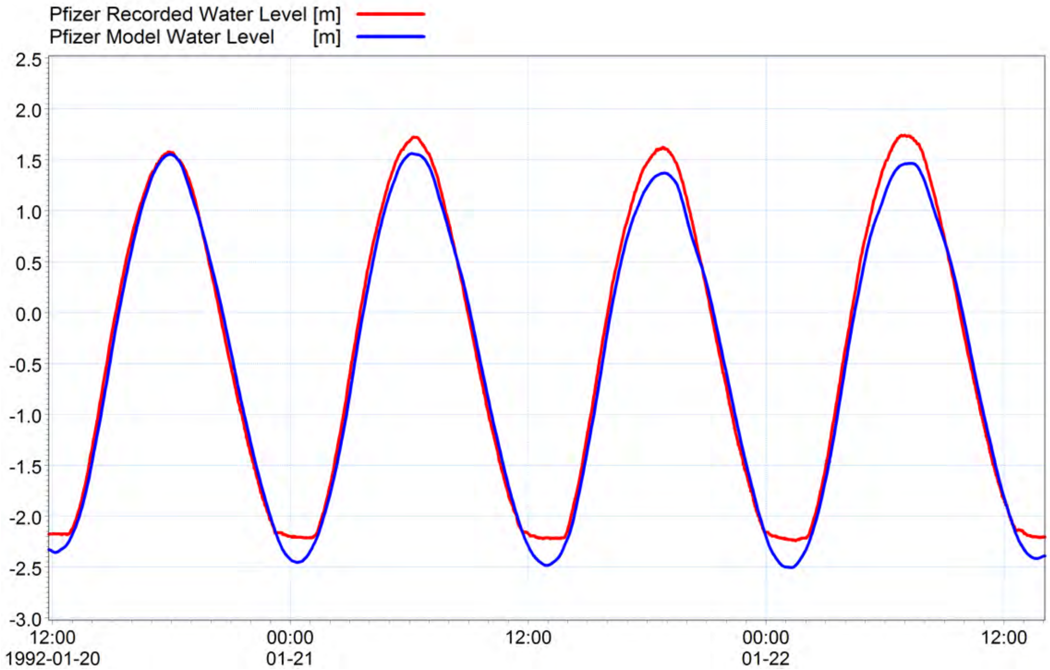
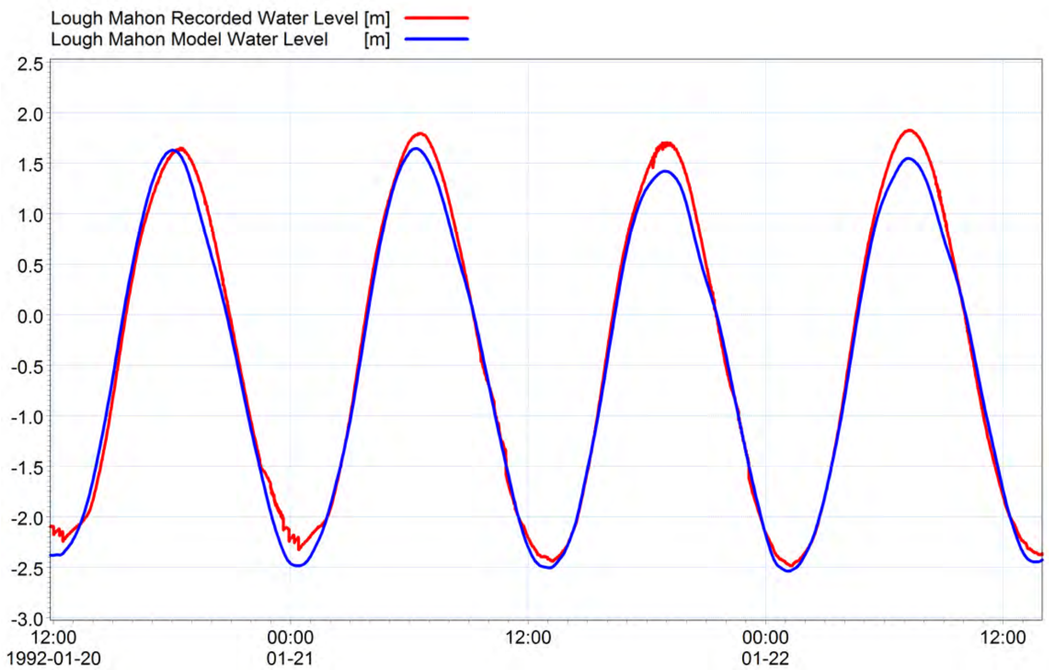


Figure 88 presents the calibration plot for a gauge in the centre of Lough Mahon. It can be seen from the plot the model is a good match to the recorded data at this location. As with calibration at the Pfizer gauge, the peak water levels at this location are underestimated by the model.

Figure 88: Recorded water level (red) against modelled (blue) at a point in Lough Mahon



The plots clearly demonstrate he ability of the model to reproduce observed water levels in the harbour.

A5.2 Velocities

Figure 89 presents the velocity calibration for the Pfizer gauge location. We can see from the plot that the modelled velocity is a very good match to the recorded velocities. The peak velocities on the flood tide are an excellent match to the recorded data while the peak velocities on the ebb tide are also in very good agreement with the recorded data, but are slightly underestimated. The time at which the tide turns is also very well captured by the model as both time series are generally in phase.

We note that oscillations in the recorded velocity time series are due to localised turbulence in the water column and does not affect calibration of the model.

Figure 89: Recorded velocity (red) against modelled (blue) at Spit Bank off Cobh

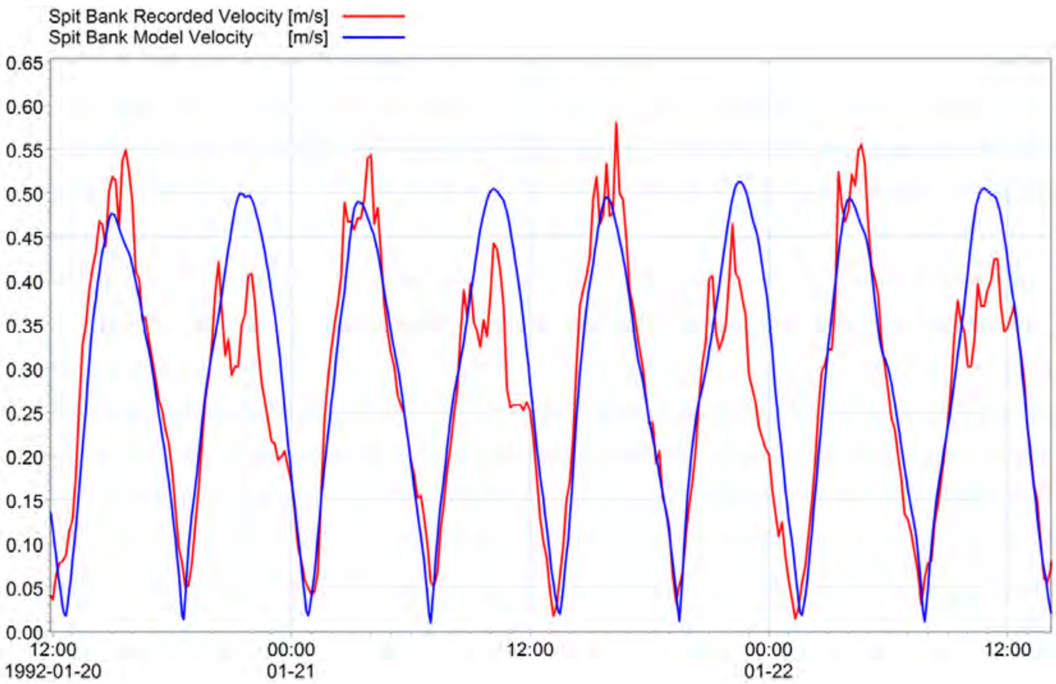
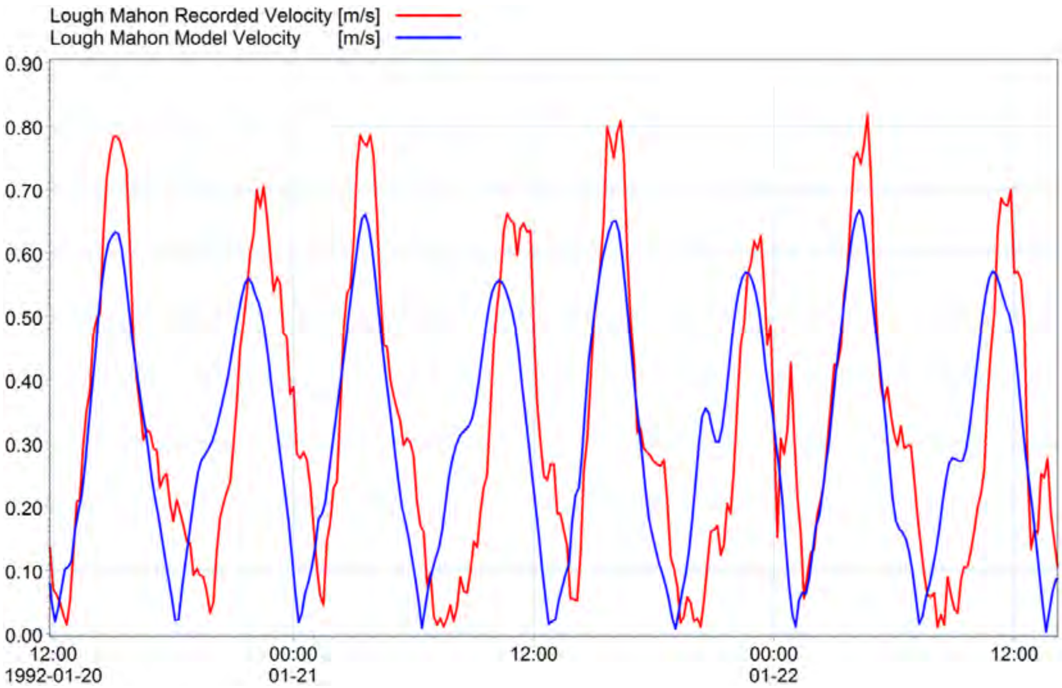


Figure 90 below shows the velocity calibration for Lough Mahon. It can be seen that the peak velocities are slightly underestimated by the model on both the flood and ebb tides. Overall however the model is a very good match to the recorded velocity data at this location.

Figure 90: Recorded velocity (red) against modelled (blue) at a point in Lough Mahon



A5.3 Flow Direction

Figure 91 presents the recorded and modelled flow direction the gauge at Spit Bank. It can be seen the model is a very good match to the recorded flow direction data at this location.

Figure 91: Flow direction calibration at Spit Bank

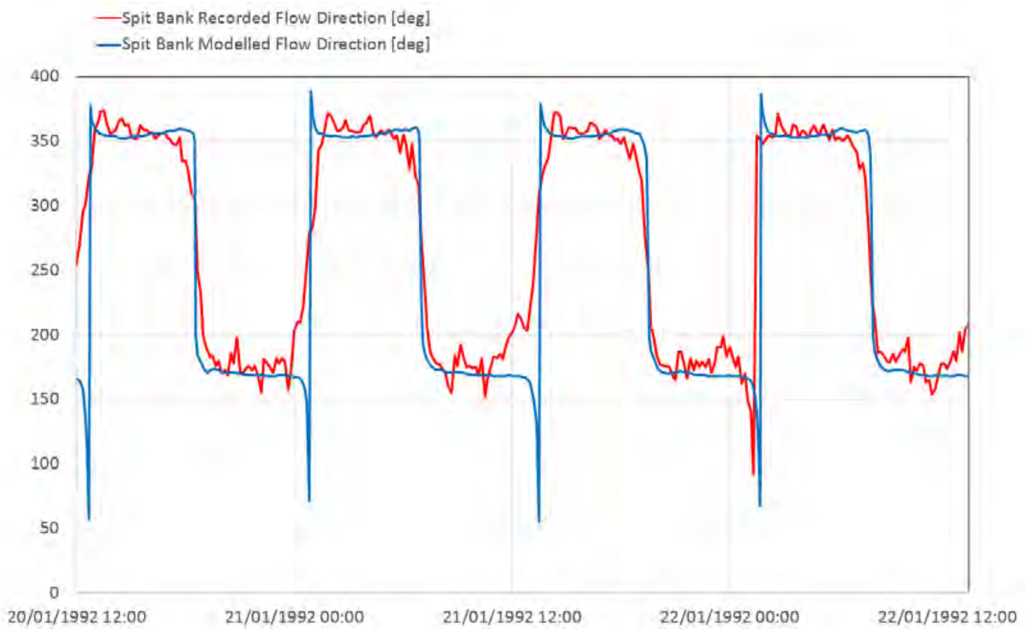
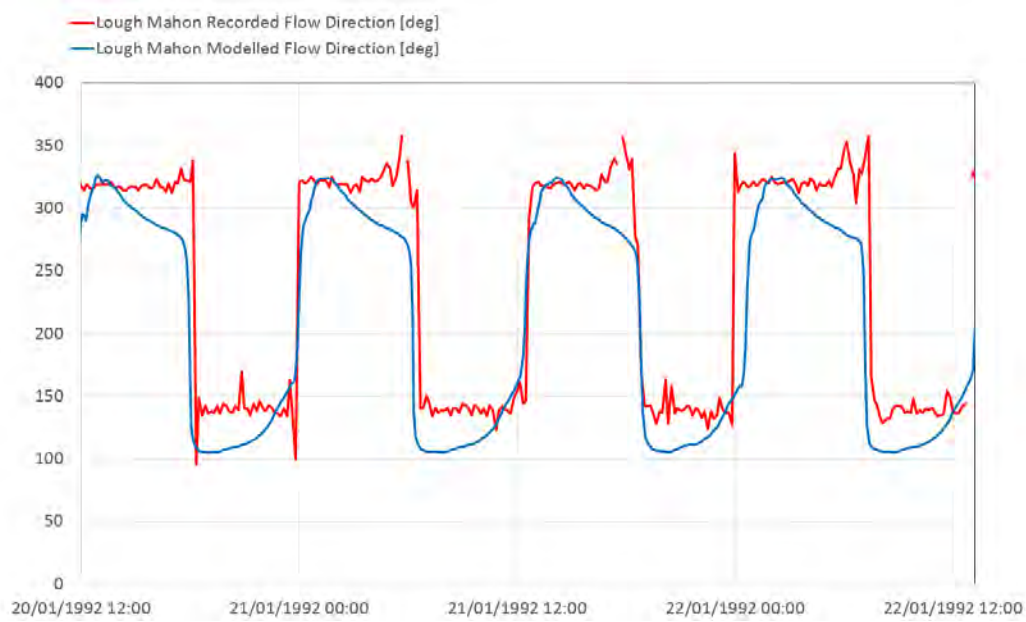


Figure 92 below shows the recorded and modelled flow direction for the gauge in Lough Mahon. Again it can be seen that the model and the recorded data are a very good match.

Figure 92: Flow direction calibration at Lough Mahon



A5.4 Calibration Conclusion

The model is well calibrated against recorded data from both the outer harbour and Lough Mahon.

Appendix B

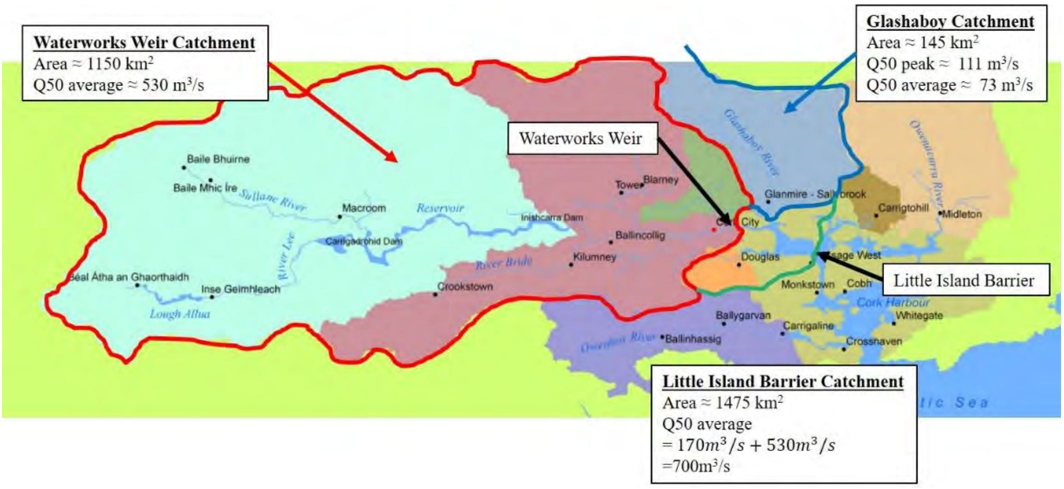
Estimate of Fluvial Inflows

B1 Estimate of Fluvial Inflow at Little Island

Figure 93 presents an outline the various subcatchment areas and the Q50 peak and average flows relevant to the estimation of flows at the Little Island barrier location. We can see that the Q50 average flow at the Little Island barrier location is estimated as 700m^3/s which is derived by adding two separate flows together:

- Q50 average flow to the waterworks weir - **530m^3/s** (allowing for attenuation at the reservoirs based on the new rules)
- Q50 average flow for the catchment area between the Waterworks Weir and Little Island Barrier – **170m^3/s** (calculation detailed below).

Figure 93: Little Island Barrier Catchment and Sub Catchments



Catchment area between the Waterworks Weir and Little Island Barrier

Area = (1475km^2 - 1150km^2) = 325km^2

% of catchment downstream of Waterworks Weir = $\frac{325km^2}{1475km^2} = 22\%$

% of catchment upstream of Waterworks Weir = $\frac{1150km^2}{1475km^2} = 78\%$

Estimate of flows for the catchment area between the Waterworks Weir and Little Island Barrier

The Q50 peak on the Glashaboy catchment is 111 m^3/s for the current scenario and 134m^3/s for the MRFS. We can therefore estimate the Q50 peak for Catchment area between the Waterworks Weir and Little Island Barrier using this value by scaling up based on catchment area:

Q50 peak (scaled based on Glashaboy Catchment Q50 peak)

$$= \frac{325km^2}{145km^2} \times 111m^3/s = 249m^3/s$$

Alternatively, we can also estimate the Q50 peak for Catchment area between the Waterworks Weir and Little Island Barrier by scaling up the flows from the catchment upstream of the waterworks weir (theoretical non reservoir case):

Q50 peak (scaled based on Waterworks Weir Catchment Q50 peak

$= \frac{325km^2}{1150km^2} \times 924m^3/s = 260m^3/s$

The estimate of $260m^3/s$ is considered more appropriate as it is marginally more conservative.

If we consider that the average flow on the Glashaboy catchment is circa 65% of the peak, we can estimate the average flow between the Waterworks Weir and Little Island Barrier as:

Q50 average = $260m^3/s \times 0.65 = 170\ m^3/s$

Adding this Q50 average to the average 1 in 50 year design inflow at waterworks weir of circa $530m^3/s$ (allowing for attenuation at the reservoirs based on the new rules) gives a total average inflow of circa $700m^3/s$.

Account for climate change

As described earlier in this report, in the future climate change scenario (HEFS), the critical parameters have been defined as follows:

- Barrier Closed at circa 0.261mOD (low tide)
- Barrier Reopened at 2.4mOD (on ebb tide)
- Barrier Closure time is 10 hours
- Storage available between 0.261mOD and 2.4mOD

At the Little Island location, the storage volume available between 0.261mOD and 2.4mOD is calculated from bathymetry data as $19{,}164{,}683m^3$. Over the 10 hour closure duration, this equates to an available average inflow of $532m^3/s$.

As set out in the options report, if no further modifications are made to the dams, or alternative upstream measures put in place, the peak flow at waterworks weir would increase by circa 40% for a 20% increase in inflow to the reservoirs. The increase will be even greater for the 30% increase in inflows for the HEFS.

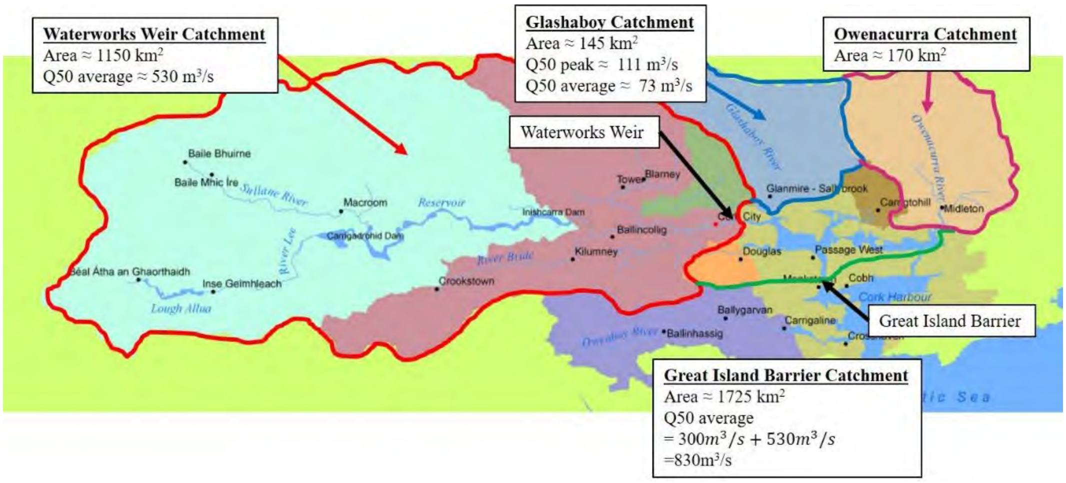
Even if a conservative 30% increase is applied to the average catchment inflow of $700m^3/s$ estimate above, this would equate to an average inflow of circa $910m^3/s$. This is significantly in excess of the available storage, and so it is evident that the tidal barrier location at Little Island is unlikely to be suitable for the HEFS and in all probability is unlikely to be viable in the MRFS. However, detailed modelling would be required to accurately identify the point at which it would become viable.

B2 Estimate of Fluvial Inflow at Great Island

Figure 94 presents an outline the various subcatchment areas and the Q50 peak and average flows relevant to the estimation of flows at the Little Island barrier location. We can see that the Q50 average flow at the Great Island barrier location is estimated as 830m^3/s which is derived by adding two separate flows together:

- Q50 average flow to the waterworks weir - **530m^3/s** (allowing for attenuation at the reservoirs based on the new rules).
- Q50 average flow for the catchment area between the Waterworks Weir and the Great Island Barrier – **300m^3/s** (calculation detailed below).

Figure 94: Great Island Barrier Catchment and Sub Catchments



Catchment area between the Waterworks Weir and Great Island Barrier

Area ≈ (1725km^2 - 1150 km^2) = 575 km^2

Percentage of catchment downstream of Waterworks Weir = $\frac{575km^2}{1725km^2} = 33\%$

Percentage of catchment upstream of Waterworks Weir = $\frac{1150km^2}{1725km^2} = 67\%$

Estimate of flows for the catchment area between the Waterworks Weir and Great Island Barrier

The Q50 peak on the Glashaboy catchment is circa 111 m^3/s for the current scenario and 134m^3/s for the MRFS. We can therefore estimate the Q50 peak for Catchment area between the Waterworks Weir and Great Island Barrier using this value by scaling up based on catchment area

Q50 peak (scaled based on Glashaboy Catchment Q50 peak)

$$= \frac{575km^2}{145km^2} \times 111m^3/s = 440m^3/s$$

Alternatively, we can also estimate the Q50 peak for Catchment area between the Waterworks Weir and Great Island Barrier by scaling up the flows from the catchment upstream of the waterworks weir (theoretical non reservoir case):

Q50 peak (scaled based on Waterworks Weir Catchment Q50 peak)

$$= \frac{575km^2}{1150km^2} \times 924m^3/s = 460m^3/s$$

The estimate of $460m^3/s$ is considered more appropriate as it marginally more conservative.

If we consider that the average flow on the Glashaboy catchment is circa 65% of the peak, we can estimate the average flow between the Waterworks Weir and Great Island Barrier as:

Q50 average $=460m^3/s \times 0.65 = 300\ m^3/s$

Adding this Q50 average to the average 1 in 50 year design inflow at waterworks weir of circa $530m^3/s$ (allowing for attenuation at the reservoirs based on the new rules) gives a total average inflow of circa $830m^3/s$.

Appendix C

Ecological Report

OIFIG na nOIBREACHA POIBLÍ
OFFICE OF PUBLIC WORKS

Lower Lee (Cork City) Drainage Scheme

Ecological Assessment of Options: Tidal Barrier

November 2017

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Introduction

Cork Harbour is a designated protected area for the conservation of Birds and Habitats under the Natura 2000 Network. The overarching frameworks for the conservation of wild birds within Ireland and Europe and is provided by Directive 2009/147/EC. Together with the EU habitats Directive (92/43/EEC) these legislative measures provide for wild bird protection known as Special Protection Areas (SPA).

Similar, the EU Habitats Directive provides legislative measures for the protection of habitats and species known as Special Areas of Conservation (SAC).

The overriding conservation objectives of these Natura 2000 sites is the maintenance (or restoration) of favourable conservation status of habitats and species.

Cork Harbour SPA (004030)

Cork Harbour is a large sheltered bay stretching from the two main estuaries of the River Lee and the Owencurra River. It is a complex site with many other estuaries and inlets including North Channel, the Douglas River Estuary, inner Lough Mahon, Monkstown Creek, Lough Beg, the Owenboy River Estuary, Whitegate Bay and the Ringabella Creek and the Rostellan and Poulnabibe inlets.

Cork Harbour is internationally important in terms of bird populations, supporting in excess of 20,000 wintering waterfowl for which it is amongst the top ten sites in Ireland. Of particular note are internationally important populations of Black-tailed Godwit and Redshank, with a further 20 non-breeding birds in numbers of national importance. The Annex I species Common Tern has a breeding population on the site. Cork Harbour is also designated as a Ramsar site, an Important Bird Area (Birdlife International) and a Wildfowl Sanctuary.

The following birds are listed as of conservation interest within the SPA:

A004 Little Grebe *Tachybaptus ruficollis*

A005 Great Crested Grebe *Podiceps cristatus*

A017 Cormorant *Phalacrocorax carbo*

A028 Grey Heron *Ardea cinerea*

A048 Shelduck *Tadorna*

A050 Wigeon *Anas penelope*

A052 Teal *Anas crecca*

A054 Pintail *Anas acuta*

A056 Shoveler *Anas clypeata*

A069 Red-breasted Merganser *Mergus serrator*

A130 Oystercatcher *Haematopus ostralegus*

A140 Golden Plover *Pluvialis apricaria*

A141 Grey Plover *Pluvialis squatarola*

A142 Lapwing *Vanellus*

A149 Dunlin *Calidris alpina*

A156 Black-tailed Godwit *Limosa*

A157 Bar-tailed Godwit *Limosa lapponica*

A160 Curlew *Numenius arquata*

A162 Redshank *Tringa totanus*

A179 Black-headed Gull *Chroicocephalus ridibundus*

A182 Common Gull *Larus canus*

A183 Lesser Black-backed Gull *Larus fuscus*

A193 Common Tern *Sterna hirundo*

A999 Wetlands

There are two main conservation objectives identified by NPWS.

Conservation Objective 1 requires that the favourable long-term population trends for each water bird should be stable and / or increasing. There should be no significant decrease in the range, timing or intensity of use of areas by the water birds other than occurring from natural patterns of variation.

Objective 2 requires favourable conservation condition to maintain a permeant area occupied by wetland habitat to be stable and not be significantly less than the area of 2,587 ha other than that occurring from natural patterns of variation.

A number of factors can adversely affect the achievement of the conservation objectives including habitat modification (including how the species use the site e.g. feeding resources), disturbance (anthropogenic disturbance either singularly or cumulatively) and Ex-situ factors which includes impacts on habitats situated within the immediate hinterland of the SPA or areas outside of the SPA but ecologically connected to it.

Potential for Impact on Cork Harbour SAC Caused by Disturbance

Any activity that causes disturbance can lead to displacement of water birds and can be considered significant. In terms of foraging habitat, displacement from feeding opportunities can reduce a bird's energy intake and lead to increases in energy use due to flying to alternative foraging areas. Displacement can also result in increased competition for food. Heavy or on-going disturbance can effectively result in habitat loss. If disturbance effects species fitness (survival or reproductive success) population number may be affected. Waterbird responses will likely between individual events and species. The significance of a disturbance is dependent on frequency /duration, intensity and response of waterbirds.

There are varying influencing factors:

- Temporal availability (can the area be exploited when the disturbance does not occur);
- Availability of compensatory habitat;
- Behavioural changes as a result of a disturbance - e.g. degree of habituation;
- Time available for acclimatisation (lack of time for waterbirds during the staging period);
- Age e.g. immature birds may be marginalised by older flocks so access to prey resources is limited and may already be under pressure;
- Timing/seasonality e.g. more vulnerable at the end of the winter when resources are lower;
- Weather;
- Site fidelity of species;
- Predation and competition (alternative sites have increased competition or predation).

Great Channel Islands SAC

The Great Island Channel extends form Little Island to Midleton and is an integral part of cork Harbour. The site is designated for:

1140 Mudlfats and sandflats not covered by seawater at low tide;

1330 Atlantic Salt Meadows (Glauco-Puccinellietalia marintiae)

Mudflats and sandflats not covered by seawater at low tide

Tidal mudflats are made up of mainly soft mud, green algal species occur including Spartina in places (Rossleague and Belvelly). The habitat sub type is classified by NPWS as mixed sediment to sandy mud with polychagtes and oligochates community complex.

Silt-clay represents the major portion of the area. The distinguishing species of this community complex are the polychaetes *Hediste diversicolor* and *Nephtys hombergii* and the oligochaetes *Tubificoides benedii*. Other species recorded here include the gastropod *Peringia ulvae* and the bivalve *Scrobicularia plana*.

Marine Annex I habitats are considered to be key contributors to overall biodiversity by virtue of their structure and / or function and their low resilience should be afforded a high degree of protection from significant anthropogenic disturbance.

Targets for the habitat type Mudflats and sandflats not covered by sea at low tide are:

- Target 1: The permanent habitat area is stable or increasing, subject to natural processes;
- Target 2: Conserve mixed sediment to sandy mud with polychaetes and oligochaetes community complex.

Atlantic Salt Meadows

Atlantic Salt meadows are scattered thought-out the site. While other saltmarsh habitat including Salicornia flats are recorded within the SAC, the site is only designated for Atlantic Salt meadows. Two specific salt meadow sites have been surveyed by NPWS within the SAC.

The Conservation Objectives and targets for Salt marsh habitat include:

- Habitat are should be increasing, subject to natural processes, including erosion and succession;
- No decline or change in distribution of saltmarsh habitats (excluding natural processes);
- Maintain the natural circulation of sediment and organic matter, without any physical obstructions;
- Maintain and restore creek and pan networks;
- Maintain flood regime whereby lower levels of saltmarsh are flooded daily and upper levels are flooded occasionally;
- Maintain coastal habitats, including transitional zones, subject to natural processes including erosion and succession;
- Maintain structural variation within the sward (sward ration of 30% tall: 70% short across the entire saltmarsh);
- Maintain 90% of area outside of creeks vegetated;
- Ensure typical flora is maintained;
- Negative indicators such as Spartina should be absent or under control. (current target is no significant expansion and an annual spread of less than 1%).

Potential impact on Cork Harbour SPA as a result of construction and management of Tidal Barriers.

All Tidal Barrier Options have potential to impact on Cork Harbour SPA.

The construction of the Jack Lynch Option provided will have a direct impact on the SPA resulting in direct loss of habitat where structures are located and where sediment deposition is altered as a result. While Little Island Tidal Barrier can be located outside of the SPA, works to the east of the island will have a direct impact on the SPA. All other options can be constructed without direct loss of wetland habitat within the SPA. However, it should be noted that detailed surveys of bird activity within the harbour should extend to outside the SAC where the designed birds species may also be using the site for foraging and / or roosting. Construction disturbance is likely to be a factor of influence for any barrier option in this internationally important site, risk of displacement during construction can result in significant impact to bird populations as discussed in Section 1.1.

Operational impacts are dependant upon the frequency of use of the tidal barriers, while closing of the barriers on less than two events is not likely to significantly impact on habitats and foraging resources, regular closing of barriers is likely to be significant and could alter the environment and function of the site where it is no longer preferable for overwintering birds.

Any option brought forward would need to consider the potential impact on birds and their wetland habitat both within and adjoining the SAC. Monitoring of activity including high tide roosts and forging behaviour would need to be examined in detail as part of a Natura Impact Statement.

Potential impact on Great Island Channel SAC as a result of construction and management of Tidal Barriers.

The structure and functioning of mudflats and sandflats is dependent on the tidal cycle and could potentially be impacted by the construction of structures within the designed site. Any construction within the SAC will result in loss of habitat area which is in conflict with the Targets set for the site. Construction of tidal barriers outside the SAC but in proximity to it could also have potential to impact on the structure and function of the site by changes in accretion of sediment, flow and velocities within the tidal zone. As for the SAC, operation of tidal barriers is dependent on frequency, while the habitat is likely to tolerate infrequent use of tidal barriers, frequent closing of the barriers is likely to have a significant impact on the structure and function of the Annex I habitat mudflats and sandflats.

Saltmarsh habitat is largely located to the north of the SAC. While construction phase development is unlikely to create a significant impact on saltmarsh, there is potential impact on its structure and function as a result of long term operational impacts.

Barrier Adjacent to Jack Lynch Tunnel

This barrier is located within the Cork Harbour SPA. This barrier will result in loss of wetland habitat within the SPA. An objective of the SPA is to maintain the permeant area occupied by wetland habitat. In addition, the area immediately around the barriers supports thirteen species of birds with 3 roost locations. Species include both foraging and roosting shelduck, Blacktailed Godwit, Curlew and Wigeon, roosting Cormorant, Blackheaded gull, Blackbacked gull, foraging Grey Heron in small numbers, bar tailed Godwit and Dunlin, roosting Oystercatchers and Lapwing.

The site is outside and upstream of the Great Island Channel SAC and will not impact on this Natura 2000 site.

Barrier at Roche's Point

This tidal barrier is outside the boundary of both the SAC and SPA. However, this site has been monitored for bird activity (White Bay to Graball Bay) by NPWS. Small numbers of Great Crested Grebe and known to forage here with Cormorant and blackheaded foraging and roosting sites present. Oyster Catcher uses the coastline in this location for foraging and roosting. In total there are 9 roost locations and 7 species are known to use the site. While it is outside the SPA consideration of impact on these birds would need to be considered and appropriately mitigated against during construction and operational phase of the project.

Barriers at Little Island

This option can be constructed outside of the SAC, but is marginally within the SPA. In addition, the impact of the works is likely to extend outside the footprint of the barrier with change to sediment accretion as a result of a new structure within the bay. SPA listed birds include Shelduck, and Blackheaded gull both foraging and roosting; Little grebe, bar tailed godwit (in small numbers), Oystercatcher and Dunlin Roosting; and Wigeon and Grey crested grebe (in small numbers), curlew, teal and redhshank foraging.

Barriers at Great Island – with Separate Structures at Monkstown and Marlogue Point

Both barriers and Monkstown and Marlogue Point are outside of designated Natura 2000 site. Should construction be carried out with appropriate mitigation to avoid disturbance of the adjoining sites there is potentially no direct impact. However, the area is used for Birds which are designated for protection under the Cork Harbour SPA. Therefore, there could be an impact on these species all be it outside of their designed site. NPWS have identified the following birds foraging and / or roosting in these areas Blackheaded Gull, Lesser Blackheaded Gull, Common Gull, Cormorant, Teal and Oystercatcher.

In consideration of a tidal barrier it is noted that any barrier within or in close proximity to the SAC or SPA will have an impact on the Conservation Targets for those sites, namely the requirement for the permanent habitat area to be stable or increasing, subject to natural processes.

Where options are outside of the SPA it should be noted that Conservation Objective 1 requires that the favourable long-term population trends for each water bird should be stable and / or increasing. While the site of the works location may not be designated, the loss of habitat for which these species use could have a resultant impact on the population success of these species. In addition, the operational and construction impact with regard to both disturbance impacts from noise and changes to land use would require significant consideration before being progressed. In the case of any tidal barrier being progressed detailed assessment on bird populations and behaviour would be required to allow the project to rule out potential impact on the Natura 2000 Sites.