King's Island Flood Relief Scheme

Options Assessment Report

Final Report

August 2018

JBA Project Manager

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
V1.0/ 13/03/2017	Initial draft issue	Limerick City & County Council
V2.0 09/11/2017	Reworking of measures, MCA and CBA	Limerick City & County Council
V3.0 16/11/2017	Figure and text updates prior to TAG	Technical Advisory Group
V4.0 26/02/2018	Damages updated to include additional commercial properties	Technical Advisory Group
V5.0 03/08/2018	Post PID updates	Technical Advisory Group
V6.0 08/05/2019	Minor amendments, but no material changes to the preferred scheme post-August 2018	Technical Advisory Group

Contract

This report describes work commissioned by Limerick City & County Council as part of Kings Island Flood Relief Scheme. Declan White, Elizabeth Russell, Declan Egan and Bernadette O'Connell of JBA Consulting carried out this work.

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Purpose

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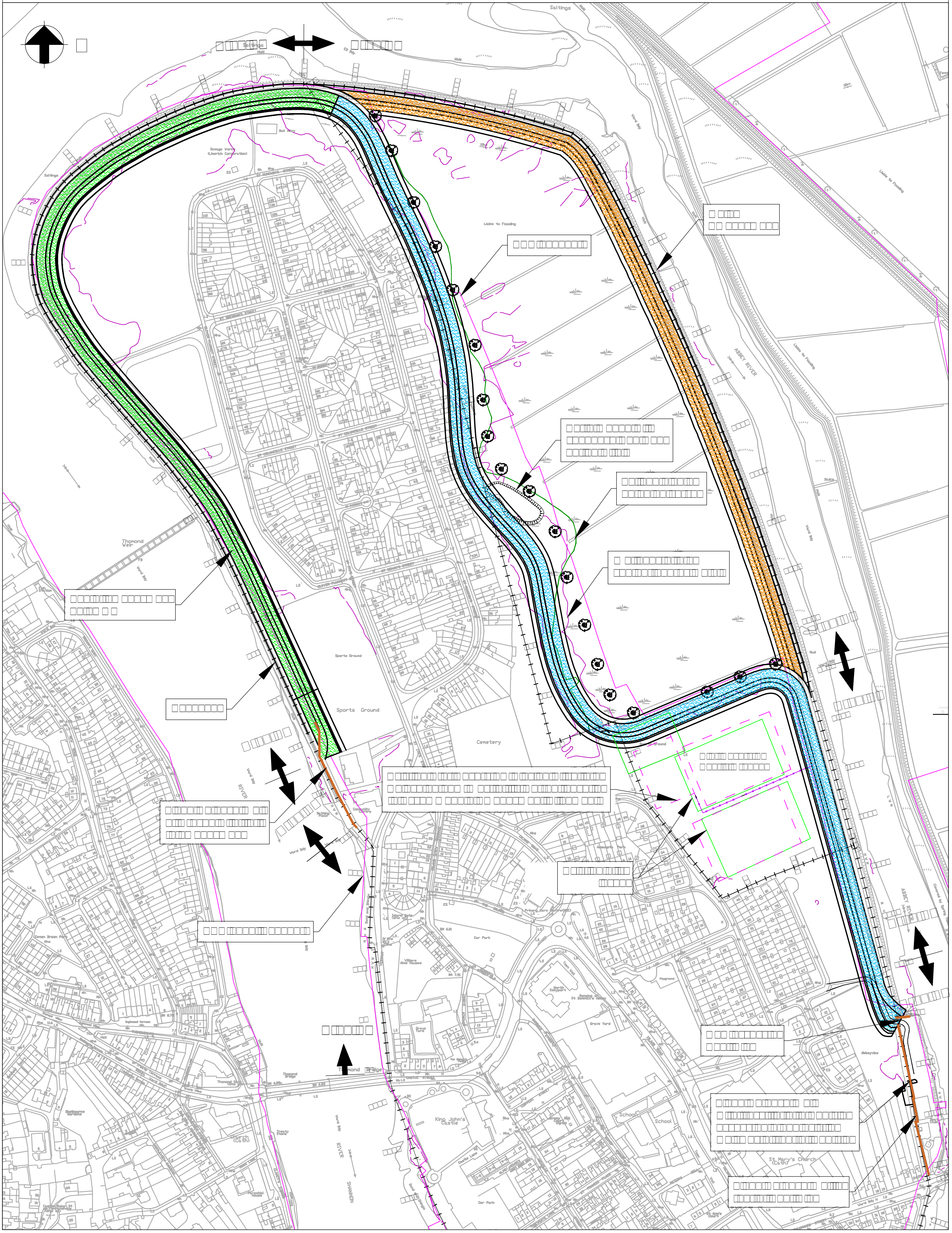
Appendices

A Chainages around King's Island

KING'S ISLAND FLOOD RELIEF SCHEME

KING'S ISLAND - NORTH



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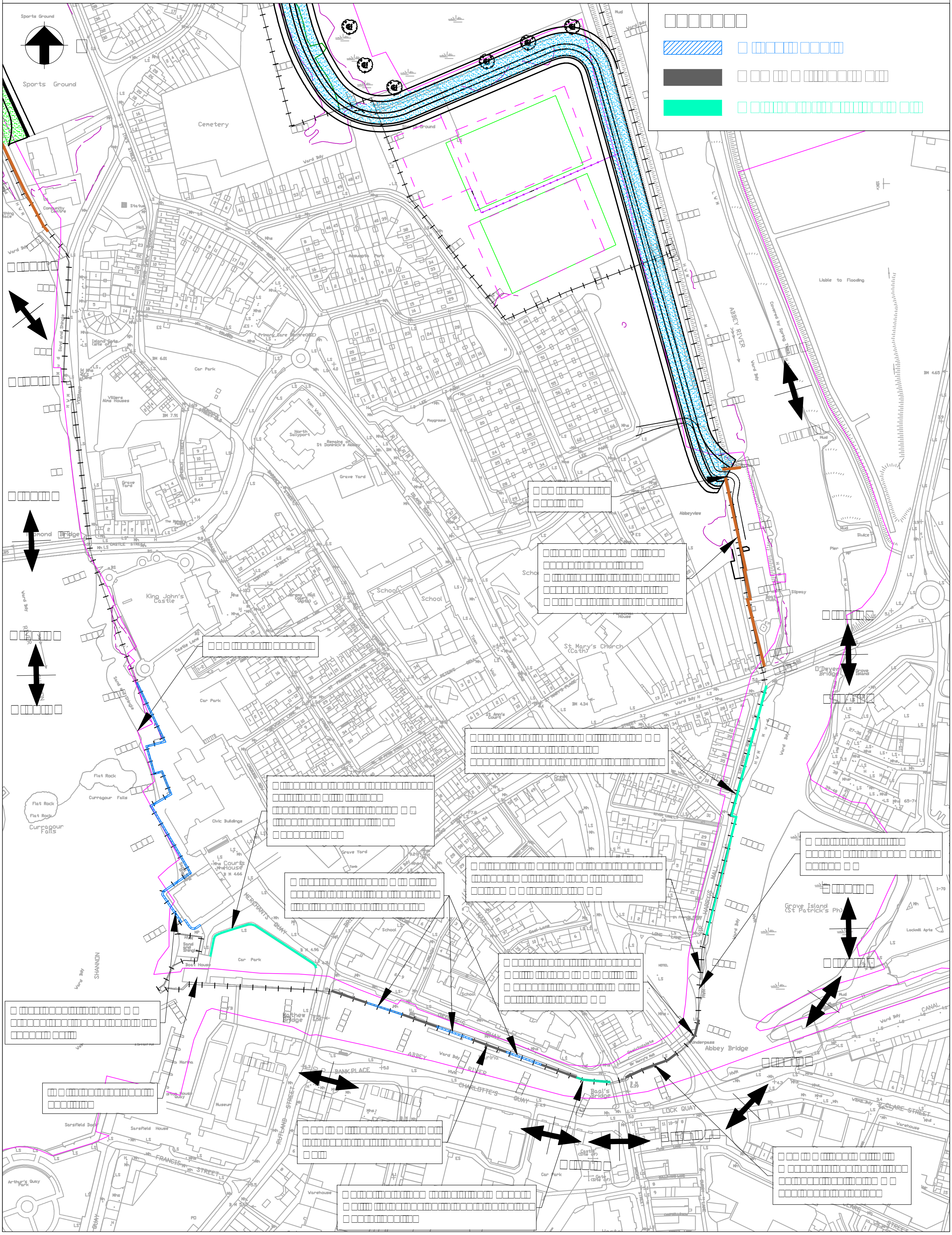
KING'S ISLAND - SOUTH



B Development of Design Flood Level

B.1 Overview

The purpose of this appendix is to summarise the tidal information available to JBA and the calculation process by which the design defence level was derived. This summary will also discuss the approach to climate change adopted on this project, and how best to cater for it in the final design.

B.2 Data available

This section will summarise the tidal information available for analysis and the means by which the design water levels were calculated. The data available is at three locations within the Shannon Estuary (see Figure B-1):

- ICPSS-S26 data point
- Limerick Dock gauge
- Baal's Bridge gauge

Figure B-1: Gauge and data point locations

B.2.1 ICPSS (Irish Coastal Protection Strategy Study) – Shannon Estuary

The Irish Coastal Protection Strategy Study was a national study that was commissioned in 2003 with the objective of providing information on coastal flooding and coastal erosion. In the absence of long term historic levels, extreme sea levels for the Irish Coast were generated using computer modelling. To simulate the development of storm surges around the main coastline a storm surge model, referred to as the Irish Seas Tidal Surge Model (ISTSM) was produced. This model was tested and calibrated with tidal water levels along the coast. This model was used to conduct a detailed analysis for the Shannon Estuary, the resolution of which was 45 metres. The estuary bathymetry was derived from a variety of sources including GSI and Marine Institute Survey and Admiralty charts. The predicted extreme water levels, as produced by the ICPSS, are shown in B-1.

Table B-1: ICPSS data for Point S26

Characteristic		Value
Longitude		-8.745
Latitude		52.677
MSL to OD Malin Head conversion		-0.26m
Seich/Set up Allowance		0.15m
AEP of tidal event (m Malin Head)	50%	3.41
	20%	3.65
	10%	3.83
	2%	4.00
	1%	4.24
	0.50%	4.59
	0.10%	5.00

B.2.2 Shannon CFRAM

The current primary source of data with which to identify coastal flood risk is the Shannon Catchment Flood Risk Assessment and Management Study (Shannon CFRAM Study). This study involved detailed hydraulic modelling of rivers and their tributaries along with the coastal flooding. Limerick is within Unit of Management 24 of the Shannon CFRAM.

Design flood levels and flood extent maps for the 10%, 0.5% and 0.1% AEP events, accounting independently for tidal and fluvial sources are publicly available through the CFRAM Study website. The downstream tidal limits for the CFRAM were based on levels contained in the ICPSS. This level (discussed further in the following section) was propagated up the estuary through the CFRAM hydraulic model. Resulting levels for the 0.5% AEP event at various cross sections are provided in Table B-2. It can be seen from the table that there is a small variation in tidal event levels from the upstream to downstream limits of King's Island on both the Shannon and Abbey Rivers.

Table B-2: Shannon CFRAM tidal event levels

CFRAM Cross Section	Description of location	0.5% AEP event height (mOD)
05LSH02004	Upstream of railway crossing and King's Island	4.78
01ABB01831	Upstream end of Abbey River	4.77
05LSH01258	Upstream of Thomond Weir	4.76
01ABB00639	Downstream of O'Dwyers Bridge	4.75
05LSH00276	Upstream of Merchant's Quay on the River Shannon	4.73
05LSH02422	Immediately downstream of Sarsfield Bridge	4.72

B.2.3 Limerick Dock

The Limerick Dock tide gauge has been in operation since 1877. Data prior to 2002 was recorded using 'visual inspections' of a tide board, therefore, a degree of caution must be noted when using this data. Prior to 1980, all data was recorded in feet and inches and was converted to metres. As well as this, there are large gaps in the gauge record due to paper copies going missing and malfunctioning of the gauge. The complete AMAX dataset is shown in Table B-3.

Table B-3: Limerick dock gauge data

Hydrometric Year	Date	Water Level (Malin mOD)	Comment
2014	02/01/2014	4.51	This may not have been the absolute peak as gauge failed shortly after this level was recorded, thus missing the 'actual' peak. The 3rd February event was probably larger than this event. However, there is no

Hydrometric Year	Date	Water Level (Malin mOD)	Comment
			gauge information available during the peak of this event.
2013	05/12/2013	3.56	Adjustment data (sudden spike, ~1m in 10 min)
2012	14/12/2012	3.78	
2011	-	-	No Data
2010	01/03/2010	3.62	Adjustment data (malfunction of the gauge, sudden spike)
2009	06/18/2009	3.52	
2008	11/03/2008	3.72	
2007	18/01/2007	3.72	
2006	08/10/2006	3.82	
2005	24/05/2005	3.02	Not included
2004	19/03/2004	3.62	
2003	25/11/2003	3.42	
2002	28/04/2002	4.02	
2001	-	-	No Data
2000	25/11/2000	3.62	
1999	25/12/1999	3.72	
1998	30/03/1998	3.72	
1997	10/02/1997	5.67	Not included
1996	22/01/1996	3.72	
1995	17/01/1995	3.82	
1994	27/02/1994	3.82	
1993	05/04/1993	3.92	
1992	19/03/1992	3.42	
1991	05/01/1991	3.92	
1990	27/02/1990	3.82	
1989	21/02/1989	4.12	
1988	28/08/1988	3.72	
1987	07/10/1987	3.67	
1986	27/03/1986	3.52	
1985	07/04/1985	3.67	
1984	23/11/1984	3.87	
1983	31/01/1983	3.85	
1982	17/10/1982	3.82	
1981	14/12/1981	4.22	
1980	18/02/1980	3.62	
1979	06/10/1979	3.6464	
1978	10/01/1978	3.4686	
1977	11/11/1977	4.002	
1976	20/01/1976	3.4686	
1975	30/01/1975	3.7988	
1974	11/01/1974	3.8496	
1973	28/09/1973	3.3924	
1972	15/02/1972	3.2908	

Hydrometric Year	Date	Water Level (Malin mOD)	Comment
1971	30/01/1971	3.367	
1970	04/09/1970	3.6972	
1969	-	-	No Data
1968	-	-	No Data
1967	-	-	No Data
1966	-	-	No Data
1965	21/12/1965	4.3576	Not included
1964	24/09/1964	3.3162	
1963	02/11/1963	3.2654	
1962	08/03/1962	3.494	
1961	22/10/1961	3.8496	
1960	13/04/1960	3.24	
1959	01/02/1959	3.5448	
1958	06/01/1958	3.24	
1957	04/02/1957	3.6972	
1956	05/09/1956	3.113	
1955	28/12/1955	3.1638	
1954	27/11/1954	3.4686	
1953	23/09/1953	3.1384	
1952	20/12/1952	3.3924	
1951	27/12/1951	3.6972	
1950	13/09/1950	3.3162	
1949	21/11/1949	3.6972	
1948-1903	-	-	No Data
1902	15/12/1902	3.2908	
1901	28/10/1901	3.0114	
1900	20/12/1900	3.0876	
1899	12/1/1899	3.4686	
1898	30/08/1898	3.1638	
1897	29/08/1897	3.0368	
1896	8/10/1896	3.4432	
1895	15/11/1895	3.3416	
1894	22/12/1894	3.0876	
1893	16/8/1893	3.6972	
1892	29/4/1892	3.1384	
1891	18/10/1891	3.3924	
1890	25/1/1890	3.3162	
1889	7/10/1889	3.3924	
1888	03/12/1888	3.1384	
1887	16/12/1887	3.24	
1886	8/12/1886	3.6972	
1885	31/1/1885	3.3416	
1884	3/12/1884	3.3162	
1883	31/1/1883	3.4686	

B.2.4 Baal's Bridge gauge

The Baal's Bridge gauge is located on the Abbey River at the southeast end of Kings Island. The gauge has been actively recording water levels since 1957. Some years are omitted due to works been carried out on the river. In 2001 the gauge was temporarily removed; this year is not included in the data. In total, there is 55 years available for analysis, see Table B-4.

Table B-4: Baal's Bridge gauge data

Hydrometric Year	Date	Water Level (Malin mAOD)	Comment
2013	01/02/2014	4.513	
2012	30/01/2013	3.763	
2011	13/12/2011	3.633	
2010	20/02/2011	3.603	
2009	06/12/2009	3.663	
2008	20/08/2009	3.502	
2007	11/03/2008	3.783	
2006	08/10/2006	3.713	
2005	30/03/2006	3.761	
2004	08/01/2005	3.677	
2003	19/03/2004	3.527	
2002	01/12/2002	3.86	
2001	-	-	
2000	12/12/2000	3.35	
1999	25/12/1999	3.41	
1998	02/01/1999	3.71	
1997	07/09/1998	3.69	
1996	10/02/1997	3.23	
1995	28/09/1996	3.607	
1994	17/01/1995	3.927	
1993	01/12/1994	3.89	
1992	26/10/1992	3.967	
1991	17/12/1991	3.747	
1990	05/01/1991	4.067	
1989	27/02/1990	3.947	
1988	03/09/1989	3.657	
1987	02/09/1988	3.847	
1986	01/01/1987	3.827	
1985	01/11/1986	3.447	
1984	23/11/1984	3.377	
1983	21/01/1984	3.64	
1982	31/01/1983	4.03	
1981	14/12/1981	3.75	
1980	03/08/1981	3.667	
1979	10/06/1979	3.647	
1978	27/03/1979	3.447	
1977	11/11/1977	3.9	
1976	21/01/1977	3.677	
1975	01/01/1976	3.947	
1974	30/01/1975	3.917	
1973	01/11/1974	3.837	

Hydrometric Year	Date	Water Level (Malin mAOD)	Comment
1972	20/01/1973	3.567	
1971	02/02/1972	3.497	
1970	-	-	
1969	02/07/1970	3.657	
1968	22/12/1968	3.887	
1967	11/01/1967	3.717	
1966	12/01/1966	3.657	
1965	12/09/1965	3.797	
1964	17/01/1965	4.047	
1963	18/11/1963	3.777	
1962	09/12/1962	3.42	
1961	22/10/1961	4.32	
1960	02/11/1960	3.73	
1959	29/12/1959	3.85	
1958	12/12/1958	3.59	
1957	08/01/1958	3.3	

B.3 Analysis and methodology

B.3.5 Purpose of the assessment

As the ICPSS is the most recent mathematically derived tidal estimate, the analysis undertaken had the aim of validating the levels contained in that study, and if validation could not be undertaken, then generation of a new dataset would follow.

B.3.6 Audit of information obtained

Before any tidal analysis was undertaken, the information available was audited to ensure any anomalies or discrepancies were either noted or removed. At Limerick Dock, three years of data were deemed unusable: 1965, 1997 and 2005. 2014, despite being a noticeable outlier, was retained as this event was known to be quite exceptional in magnitude. A level of 4.51 mOD has been estimated for the January 2014 event at Limerick based on a visual inspection of the recorded tidal graph. As noticed previously, the actual level may have been slightly higher or lower as the gauge experienced a malfunction during the peak of the event.

B.3.7 Application of historical sea level rise

To accurately predict present-day extreme still water sea levels (ESWSLs), the AMAX data was de-trended to account for any historical sea-level rise that has occurred. The de-trending is based on evidence of sea level rise seen in the Limerick Dock AMAX data since 1875. When the AMAX is plotted and a linear trend line applied to the data, it is shown that on average the sea level has risen by 4mm per year since 1875. This excluded outliers of 1965, 1997 and 2005 which were not notable events but recorded extreme levels. However, as sea level rise is not necessarily a continuous process and can be accelerated due to anthropogenic influence, it was decided that the tidal record be split into two distinct segments: pre- and post-WW2. The post-WW2 record consequently, when plotted, showed a trend of 7mm/yr. The trend applied to pre-WW2 data was the difference in means i.e. 7 – 4 = 3mm/yr. The tidal record was then de-trended for the appropriate rate.

Figure B-2 shows the de-trended levels for Limerick Dock. If the sea level rise had been a uniform, linear trend over the entire record, then the resultant line of best fit for the de-trended dataset would be flat.

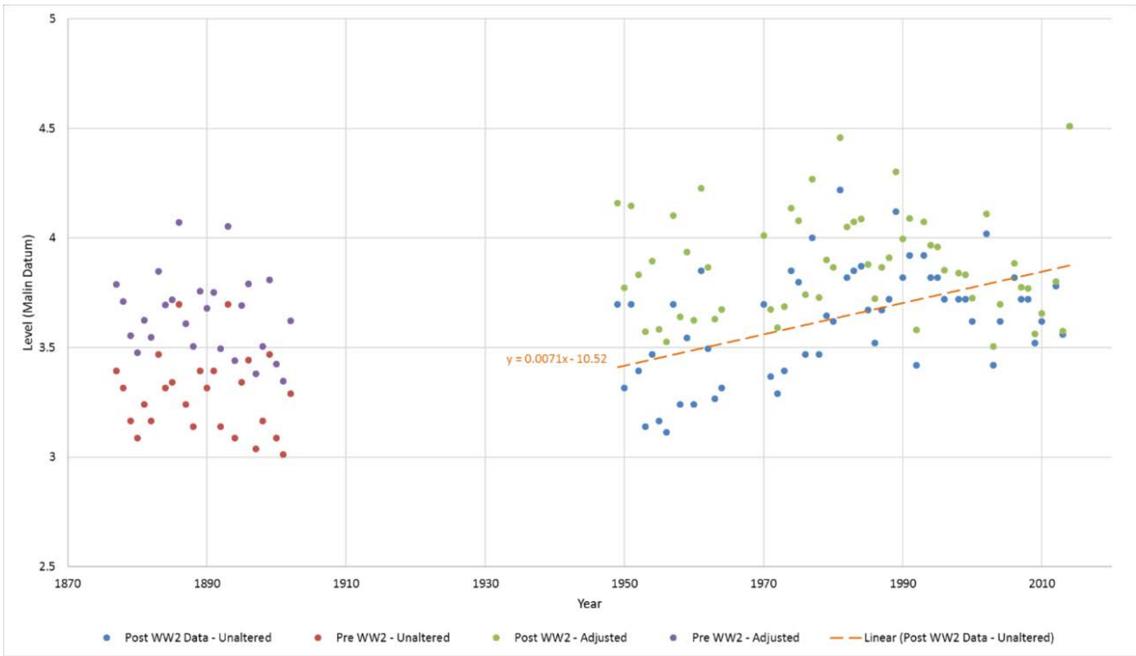


Figure B-2: Limerick Dock AMAX 1949-2014 de-trended

B.3.8 Extreme Value Analysis – WINFAP FEH

Extreme value analysis (EVA) was undertaken by fitting theoretical probability distributions to the AMAX series derived from the gauge data. The WINFAP-FEH software package was used for this analysis.

Candidate probability distributions were fitted to the data and are listed below:

- Logistic
- Generalised Logistic (GL)
- Gumbel (GEV Type 1)
- Generalised Extreme Values (GEV 3 parameter)
- Log Normal 2 parameter (LN2)
- Log Normal 3 parameter (LN3)

The appropriate distribution for the AMAX series is chosen on a ‘best-fit’ basis and the accuracy of your selection is directly related to the length of the data series at your disposal.

B.4 Results

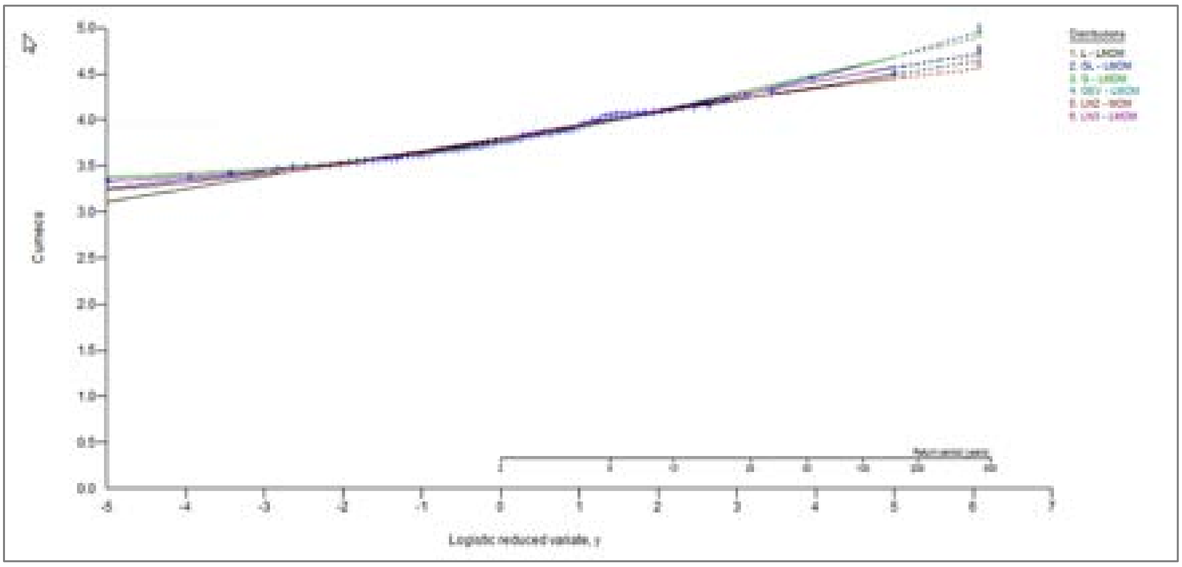
B.4.9 Limerick Dock

The results of the Limerick analyses are summarised in Table B-5. It is evident from the table that there is a difference in water levels for each return period, depending upon the distribution that is chosen. In order to choose the most appropriate distribution, the respective confidence limits (C.I) have been assessed, as well as the data-fit in the tide frequency curve. From this analysis, the 2-parameter Log Normal (LN2) distribution has been deemed most appropriate for application to this dataset as shown in Figure B-3. It better traces the path of data, in comparison to the other distributions, as well as providing the tightest confidence limits (not shown). Using the de-trended calculations, the design 0.5% AEP tide level becomes 4.48 mOD. This is in reasonable agreement with the ICPSS, which states a corresponding level of 4.59 mOD. Based on this analysis, the return period for the January 2014 event (level of 4.51mOD) can be estimated as approximately the 0.5% AEP event (1 in 200 year).

Table B-5: Summary of Calculated Water Level Data for Limerick Dock and Comparison with ICPSS (De-trended)

AEP	ICPSS Data	WINFAP de-trended					
	S26	L	GL	G	GEV	LN2	LN3
50%		3.81	3.78	3.76	3.78	3.80	3.78
20%		3.99	3.98	3.99	4.00	4.01	4.00
10%	3.82	4.11	4.12	4.14	4.14	4.12	4.13
4%		4.24	4.30	4.33	4.30	4.25	4.29
2%		4.34	4.44	4.47	4.41	4.33	4.41
1%		4.43	4.59	4.61	4.51	4.41	4.51
0.5%	4.59	4.54	4.76	4.74	4.60	4.48	4.62
0.2%		4.66	4.99	4.93	4.72	4.57	4.76

Figure B-3: Limerick Dock Tide Level Growth Curve – De-trended



B.4.10 Baal's Bridge

The results of the Baal's Bridge gauge analysis are summarised in Table B-6 and Table B-7. From this analysis, the Logistic (L) distribution has been deemed most appropriate for application to this dataset as shown in Figure B-4. It better traces the path of data, in comparison to the other distributions, as well as providing the tightest confidence limits. This finding is common to both the trended and de-trended analyses. Using the de-trended calculations, the design 0.5% AEP tide level becomes 4.64 mOD. This is in good agreement with the ICPSS, which states a corresponding level of 4.59 mOD. Based on this analysis, the return period for the January 2014 event (level of 4.51mOD) can be estimated as approximately the 1% AEP event (1 in 100 year).

Table B-6: Summary of Calculated Water Level Data for Baal's Bridge and Comparison with ICPSS (Trended)

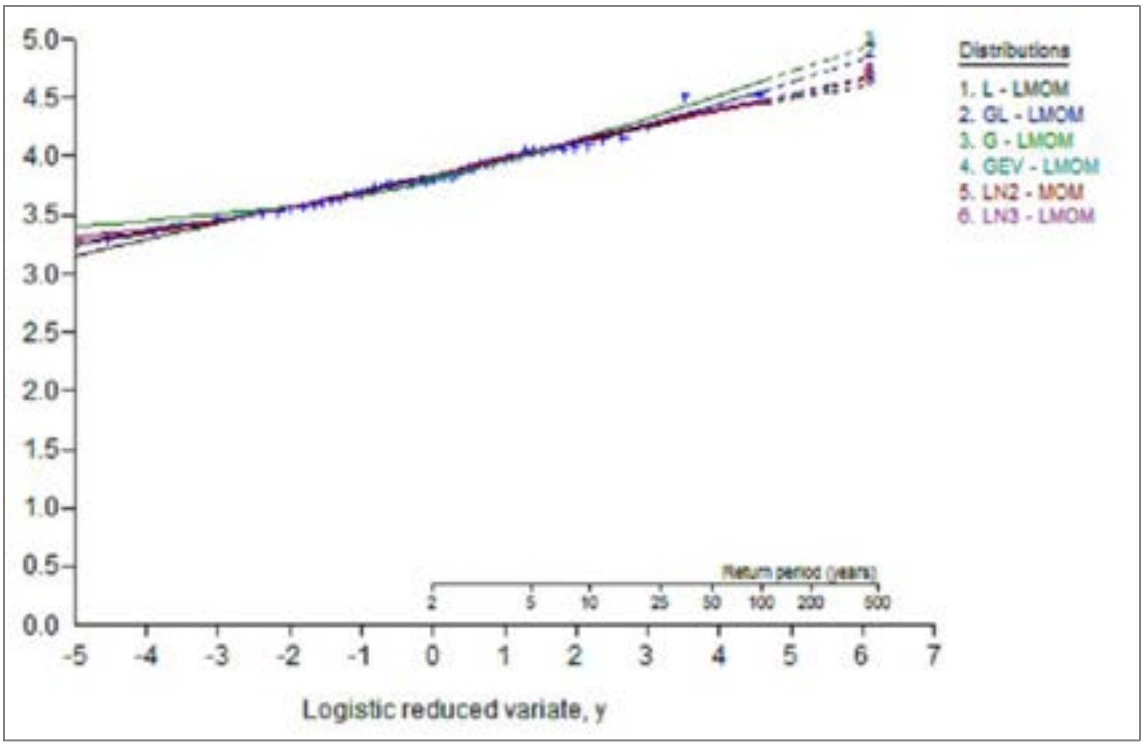
AEP	ICPSS Data	WINFAP trended					
	S26	L	GL	G	GEV	LN2	LN3
50%		3.725	3.713	3.686	3.711	3.718	3.712
20%		3.906	3.900	3.899	3.918	3.922	3.915
10%	3.82	4.012	4.017	4.040	4.034	4.034	4.030
4%		4.139	4.165	4.218	4.159	4.156	4.159

AEP	ICPSS Data	WINFAP trended					
	S26	L	GL	G	GEV	LN2	LN3
2%		4.232	4.279	4.350	4.239	4.237	4.246
1%		4.324	4.396	4.482	4.309	4.311	4.327
0.5%	4.59	4.415	4.516	4.612	4.371	4.38	4.404
0.2%		4.535	4.683	4.785	4.441	4.465	4.500
0.1%	5.00	3.725	3.713	3.686	3.711	3.718	3.712

Table B-7: Summary of Calculated Water Level Data for Baal's Bridge and Comparison with ICPSS (De-trended)

AEP	ICPSS Data	WINFAP de-trended					
	S26	L	GL	G	GEV	LN2	LN3
50%		3.840	3.826	3.798	3.823	3.832	3.824
20%		4.031	4.024	4.023	4.043	4.045	4.040
10%	3.82	4.143	4.148	4.172	4.167	4.161	4.162
4%		4.278	4.307	4.361	4.302	4.288	4.301
2%		4.376	4.430	4.500	4.389	4.372	4.395
1%		4.473	4.556	4.639	4.465	4.449	4.483
0.5%	4.59	4.569	4.687	4.777	4.532	4.521	4.566
0.2%		4.695	4.868	4.960	4.610	4.61	4.671
0.1%	5.00	3.840	3.826	3.798	3.823	3.832	3.824

Figure B-4: Baals Bridge Tide Level Growth Curve – De-trended



B.5 Conclusion of design downstream boundary

It has been concluded that the ICPSS point correlates reasonably well with the data analysis at both the Limerick Dock and Baals Bridge gauges, but provides a more robust estimate of predictive levels as it has been calculated using a numerical model that incorporates a long series of extreme events to derive the tide level estimates. Its use in the CFRAM is therefore justified, and It can therefore be used as a suitable downstream boundary for the design of the King's Island flood relief scheme.

B.6 Climate change allowances

The effects of climate change are likely to result in increased sea level and subsequently increased flood levels and greater frequency of flooding. Climate change could increase the mean sea level by 0.5m in the OPW's Medium Range Future Scenario (MRFS) and 1m in the High End Future Scenario (HEFS). In the same scenarios, fluvial flows are projected to increase by 20% and 30% respectively. In planning to manage this increase, the following options are available:

- Climate change is not factored into the design and is left for future generations to manage.
- Build the scheme to be adaptable to climate change (e.g. walls have foundations which are strong enough to allow the walls to be raised by 0.5m in the future);
- Build the scheme to include a climate change allowance (e.g., walls are 0.5m higher than the current design flood level);
- An alternative approach to managing future risk, which may not be cost beneficial in the current scenario, is adopted, such as a tidal barrier;

Each option has been assessed for its adaptability to climate change, including consideration of the impact of greater wall or embankment heights, and this has been factored into the MCA. In general, the aim is to design the scheme to be adaptable to climate change and where this is likely to be problematic in the future this has been highlighted.

B.7 Post Scheme Impacts

B.7.1 Approach

Investigation into the post-scheme impacts of defending King's Island was carried out. This was achieved by running a hydraulic model of the Shannon and Abbey Rivers which included 'glass wall' defences around the Island. The glass wall defences mean that no matter how high the waters reach in channel, they will not spill into the island. This provides a check on the design height of the defences, and also shows the projected water level as a result of the scheme being constructed.

Although this was investigated as a matter of course as part of the options assessment, it was also a question which was raised by a couple of attendees at the PID; particularly in relation to water levels in Corbally and Shannonbanks.

B.7.2 Results

The modelling results show no net increase in water level in the post-scheme scenario. Small variations in modelled water level are noted, but these are associated with the numerical solution rather than a sustained difference in water level. There are a couple of reasons for this. Firstly, as tide levels provide the dominant source of flood risk flood levels are dictated by the tide height rather than the volume of floodplain storage. Secondly, in the current (with sandbags in place) scenario, defence failure would be required before flood damages are experienced; overtopping is not predicted to occur until the higher level events. This means the change in situation between the pre- and post-scheme design is minimal in terms of defence elevation, but clearly provides a significantly improved standard of protection when integrity of the defence is considered.

C Tidal Barrier Feasibility

The purpose of this analysis is to test the feasibility of a tidal barrier in the River Shannon downstream of Limerick City as an alternative or in combination with flood defences around the Island. This assessment is solely based on technical grounds and does not take into account other criteria such as cost, environmental, social etc.

C.1 Potential location

The tidal barrier would have to be located as far downstream of Limerick City as possible to provide maximum storage for fluvial contributions on the upstream side of the barrier when in operation i.e. when the barrier is closed there must be enough spare volume in the river channel to comfortably accommodate flows coming downstream.

Upon further examination, it was found that the optimum location for the tidal barrier would be close to Coonagh West, just downstream of the tunnel (see Figure C-1). If the barrier was located further downstream, the channel width across which the barrier would have to span would be significant, increasing costs. With the barrier moved further downstream, contributions from other watercourses (e.g. River Maigue, River Owenagarney, River Fergus etc.) would have to be factored into the storage calculations upstream of the barrier.

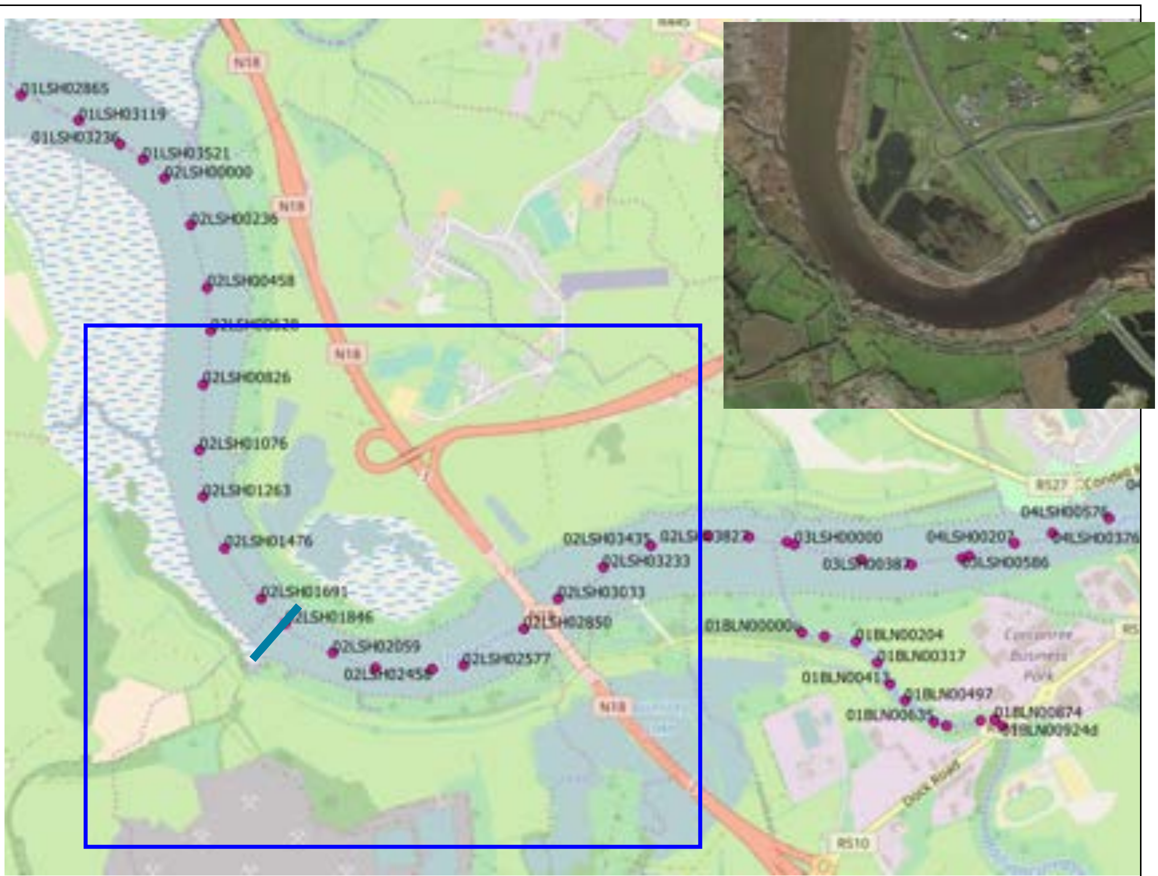


Figure C-1: Proposed location of tidal barrier

It has been assumed that the width of the tidal barrier would extend across the River Shannon only, from bank-top to bank-top, and not its floodplain. Therefore, the total channel width at the proposed location (02LSH01846 in the hydraulic model) is 435m. The actual 'clear-width' through which water can flow (i.e. 435m – allowance for barrier structure) is set at 90% of the total channel width.

C.2 Testing of Tidal Barrier Options

C.2.1 Current Scenario

A number of barrier configurations were tested based on initial closing levels, closing speed and maximum closing levels, all based on current tide curves. An example of a stage-flow curve at the tidal barrier for one of these configurations is shown below in Figure C-2.

In summary, each configuration tested has shown that there is insufficient storage behind the barrier to yield a workable barrier solution. The initial closing trigger level has a significant effect on the water level generated upstream. With a higher the trigger level, the lesser the volume of storage required behind the barrier when closed. On the other hand, if the initial closing level is set lower, the longer the barrier will be fully closed and the larger the volume of fluvial flows that have to be stored as a consequence. Also, the barrier has to open in a controlled manner when tide levels are receding, and this will allow stored fluvial water to escape. The flow through the gate is driven by the head in the inner estuary, and hence the flow out of the gate quickly dissipates, as seen in Figure C-2.

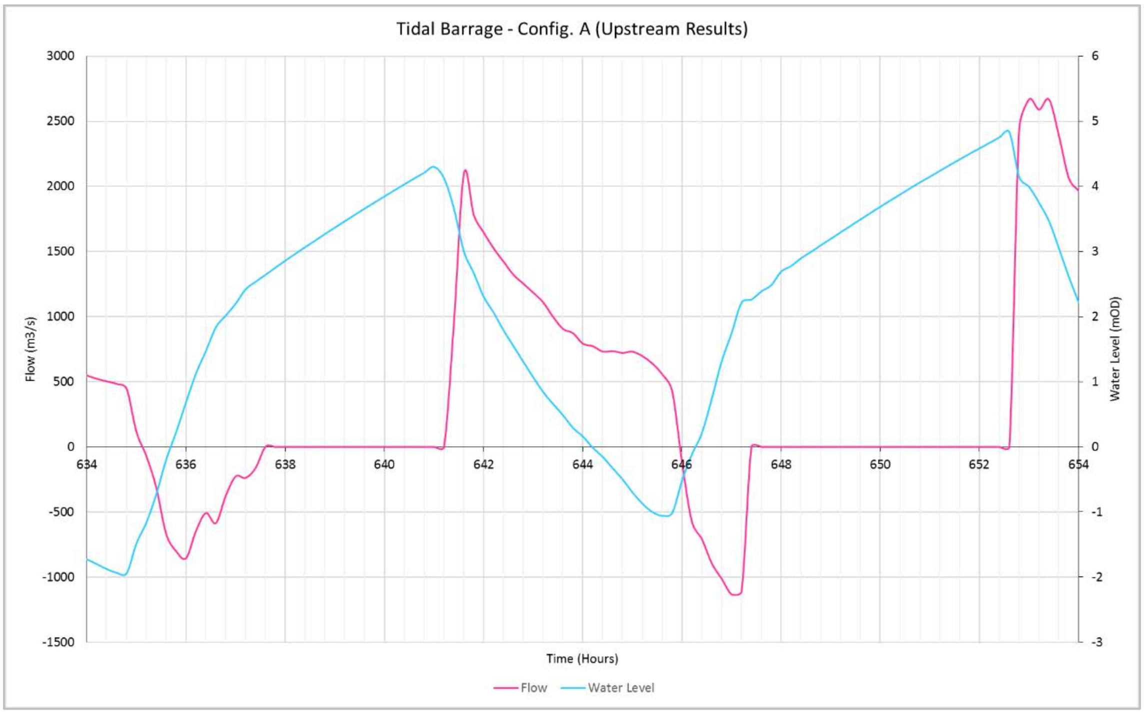


Figure C-2: Tidal barrier test output at 02LSH01846 (barrier XS)

Figure C-3 shows the output from the downstream side of the tidal barrier when in operation for a particular operation. All configurations tested (involving different start levels) show similar results. Water levels are predicted to increase slightly adjacent to the barrier.

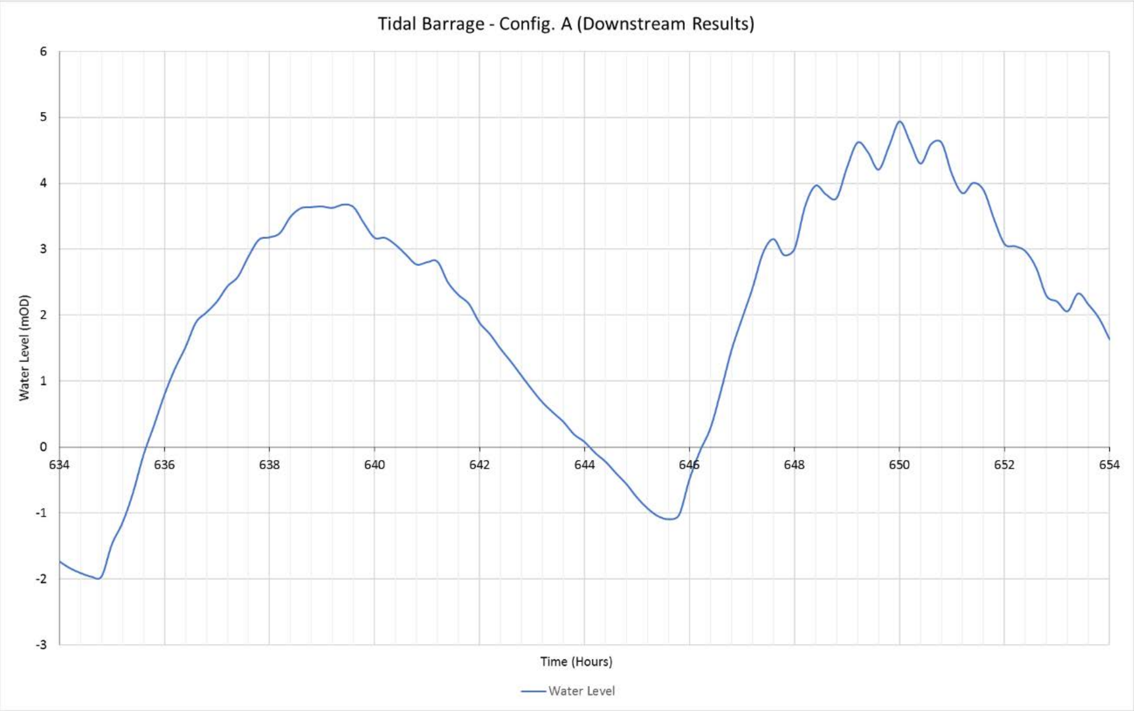


Figure C-3: Tidal barrier test output immediately downstream of barrier

C.2.2 Climate Change Scenario

Climate change scenario modelling was carried out in a similar fashion as the current scenario. The downstream boundary peak water level was increased by 500mm as per OPW guidance for the Mid-Range Future Scenario (MRFS). As well as this, upstream flows were increased by 20% and input into the model. Similar operating rules as the existing scenario were applied to the barrier for testing. Figure C-4 and Figure C-5 show that the barrier does not make the difference on MRFS design levels; indeed in the configurations tested, the tidal barrier actually increases climate change levels around King's Island by approximately 100-500mm. Again, this shows that there is not enough storage available behind the barrier to contain the design volumes to a reasonable level.

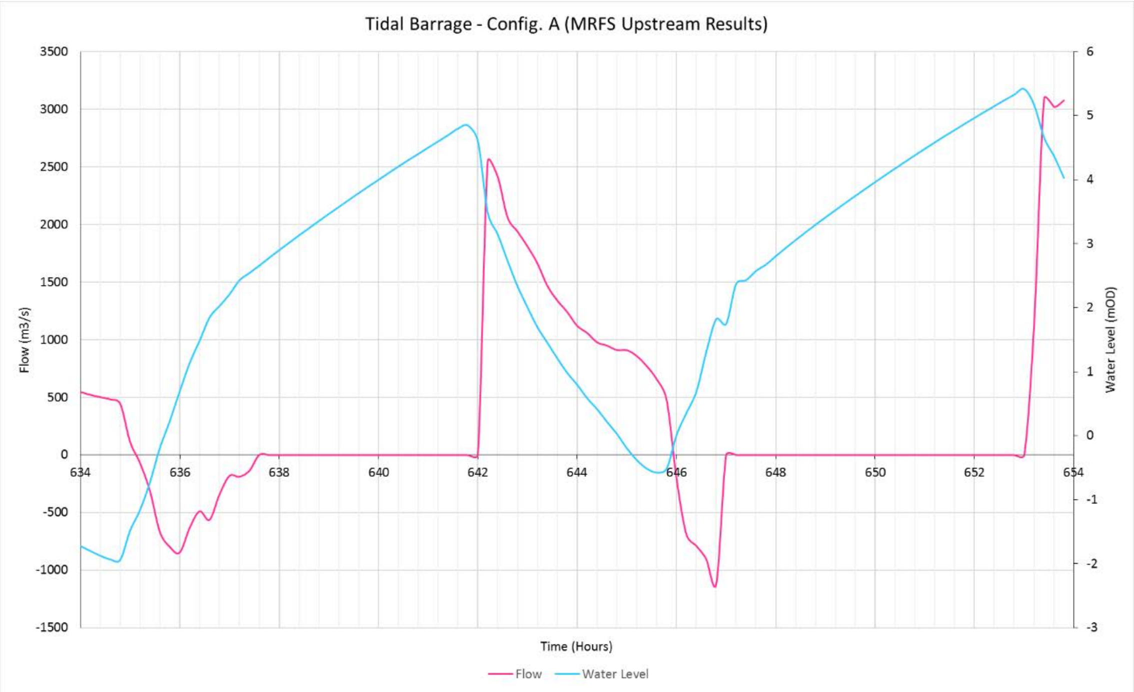


Figure C-4 MRFS tidal barrier test output at 02LSH01846 (barrier XS)

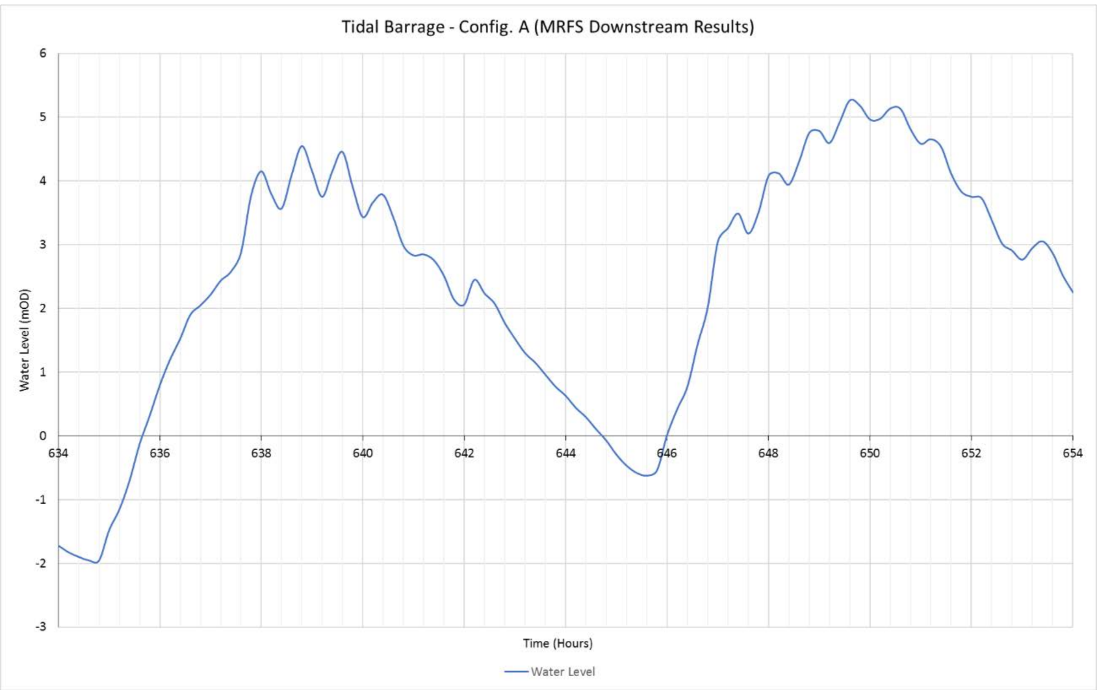


Figure C-5: MRFS tidal barrier test output at XS immediately downstream of barrier

C.3 Conclusion

Including a tidal barrier in the inner estuary does not appear to offer an alternative defence against the peak 0.5% AEP tide level. The maximum water level upstream in Limerick City remains very similar if not higher for every configuration that was tested, as shown in Figure C-6. This is due to insufficient capacity upstream of the tidal barrier and significant fluvial flows during the period of barrier closure. Significant defences would still be required at King's Island and the scale of works required as part of a tidal barrier could not be justified. Additional floodplain storage upstream of Limerick or a conjunctive use scheme with ESB would be the only way to realise any water level reductions in flood defence level with a tidal barrier.

Locating the barrier further down the estuary, for example in the vicinity of Foynes or Tarbet, may provide a reduction in flood risk as there is an increased storage volume within the estuary. However, this would also be managing flows from the Fergus and Maigue catchments and would form a substantially increased scope of scheme.

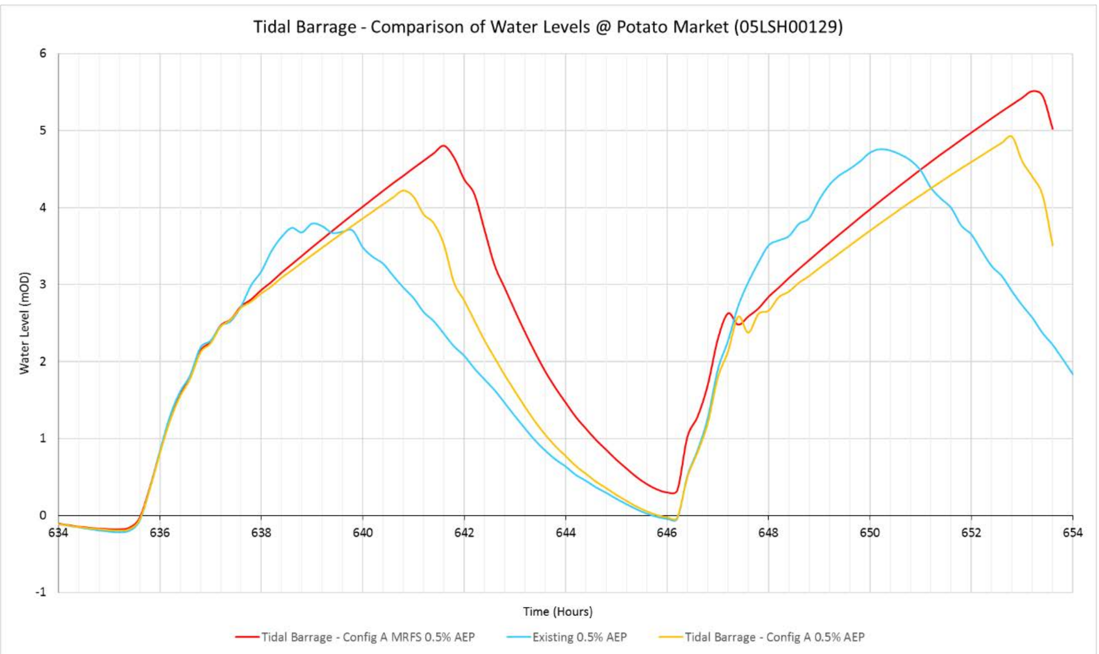


Figure C-6: Comparison of water levels for pre- and post-tidal barrier at King's Island

D Multi-Criteria Assessment

D.1.1 Introduction

The effectiveness of each of the viable options can be measured in terms of how it achieves a set of flood risk management objectives. This section describes the detailed multi-criteria analysis (MCA) of the shortlisted options which was carried out to evaluate the performance of each option in terms of predefined objectives. It follows the OPW Guidance Note adopted for the Flood Risk Management Plans, which can be applied to a detailed scheme appraisal.

As part of this process, each objective was given a global and local weighting. Each option was then scored relative to the present-day situation (baseline), based on how well they met the objectives. The output from this stage was a total weighted score for each option. The option with the highest score is deemed to be most desirable.

D.1.2 Flood Risk Management Objectives and Weightings

The flood risk management objectives were categorised as follows:

- Technical
- Economic
- Social
- Environmental

The FRM objectives reflect what the overall flood risk management programme is seeking to achieve, expanding on the requirements of the National Flood Policy Review and the EU 'Floods' Directive.

At a local level, and for the purposes of the MCA, the objectives set out an aim that each flood risk management option should be seeking to achieve. The degree to which an option achieves the objective for the cost is an indication of the 'success' of the option, and equally, the more an option achieves across all of the objectives, then the greater the preference that will be given to that option relative to others.

D.1.3 Global weightings

Global Weightings are assigned to each objective to give it more or less weight in the overall assessment of the suitability or value of the option. The Global Weightings are fixed nationally to ensure a consistent approach and basis for prioritisation, and are intended to represent the 'societal value' for the objective relative to the others, i.e., with those of most weight representing the most important objectives.

D.1.4 Local weightings

The Local Weightings are assigned to each objective for each location under consideration (i.e., each spatial scale of assessment (SSA)), and are intended to represent the local importance of that objective within the local context. They are very important within the framework as they provide scale to the process, allowing locally important objectives to have a greater weight in selection of the option. Similarly, the importance of an issue / objective in one location relative to another can also be provided for through the Local Weightings.

D.1.5 MCA scoring

Each sub objective has a basic requirement and an aspirational target associated with it. The Basic Requirement represents a neutral status or 'no change', whereby if an option has no impact on the matter the objective relates to, or meets what might be termed for some objectives as minimum requirements for acceptability, then that option will have met the Basic Requirement. If an option performs worse than the Basic Requirement, i.e., has a negative impact (a dis-benefit) or does not meet the minimum requirements for acceptability, it will score a negative-value score for that objective.

The aim is defined as an Aspirational Target, whereby an option would be deemed as perfect with respect to the given objective if it were to meet the Aspirational Target. Typically, this will represent complete removal of a risk, or the full achievement of another benefit. Once all the objectives have been analysed the MCA score for each criterion can be calculated by multiplying the score for each sub objective by the global and local weighting and then by summing the weighted scores for all the sub objectives under that criteria.

D.1.6 MCA outcomes

A suite of different scores present the findings of the MCA. These are compiled of different elements of the MCA to demonstrate how each option delivers against the objectives. The scores are as follows:

- Technical Criteria Score – this is produced for each of the technical, economic, social and environmental objectives and is the sum of their respective sub-objectives
- MCA Benefit Score – this score represents the net benefits of the scheme and is the sum of 'Technical Criteria Scores' from the economic, social and environmental objectives.
- Option Selection MCA Score - this is the sum of all the 'Technical Criteria Scores'

The results of the MCA process were used to guide the decision-making process, subject to application of professional judgement and public consultation with the steering and progress groups. Greatest weight was given to the MCA Benefit score as this provides a method of the overall benefits per invested euro. Local consultation was also taken into account. The reasoning for the preferred option selection is recorded and reported in the relevant individual POR reports. It should be recognised that whilst a numeric scheme is used by the OPW in the MCA process, the selection of scores and overall recommendation of preferred option is still subjective and based on experience.

E Scheme Cost Assessment

E.1 Methodology

When building up cost estimates for a scheme of this scale, it is important that the expected whole life costs of the works and its management are developed and not just the scheme capital costs. The following are the elements that were considered when developing cost estimates for the project:

- Construction costs (including environmental mitigation measures), refer to section E.3 for budget construction cost build up for all sub-areas within both Flood Cell A and B making up the scheme
- Design and site supervision costs
- Site investigation and survey costs
- Land purchase and compensation costs
- Maintenance costs
- Allowance for optimism bias
- Allowance for art

The following costs were excluded:

- Value Added Tax
- Cost of OPW/Limerick City & County Council staff time on the project

E.2 Construction Costing Method

Base costs for construction elements of the scheme were obtained from the following sources:-

- Estimates and tendered rates from similar civil engineering contracts and
- Published cost databases, including the NRA unit cost database and the draft OPW unit cost database.

The following assumptions have been made when compiling the construction cost estimates:

- Normal working week for construction personnel and plant
- No exceptional adverse weather.
- Construction contracts with values of between €15m and €20m and durations of 18 to 24 months.
- Significant costs of traffic management within space restrictions in busy city environment.
- Allowance of 10% for known unmeasured items such as local drainage, services etc.

E.2.1 Environmental/Archaeological Monitoring, Mitigation Works and Improvement Works

Environmental and archaeological monitoring will be required during the construction of the works. It is also likely that some environmental mitigation and improvement works will be necessary. A provisional allowance of 10% of the construction cost estimate has been included in the cost estimate.

E.2.2 Specialist Survey Costs incurred to end of Stage 1

Specialist surveys, including site investigation, topographic survey, archaeological survey and various environmental surveys and monitoring assessments have been carried out for the scheme. The total cost of investigations and surveys undertaken to the end of Stage 1 is €488,275 and has been included in the cost estimate. Future environmental monitoring, including hydro-geomorphological and ecological assessment associated with the outer alignment, has been captured under 'environmental / archaeological monitoring' (above).

E.2.3 Design and Supervision Costs

An allowance of 13% of the construction cost has been made for design and site supervision costs, reflecting the current best estimate of the likely duration of the construction contracts and required size of site supervision teams.

E.2.4 Land Purchase and Compensation

€200,000 has been added to the construction cost of the scheme to allow for:

- Land purchases and compensation.
- Planning, highway and other third party costs.
- Administration and legal costs associated with land exchanges, statutory approvals, planning applications, service diversions, highway adoptions etc.
- Loss of revenue to adjacent or affected buildings.

E.2.5 Maintenance Works Costs

The total maintenance cost over the 50-year life span of the scheme is estimated as 1% of the construction cost in Net Present Value terms.

E.2.6 Project Contingency/Optimism Bias

There can be a tendency for budget cost estimates for flood defence schemes to be overly optimistic. In a project of this nature where access for labour, plant and materials will be difficult, including a robust contingency in the cost estimate is essential.

A contingency/optimism bias of 20% of the construction cost has been included in the whole project cost.

E.2.7 Allowance for Art

The “per cent for art” scheme is compulsory for all major public works contracts. For this size of project, the required allowance for art is 1% of the capital cost up to a maximum of €64,000. Therefore, the maximum allowance of €64,000 has been included in the cost estimate.

E.3 Baseline Construction Cost Build Up for Refined Scheme

The following tables summarise the construction costs (measures items) associated with each sub area of the flood scheme and are inclusive of the landscape additions as discussed in Section 12 'Refinement of Preferred Option', arising following the December 2017 PID.

Table E-1: Construction Costs Sub Area A1

Sub Area A1- Verdant Place				
Work Activity	Quantity	Unit	Rate	Cost
New Coping and railing north of Thomond Bridge	40	m	€400	€16,000
Total A1 Budget Cost				**€16,000**

Table E-2: Construction Costs Sub Area A2

Sub Area A2- Verdant Place Steps & Creche				
Work Activity	Quantity	Unit	Rate	Cost
Flood Wall with Piled Foundation	82	m	€4,000	€328,000
Regrading of existing footpath to a level of 4.1mOD	410	m^2	€28	€11,501
New Non-Return Valve to replace existing plus general tidy-up		Item		€5,000
Total A2 Budget Cost				**€344,501**

Table E-3: Construction Costs Sub Area A3

Sub Area A3- North West Embankment St Mary's Park				
Work Activity	Quantity	Unit	Rate	Cost
Earth Embankment between Ch +330 to Ch +480 due to deepening of soft deposits	150	m	€1,133	€169,894
Fill in existing open drain with clay material, ave width 4m x 1m deep	650	m	€52	€33,644
Earth Embankment between Ch +480 to Ch +1300	820	m	€906	€743,001
Extra Over subsoil for soft landscaping on dry side	970	m	€350	€339,500
Extra over for subsoil filling between existing and new embankment (to prevent depression for dumping etc)	970	m	€75	€72,750
Access steps to/from Oliver Plunkett Street	100	m	€800	€80,000
Allowance for French Drain	620	m	€10	€6,200
Excavation for new open drain for reinstatement of pondweed, say 350m	700	m^3	€7	€4,900
Removal of existing sandbags to existing embankment on completion of the works	970	nr	€15	€14,841
New Storm pipe and outfall with WaSTOP or Tide Flex to replace existing at c. Chainage +500	40	m	€100	€4,000
Fisherman Access provision		Item		€10,000
Remove and disposal of 150mm existing road surfacing from Island Road / Castle Street Junction to St Itas / St Munchins Street junction	1800	m^2	€7.40	€13,320
300m Re-surfacing of Island Road to junction of St Itas and St Munchins Street:- 150mm deep asphalt (surface course and binder course)	1800	m^2	€40	€72,000
Public Lighting Ducting and Cabling	970	m	€25	€24,250
Lighting Columns	39	nr	€1,500	€58,200
Spare Ducting, say 2 nr 100mm ducts	1940	m	€25	€48,500
ESB Set-Up Costs		Item		€10,000
Reinstatement of Green open areas with 100mm topsoil and seed	14,550	m^2	€4	€58,200
Total A3 Budget Cost				**€1,763,200**

Table E-4: Construction Costs Sub Area A4

Sub Area A4- St Munchin's Street / SAC				
Work Activity	Quantity	Unit	Rate	Cost
Earth Embankment between Chainage 0+000 to Chainage 0+700	700	m	€906	€634,270
Allowance for toe drain, Ch. 0+000 to 0+700	700	m	€10	€7,000
Flood Wall tied into Embankment at both ends between Ch 0+700 and 0+770	70	m	€3,500	€245,000
Cantilever Boardwalk to flood wall	70	m	€844	€59,080
Earth Embankment between Ch 0+770 to Ch 0+900	130	m	906	€117,793
Allowance for toe drain 100	130	m	€10	€1,300
Allowance for horse access between CH 50 and		Item		€10,000
Removal of sandbags on completion of the works	850	nr	€15	€13,005
Public Lighting Ducting and Cabling	900	m	€25	€22,500
Lighting Columns	36	nr	€1,500	€54,000
Spare Ducting, say 2 nr 100mm ducts	1,800	m	€25	€45,000
Prolonged Stage Construction of Embankment and management of Existing Peat		Item		€200,000
Temporary Gates until St Munchins St Properties are demolished	2	nr	€2,000	€4,000
Removal and disposal of 150mm existing road surfacing from Island Road / Castle Street Junction to St Itas / St Munchins Street junction	900	m^2	€7	€6,600
300m Re-surfacing of Island Road to junction of St Itas and St Munchins Street:- 150mm deep asphalt (surface course and binder course)	900	m^2	40	€36,000
Cut existing sheet piles down to existing ground level, remove off site and reinstate locally		Item		€25,000
Repaired outer walkway	830	m	€67	€55,610
Reinstatement of Green open areas with 100mm topsoil and seed	6,200	m^2	4	€24,800
Relocation of existing JKN Bund to provide for continuation of earthen embankment		Item		€110,000
Total A4 Budget Cost				**€1,671,017**

Table E-5: Construction Costs Sub Area A5

Sub Area A5- Athlunkard Villa FC & Lee Estate				
Work Activity	Quantity	Unit	Rate	Cost
Earth Embankment between Ch 2+100 to Ch 2+450	350	m	€906	€328,000
Extra Over subsoil for soft landscaping on dry side (Lee Estate chainage 2+275 to 2+450	175	m	€350	€61,250
Extra over for subsoil filling between existing and new embankment (to prevent depression for dumping etc chainage 2+100 - 2+450)	350	m	€75	€26,250
Allowance for toe drain	350	m	€10	€3,500
Stormwater Pumping Station		Item		€150,000
Removal of sandbags on completiojn of the works	350	m	€15	€5,355
Public Lighting Ducting and Cabling	350	m	€25	€8,750
Lighting Columns	14	nr	€1,500	€21,000
Spare Ducting, say 2 nr 100mm ducts	700	m	€25	€17,500
Total A5 Budget Cost				**€610,740**

Table E-6: Construction Costs Sub Area A6

Sub Area A6- Athlunkard Boat Club				
Work Activity	Quantity	Unit	Rate	Cost
Earth Embankment between Ch 2+400 to Ch 2+470	70	m	€906	€63,427
New RC Flood Wall between Ch. 2+450 and Ch. 2+610	160	m	€3,000	€480,000
Public Lighting Ducting and Cabling	210	m	€25	€5,250
Lighting Columns	8	nr	€1,500	€12,600
Spare Ducting, say 2 nr 100mm ducts	420	m	€25	€10,500
Placing of hollow blocks - allow for some dowelling in for intermediate piers as required		Item		€2,000
Individual Property Protection to Boat Club (1 door and 1 gate)		Item		€19,800
Tanking of Walls to Boat Store, say 1m high	70	m^2	€150	€10,500
Tanking of Walls to Boat Club	45	m^2	€150	€6,750
Take out timber floors	48	m^2	€40	€1,920
Concrete In-Fill Floors to boat club, assume 0.5m depth	72	m^3	€150	€10,800
Individual Property Protection to Club House (1 door plus new vents at high level etc)		Item		€50,000
IPP to boathouse		Item		€20,000
Ramped Access from Lee Estate	40	m	€725	€29,000
Ramp down to Boat Club from new embankment	35	m	€790	€27,650
3 nr Japanese Knotweed Stands		Item		€500,000
7m wide Gate to Athlunkard Boat Club (not a flood gate- already at 5.3m OD)	1	nr	€10,000	€10,000
Diversion of foul sewer line to rear of boat house into foul sewer to west of Boat Club		Item		€10,000
Reinstatement of Green open areas with 100mm topsoil and seed	2,100	m^2	€20	€42,000
Total A6 Budget Cost				**€1,312,197**

Table E-7: Construction Costs Sub Area A7

Sub Area A7- Sir Harry's Mall				
Work Activity	Quantity	Unit	Rate	Cost
Raise Existing Wall to 5.1m OD (typically 0.5m average rise)	197	m	€221	€43,339
Allow for drilling dowels into top of existing wall and formwork for concrete		Item		€15,000
Allow for dowelling horizontally into base of existing wall foundation		Item		€5,000
Stone cladding to both sides of raised wall	197	m^2	€100	€19,700
Raise existing footpath to 3.85mOD to provide views of Abbey River	180	m^2	€100	€18,000
Excavation and disposal of soil for mass concrete block	141.8	m^3	€30	€4,255
Reinforced Concrete Block dowelled into existing wall	197	m	€300	€59,100
Reinstatement of existing road	197	m^2	€40	€7,880
Railing to raised footpath	90	m	€350	€31,500
Provision of 5.1m crest to ramp on south side of Absolute Hotel		Item		€10,000
Soil strengthening Works via grout injection		Item		€175,000
Japanese Knotweed Removal from existing wall to facilitate wall pointing		Item		€15,000
Cleaning and Re-Pointing of River Wall	394	m^2	€95	€37,430
Total A7 Budget Cost				**€441,304**

Table E-8: Construction Costs Sub Area A8

Sub Area A8- Absolute Hotel Boardwalk				
Work Activity	Quantity	Unit	Rate	Cost
No works required, existing boardwalk already at a level of 5.1mOD				
Total A8 Budget Cost				**€0**

Table E-9: Construction Costs Sub Area A9

Sub Area A9- South of Absolute Hotel Boardwalk to Abbey Bridge				
Work Activity	Quantity	Unit	Rate	Cost
Cleaning and Re-Pointing of River Wall	180	m^2	€95	€17,100
Japanese Knotweed Removal from existing wall to facilitate wall pointing		Item		€15,000
Demolition of Existing Wall	45	m^2	€25	€1,125
Working Platform within the Abbey River		Item		€50,000
New RC Wall to 5.1m	40	m	€5,000	€200,000
Stone cladding to both sides of raised wall	128	m^2	€100	€12,800
Raising of existing footpath to 5.1m crest level (very slight raising locally)		Item		€10,000
Extra Over for working in confined area with no suitable access		Item		€100,000
Railing provision to provide safe guarding height between top of new 5.1m level	20	m	€350	€7,000
Total A9 Budget Cost				**€413,025**

Table E-10: Construction Costs Sub Area A10

Sub Area A10- Abbey Bridge to Baal's Bridge				
Work Activity	Quantity	Unit	Rate	Cost
Cleaning and Re-Pointing of River Wall	164	m^2	€95	€15,580
Demolition of Existing Wall	41	m^2	€25	€1,025
Stone cladding to both sides of raised wall	131.2	m^2	€100	€13,120
New RC Wall to 5.1m	41	m	€3,409	€139,774
Reinstatement of footpath	246	m^2	€75	€18,450
Total A10 Budget Cost				**€187,949**

Table E-11: Construction Costs Sub Area B1 & B2

Sub Area B1 & B2- Georges Quay				
Work Activity	Quantity	Unit	Rate	Cost
Cleaning and Re-Pointing of River Wall	1,237.5	m^2	€90	€111,375
Demolition of Existing Wall	241	m^2	€10	€2,412
Removal of 5 nr trees opposite Barrington's Hospital	5	nr	€2,000	€10,000
Infilling of excavated tree pits with suitable infill material	500	m^3	€25	€12,500
Raising of Existing Quay wall adjacent Baal's Bridge	24	m	€250	€6,000
New RC Wall Cladded on both sides	157	m	€3,409	€535,233
New Glass Wall	79	m	€4,583	€362,018
Reinstatement of Georges Quay walkway	896	m^2	€165	€147,840
New stone kerb	224	m	€164	€36,736
New paving blocks to Georges Quay road incl. CBM layer	672	m^2	€121	€81,312
Total B1/B2 Budget Cost				**€1,224,113**

Table E-12: Construction Costs Sub Area B3

Sub Area B3- Merchants Quay				
Work Activity	Quantity	Unit	Rate	Cost
Cleaning and Re-Pointing of River Wall	2,579	m^2	€90	€232,110
Flood Gate to Curragower Boat Club	1	nr	€20,000	€20,000
Flood Door to Curragower Boat Club	1	nr	€12,000	€12,000
Tanking of Walls to Curragower Boat Club	80.6	m^2	€150	€12,090
Road Raising adjacent Courthouse	36	m	€2,250	€81,000
New RC wall adjacent Courthouse to facilitate Road raising	36	m	€1,250	€45,000
New RC Wall to strengthen Existing	55	m	€1,500	€82,500
New Glass Wall to rear of Courthouse & City Hall	280	m	€4,583	€1,283,100
Return Stone clad wall towards Curragower Boat Club	14	m	€3,409	€47,728
Extra Over for Cantilever Boardwalk around Courthouse	60	m	€2,500	€150,000
Removal and storage of existing railings around the Courthouse		Item		€2,500
Monitoring of the protected Courthouse structure during construction		Item		€10,000
New Retaining Wall with Step Over and Access Ramp to Sylvester O'Halloran Bridge	55	m	€2,500	€137,500
Intermediate wall between access ramps to Sylvester O'Halloran Bridge	20	m	€1,250	€25,000
New RC Clad or Glass wall to existing viewing platform	7	m	€3,000	€21,000
New Pumping Station		Item		€175,000
Local Drainage and Outfall Structure(s)	400	m	€150	€60,000
ACO to inside of new Defence Wall	280	m	€100	€28,000
Reinstatement of excavated surfaces along glass wall	1,680	m^2	€75	€126,000
Total B3 Budget Cost				**€2,550,528**

Table E-13: Construction Costs Sub Area B4

Sub Area B4- King Johns Castle				
Work Activity	Quantity	Unit	Rate	Cost
No works required				
Total B4 Budget Cost				**€0**

F Assessment of Economic Damages and Scheme Benefit

The scope of this assessment is to derive flood damages for the Kings Island Flood Relief scheme. The economic flood damages of the scheme have been calculated in the form of Annual Average Damage (AAD), based on a range of probabilities and a resulting expected Net Present Value (NBV) of damages. This Appendix provides the supporting data for the assessment, with the results provided in Chapter 9. The methodology contained in the OPW CFRAM Guidance Note 27 has been used to calculate the damages for this study.

The flood damages have been estimated using the Flood hazard and Research Centre's (FHRC) as follows:

- The 2010 handbook and data, that is a companion volume to the 2005 Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal (MCM 2005).

The underlying philosophy is to calculate the damages which would remain after the proposed scheme is completed and to therefore ascertain the benefits that are gained (in this case damages avoided by construction of the flood defence scheme). The benefits over the design life of the scheme are converted to Net Present Value (NPV) and can be compared against the present value of construction costs and therefore ascertain the benefit to cost ratio.

F.1 Scheme Benefiting Lands

The flood relief scheme is to protect the residents and businesses of Kings Island. Properties will be protected up to and including the 0.5% AEP design event. This area is shown in Figure F-1 and this area is the benefitting lands of the scheme.

Figure F-1: Scheme Benefit Lands

F.2 Benefit of a Flood Relief Scheme

Benefits can be divided into either tangible or intangible benefits.

Tangible benefits are those to which it is possible to assign monetary values. In general, the benefit is assigned a valuation equivalent to the monetary loss that would occur if the Flood Alleviation Scheme were not in place. These include a reduction in:

- Direct Damage to buildings and contents
- Indirect Property, community and business
- Disruption of road traffic

Intangible benefits are those to which it is not possible to assign a monetary value from recognised economic principles. Monetary values placed on these benefits are therefore subjective.

Intangible benefits include:

- Avoidance of anxiety, inconvenience and ill health
- Avoidance of the inconvenience of post flood recovery.

For this appraisal, the range of benefits comprise the following:

- Tangible Benefit – Residential properties flooding avoided
- Tangible Benefit – Non-Residential properties flooding avoided
- Infrastructure utility cost, damages avoided
- Emergency services costs, damages avoided
- Intangible benefits for residential properties and some locally owned commercial properties

F.3 Flood Damage Data

A considerable amount of research has been undertaken by the Middlesex Flood Hazard Research Centre (FHRC) on the costs of flood damage in urban areas in the U.K.

The land use in a flood prone area (often referred to as the Benefit Area) influences the likely damage characteristics and costs. Houses are affected differently from offices and warehouses, which in turn, suffer different kinds and costs of damage from those experienced in industrial premises. Various land use sectors have been chosen to assess the impact of different depths of flooding on each. Flood damage data for the residential, retail, distribution, office and manufacturing sectors are provided in the MCH 2010 (CD accompanying the handbook). Detailed descriptions of these data sets are provided in Chapters 4 and 5 of the Manual. Additional costs for emergency services in dealing with flooding are also given in Chapter 6. All cost data in the Multi-Coloured Handbook is in sterling values.

In the MCH, for a particular property, the damage due to flooding is a function of both flooding depth and its duration. Depths considered in the residential dwellings sector range from -0.3m to +3.0m in relation to the ground floor of the buildings. Information is tabulated for flood durations less than and greater than 12 hours.

In addition, the MCH CD also gives detailed data for five house types, seven building ages and four different social classes of the dwellings' occupants. The flood damage/depth data sheets is further broken down into the cost of damage occurring at each flood depth, to plasterwork, floors, joinery, decorations, plumbing, etc.

The MCH CD provides a set of databases for retail, commercial and industrial flood damage. The FHRC derived the depth/damage data sets based on data collections and discussions with representatives from a range of non-residential properties.

Recently demolished properties on King's island have not been included in the damage estimation.

F.3.1 Property Categorisation Assumptions

For the analysis, property areas were geographically linked to the An Post data. Where multiple An Post points existed within the same building polygon, it was assumed the building footprint was divided equally between points. Where An Post data did not coincide with a building polygon a footprint area of zero was applied and hence no damages will be calculated for these points.

The Properties' threshold levels were set using the mean LiDAR level over the buildings' footprint polygon. Where site survey thresholds were available these were applied. Flood depths were extracted at the building footprint polygon. The mean flood depth within each building polygon was used.

The An Post directory assigns one of four codes to each of the property points to indicate the property type. These are R – residential, C – commercial, B – both and U – Unknown.

Residential properties are further categorised into detached, semi-detached, terraced, duplex and bungalow.

Commercial properties have an NACE code assigned, a European equivalent to the MCM codes but not directly comparable.

To link these data to the property descriptions and hence damage curves outlined in the Multi-coloured Manual the following assumptions were made:

- Residential damages would be based on the sector average for each type of property with the sector average applied where no category was available. No age or social class data was included in the assessment.
- Commercial property damages have been based on a conversion of the An Post GeoDirectory data to MCM codes using conversion tables provided by the OPW. Site visits and google street view was used to aid the identification of property types to ensure the correct MCM code has been applied.
- Where residential and commercial property types are within the same building, these have been reviewed and are generally commercial on the ground floor. Residential properties in these instances have been removed.
- Unknown properties were verified by using google street view and google maps.

F.3.2 Flood Duration

This is a coastal protection scheme for Kings Island and it would be expected that the flood waters would recede with the lowering tide leading to short duration (<12 hours) depth damage curves being selected. However, in past events water has filled the hollow that is effectively the centre of Kings Island, leading to inundation lasting longer than the tide cycle, with water taking several days to finally drain from the normally dry (i.e. non-wetland) parts of the island.

F.3.3 Property Capping Assumptions

The present value damages for any given property should not exceed its current valuation. This is to prevent justification for a flood mitigation scheme being based on the repeated flooding of a property over the project life when it would be more cost beneficial to simply buy out the property. Estimated property values have been determined for both residential and commercial properties.

Residential Properties

Average prices for apartments, bungalows, detached, semi-detached and terrace properties were derived for Kings Island. The final capping value was set at twice the market value to allow for intangible damages. Table F-1 gives the average residential market values and the capping values used in this assessment.

Table F-1: Residential market and capping values

Property Type	Average market price	Capping value applied
Bungalow	€100,000	€200,000
Detached	€125,000	€250,000
Duplex	€100,000	€200,000
Semi-Detached	€100,000	€200,000
Terraced	€100,000	€200,000

Non-Residential Properties

An average commercial property value is not available so has been derived for the area. The high-level approach outlined within the MCM is to estimate values as a factor of 10 greater than the rateable value, broadly defined as the annual rental value of the property. However, average commercial rental values are not widely available. Commercial rateable values were provided by Limerick City and County Council but these values are not equivalent to the rental value of the property and are not suitable for determining capping values.

The Ireland Valuation Office is currently going through a revaluation process owing to the poor correlation between the rental value of properties and the rateable value but this information is not available for the west of Ireland.

Therefore, it was found that ten times the rateable income supplied by Limerick County Council was not representative of the properties resale value. Estimated rateable values were obtained from local estate agents and have been used in this study, see Table F-2. This were €80/ft^2 for office space, €52/ft^2 for retail space and €18/ft^2 for warehouse/industrial space. These were adopted as the capped values.

Table F-2: Rateable incomes for non-residential properties

Property type	Rateable value per ft^2 (€)
Retail	52
Office	80
Warehouse	18
Leisure & Public	52
Industry	18

F.3.4 Infrastructural Utility Assets and Emergency Services Sector

For the city, economic damages to infrastructural utility assets (e.g. electrical sub-stations, gas installations and pipe-work, telecommunications assets, etc.) was calculated as 20% of total direct property costs. Costs to emergency services (which include evacuation costs) have be included in the economic damages, and have been calculated as 8.1% of the total direct property costs for the town. (Note: 8.1% value derived as average of the measured emergency services costs for the 2000 and 2007 floods in the UK).

F.3.5 Intangible and Indirect Damages

Flood events can cause significant stress, anxiety and ill health to potentially affected people, during and then after a flood. Individuals generally also incur some costs due to their properties flooding that are not directly related to damage, such as evaluation, temporary accommodation, loss of earnings, increased travel and shopping costs, etc.

For residential properties, the intangible and indirect flood damages were set equal to the total (direct) property damage. Intangible damages have also been applied in the case of small, individually or family-owned businesses where the intangible impact would be personal and similar in nature to that which might be experienced were the property residential. It was justified on a property-by-property basis.

F.3.6 Traffic Disruption

A significant diversion route is only required when both Athlunkard Street and Corbally Road are closed. Although traffic disruption historically makes up a small percentage of damages, a review of the January 2014 event was completed. During the event the Athunkard Street and Corbally road were assumed to be closed for 24 hours. The split of vehicle types (cars, OG, LGV etc.) was taken as the percentage for urban roads as outlined in FHRC MCM. An 8km diversion (via Parteen), travelling at a speed of 20km/hr was assumed. Estimating that January 2014 was a 1% AEP event leads an event damage of €923,136, an AAD of €9,231 and a scheme damage of €198,000. As a result, the damages due to traffic disruption were not included in the analysis. If included it would marginally increase the benefit to cost ratio but has been estimated based on the January 2014 event to be insignificant.

F.3.7 Discounting and Present Value Damages (PVd)

Given a choice between receiving a specific sum now and the same amount sometime later, most people will express a preference for the present sum. The tangible benefits accruing from a flood alleviation scheme will not provide cash sums to the beneficiaries; however, they will prevent a negative cash flow (avoidance of associated flooding costs) from the individuals.

The avoidance of fixed negative cash flow now is also preferable to avoidance sometime in the future.

The "social time preference" (STP) can be measured by an appropriate Discount Rate (STPDR) and is taken as the compound rate of interest 'r' (% per annum) by which 'y' Euros in 'x' years' time is equal to one euro now.

The benefits arising from a flood relief scheme commence on the completion of the scheme and exist for the life of the works. To obtain a method of the overall benefit in present day monetary values, it is necessary to:

a. Estimate the average damage arising each year of the project life, termed the Average Annual Damages (AAD)
b. Discount the AAD to present values using the appropriate discount rate.
c. Total the present values to obtain the overall damages.

The Department of Finance's discount rate for public investment is 4%. The lifetime over which the damages are discounted is taken as 50 years. For computation purposes, it is assumed that the residual value of the scheme at the end of the period is nil. This may be regarded as somewhat conservative, since works typically have a design life of 100 years.

F.3.8 Euro/Sterling Conversion Rate

Prices (damage costs) in the data provided by FHRC 2010 should be converted to euro rates applicable to Ireland in 2017 by:

- Applying a 'PPP' multiplication factor of 1.269. This is derived from the relative OECD Purchasing Price Parity values for the UK and for Ireland for 2009. The 'PPP' factor is net of currency conversion (i.e., already includes for exchange rates as well as price differences, and so no currency conversion rate should be applied in addition to this factor);
- Applying an inflation multiplication factor of 1.051 This is derived from inflation rates based on the CPI in Ireland for the period 2010- 2017.

F.4 Calculation of Annual Average Damage (AAD) and Present Value of Damages (PVd)

Using JBA's custom software package FRISM, the Annual Average Damage (AAD) was calculated using linear interpolation between damage values for each of the eight defined design event probabilities. The AAD is calculated as the sum of the damage values of each probability, up to and including the 0.5% AEP event (the design standard of the scheme) as the upper bounding event.

The analysis ignores both the damages and any additional design benefits arising from events greater than the design standard.

Accordingly, as damages have not been calculated for events greater than the Design Standard of the Scheme, construction of the Scheme would result in the total benefit being equal to the calculated total damages figure.

The Average Annual Damage, discounted at a rate of 4% per annum, is then calculated over a time-horizon of 50 years to produce a Net Present Value of the potential flood damage. This represents the Net Present Value of the benefit of the Scheme.

F.4.9 Modelling Scenarios

The existing damages (and accordingly, the benefits of a flood scheme to Kings Island) should take into account the current state of the Land Commission defences to the north of the Island. Where capital expenditure is being planned to replace defences that do not perform at a satisfactory standard, the damages arising from failure, prior to overtopping should be taken into account in the benefits assessment.

The scheme benefits, using FHRC 2010, can be taken from two damage scenarios:

1. Do-Nothing Scenario, where it is assumed that the existing defence level provides protection (Figure F-2);
2. Breach Scenario, where defences fail upon loading now, and no account is given to existing inadequate defences (Figure F-3);

The scheme benefits are then the addition of the 'do-nothing' damages and the contribution from the breach risk damages, which is factored down to account for timing and probability of a breach.

It should be noted that the breach scenario introduces more houses into a flooded area at an earlier probability. In a breach scenario, there are considerably more houses predicted to be flooded in the T20 event.

As more extreme events are included, the number of houses impacted in a breach reduces, as the breach lowers water levels in the Shannon and Abbey River by between 70 and 80mm. This reduces the overtopping component at the non-breached defences.

As extreme water levels approach the 1in 200 year levels, the breach inflow is drowned out and no reduction in water level is seen. However, a few cells are sensitive to small changes in flow routes and volume and hence there are 2 less properties impacted in the breach run than in the 0.5% event.

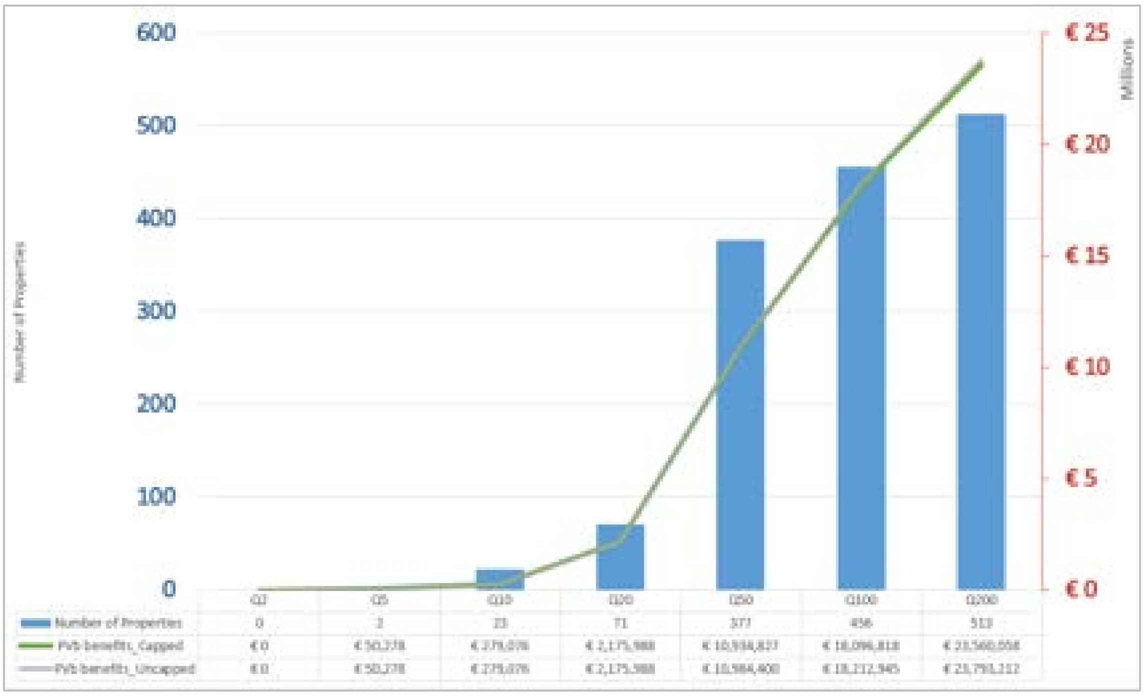


Figure F-2: Total Present Value Damages (for each Design Standard) - Do Nothing (4% discounted)

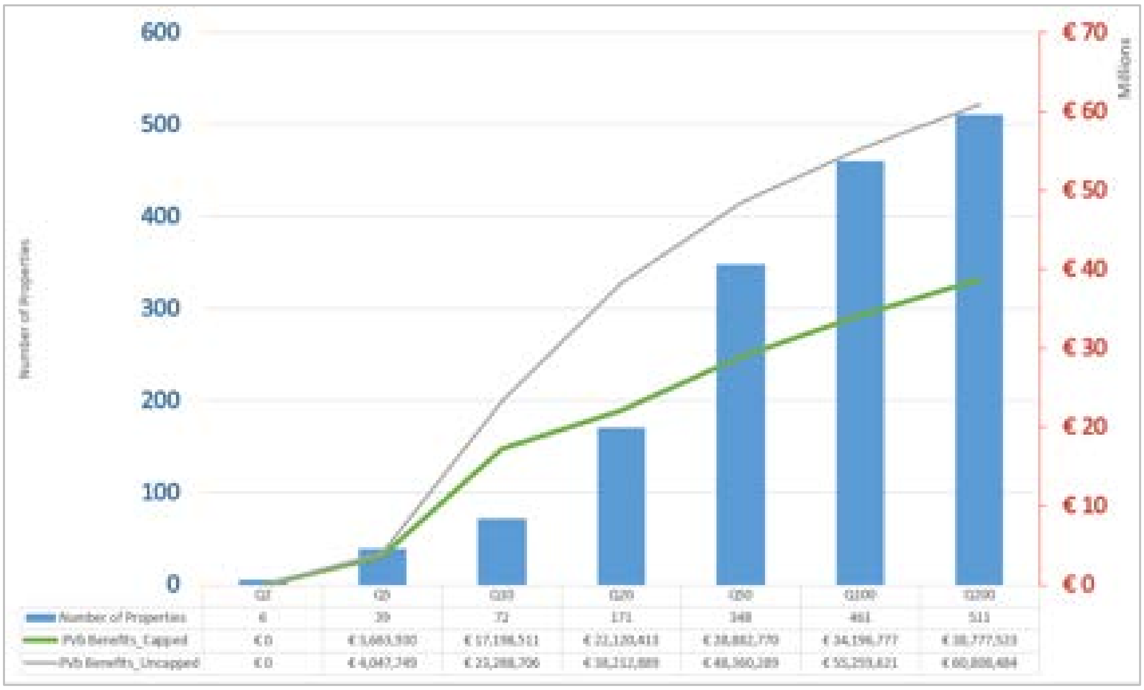


Figure F-3: Total Present Value Damages (for a particular Design Standard) in the Breach Scenario (4% discounted)

F.4.10 Full project appraisal analysis using UK based PAG guidelines for residual risks

Using the Environment Agency's Flood Risk and Coastal Erosion Management appraisal guidance an assessment of the residual risk of an existing defence is taken into account. This typically applies a failure probability and a timescale to the performance of an inadequate defence. This allows these damages to be discounted into the future. In reality, we have evidence of failures in these defences and a more conservative assessment could have been undertaken.

In this instance, we have applied a 50% chance of breach after 10 years and full breach after 25 years which then gives the combined benefit figures below, in

Table F-3.

The Benefit Analysis was also tested for sensitivity of discount rates of 3% and 5% and these results are also shown below.

Table F-3: Economic benefits for 0.5% AEP tidal design standard scheme

	Benefits for T200 Design Standard Scheme (€ Million)		
Discount Rate	3%	4%	5%
Baseline scenario	28.1	23.6	20.1
Raw Breach scenario	43.0	38.8	35.1
Integrated breach assessment based on including the damages resulting from a breach scenario assuming a 50% likelihood breach after year 10 with full breach by year 25)	42.2	36.9	32.5

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