07- CLIMATE CHANGE ADAPTATION PLANS FOR FLOOD RELIEF SCHEMES

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Abstract
The use of Scheme Climate Change Adaptation Plans (SCCAP) in flood risk management is an emerging field within the industry. The principle behind their usage is to ensure that flood risk management interventions are planned and sequenced to mirror increasing flood risks arising due to climate change, and to ensure that planning for such interventions are flexible and adaptable to the inherent uncertainty related to possible future climate scenarios. A SCCAP approach can provide greater long-term value for money than the more traditional approach of developing schemes purely to address the current day risk. Key to the success of a SCCAP is ensuring that flood schemes designed to address the present-day risk are also adaptable to modifications/interventions in the future, i.e., that there is no technical impediment to future interventions imposed on the scheme by a lack of foresight in today's design decisions. As part of the Midleton Flood Relief Scheme (FRS), Arup was commissioned by the OPW to prepare a pilot SCCAP. The objective of the study was twofold; firstly, to develop a set of viable climate change adaptation pathways for the Midleton flood relief scheme (FRS), and secondly to prepare a best practice guide to assist OPW in implementing future SCCAPs across its national portfolio of flood relief schemes. This paper summarises our approach and sets out the preliminary findings of the study.

1. INTRODUCTION

A strong body of international scientific literature, including that produced by the Intergovernmental Panel on Climate Change (IPCC), provides conclusive evidence that climate change is real, and represents an existential challenge for society. What is not so certain is how its effect can be predicted and incorporated into the economic appraisal of flood management schemes (Wilby et al. 2007). In particular, the uncertainty associated with prediction of climate change effects on flood flows and tidal levels based on past and present information is so large that traditional methods are not accurate enough to deal with it (Haasnoot et al., 2013). Traditional approaches have tended to provide a precautionary "single" climate change allowance (e.g., usually 20% uplift in flows) when calculating the cost-benefit ratio (CBR) for a preferred scheme. This precautionary approach usually results in building to a high-level upfront, thus, generally involving high cost. This approach is "static" by nature in that the solution is applied for a possible worst-case scenario expected to unfold by the end of the design horizon.

For the Midleton FRS, we applied an alternative approach known as Climate Change Adaptation Planning (CCAP), a concept introduced by Walker et al. (2001), that proposes implementing plans that can be adapted as more information becomes available. CCAPs offer a more cost-beneficial approach by sequencing interventions/modifications of an existing scheme in line with increasing flood risk in the future (Yzer et al., 2014). Key to the success of CCAPs is to ensure that that the FRS designed today, is adaptable to modifications/interventions in the future, i.e., that there is no technical impediment to future interventions imposed on the scheme by a lack of foresight in today's design (Biesbroek, et al., 2011).

The use of CCAPs in flood risk management is an emerging field within the industry and an active area of research, given that there is no accepted standardised methodology for their practical implementation as part of a scheme's design. This lack of guidance is seen as one of the limitations for their implementation and wider use within the industry (Reynard et al., 2017). However, the method was successfully applied in the UK for the management of flood risk in the Thames Estuary 2100 (TE2100) (EA, 2012) and in the Netherlands Delta Programme (2013). Other areas of application include urban transport infrastructure solutions (Wall et al. 2015; Marchau et al, 2008), water resources management (Dessai and Hulme, 2007), hydropower (Minville, et al. 2009), and water supply (Arnell and Delaney, 2006).

2. METHODOLOGY

2.1 Study Area

Figure 1 presents an overview of the study area for Midleton FRS. As the locations at risk are spread over a large geographical area, and the dominant source of flooding varies within these areas, it was considered appropriate to divide the Study Area into 6 no. management areas as shown. To demonstrate the benefits of CCAP, Areas 1 and 2 (fluvially dominated), and Area 3 (tidally dominated) were chosen, and results of our analysis presented in this paper.

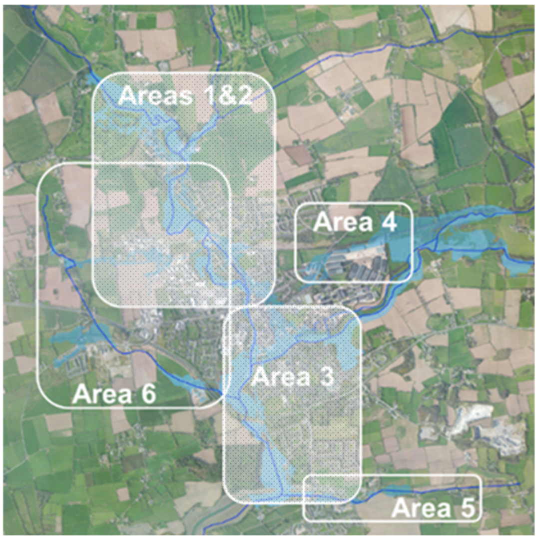

Figure 1: Key Plan of the Study Area

2.2 Climate Change Epochs

Two future climate change epochs were considered representing a Mid-Range Future Scenario (MRFS) and High-End Future Scenario (HEFS). These scenarios include for changes as set out in Table 1.

Table 1: Allowances in Flood Parameters for the Mid-Range and High-End Future Scenarios

Parameter	MRFS	HEFS
Peak Flood Flows	+ 20%	+ 30%
Mean Sea Level Rise	+ 500 mm	+ 1000 mm

The considered range and baseline for each epoch is outlined in Table 2 below.

Table 2: Allowances in Flood Parameters for the Mid-Range and High-End Future Scenarios

	MRFS	HEFS
Lower Limit	2035	2080
Upper Limit	2100	2130
Baseline	2050	2080

A sensitivity was carried out on the timing at which these epochs occur as this has an impact on the economic damages/ benefit assessment.

There is a significant amount of uncertainty surrounding these assumptions. The IPCC Global mean sea-level rise graphic below illustrates the likely upper and lower levels. It is evident from Figure 2 that rate of on set varies significantly.

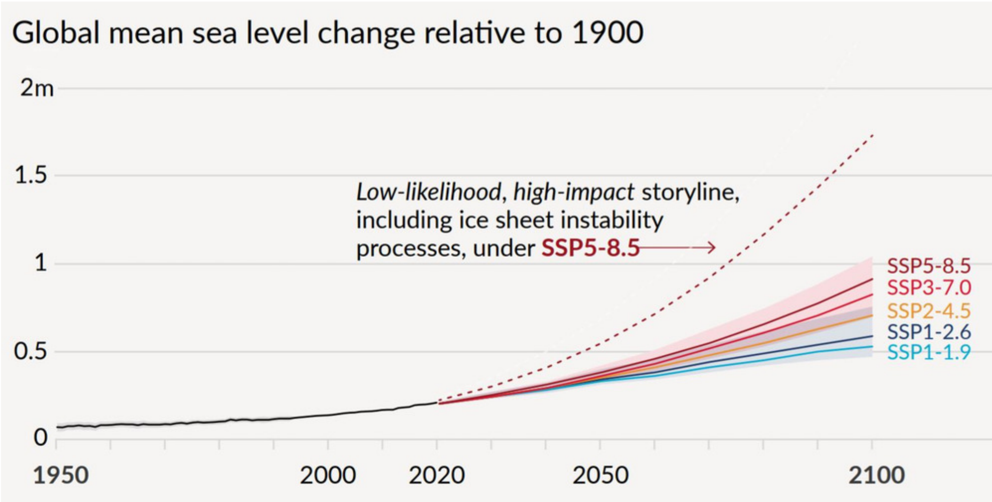

Figure 2: Global mean sea-level rise. Upper and lower likely ranges (IPCC, 2021)

2.3 Fluvial - Tidal Joint Probability

In the absence of long-term records, the interdependence of river flows and tidal surges is estimated using factors provided in the Defra Research Report (2005). A number of sites in the UK referred to in the Defra research have reasonably similar catchment and sea boundary orientations to the Owenacurra catchment which are stated as being either super or strongly correlated. It was therefore reasonable to assume a well or strong correlation dependence factor for Midleton. We have adopted a conservative approach and assumed a super dependent relationship between the river flows and tidal surges. A dependence factor (χ) of 0.2 was therefore selected and used to derive tidal/fluvial return periods for the various design events.

Table 3 lists the required Standard of Protection (SoP) for the scheme, i.e. the preferred flood relief option required to defend up to and including fluvial/tidal events.

Table 3: Design Standard of Protection

Joint Probability Scenario	Design Event	Fluvial Contribution	Tidal Contribution
Fluvial Dominant	Q100	Q100	T5
Tidal Dominant	T200	Q10	T200

2.4 Hydraulic Modelling

A combined 1D/2D model of the primary watercourses in Midleton was constructed to simulate flood events as part of the Flood Relief Scheme. The 1D model simulates the in-bank flows and was constructed in Flood modeller Pro 1D (Version 4.4). The 2D model simulates the out of bank floodplain flows and was developed in Tuflow (Version 2017-09-AC-iSP-w64). Both the 1D and 2D models are dynamically linked and run together as a coupled model. The hydraulic model used in this study represented a significant evolution of the previous Lee CFRAMS model, containing significantly more accurate and detailed information, including additional survey information and additional modelled water courses.

2.5 Potentially Viable Measures, Options and Pathways for the Study Area

All potential flood mitigation measures were initially considered. Those that were found to be potentially viable were brought forward and a suite of Midleton specific options were developed for each epoch. Measures which were screened out previously were reassessed for future epochs. The combination of the Existing Option, MRFS Option and HEFS Option is referred to as an Adaptation Pathway. 12 no. different Adaptation Pathways were developed for the Study Area and are presented in Figure 3 in the form of a Decision Tree. These different adaptation pathways can provide protection up to the MRFS and further to HEFS design standard of protection (SoP).

Following the completion of a Cost Benefit Analysis (CBA) and a detailed Multi-Criteria Analysis (MCA), the emerging preferred option for the existing scenario in all three areas consisted was direct defences. The Scheme MCA considered the impact of each of the current technically viable options have on climate change and ensured the options were adaptable to impacts of climate change and can be managed effectively and suitably into the future. As part of the MCA process, each option was assessed in the context of climate change adaptability and it was considered that the direct defences option is compatible with all the future adaptation pathways.

The optimum alignment of these defences was chosen based on analysing the flow paths and flooding mechanisms. For Midleton, there are three potential options for adaptation to the MRFS and eight potential options for adaptation to the HEFS. The adaptation pathways identify potential scheme modifications which could be taken when trigger points kick in. The trigger points define when a decision must be made so that there is sufficient time for any of the potential interventions to be made.

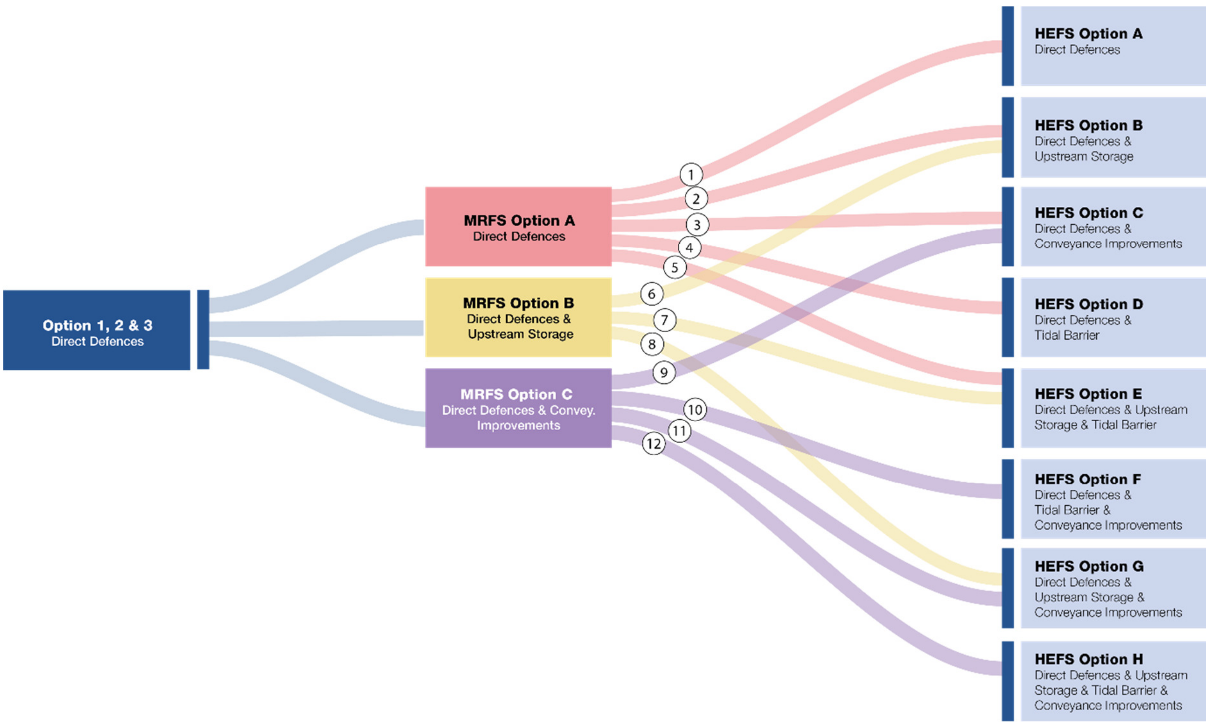

Figure 3: Decision Tree for the Selected Sites within the Study Area

An economic assessment of these pathways is outlined in Section 3.2.1 of this paper with an MCA Light process presented in Section 3.2.4.

3. DATA ANALYSIS AND FINDINGS

3.1 Adaptation Pathways

3.1.1 MRFS Option A- Direct Defences

This MRFS adaptation pathway requires modification/raising of the preferred option of direct defences throughout Area 1, 2 and 3. The locations and alignments of these defences are outlined in Figure 4 and 5 below.

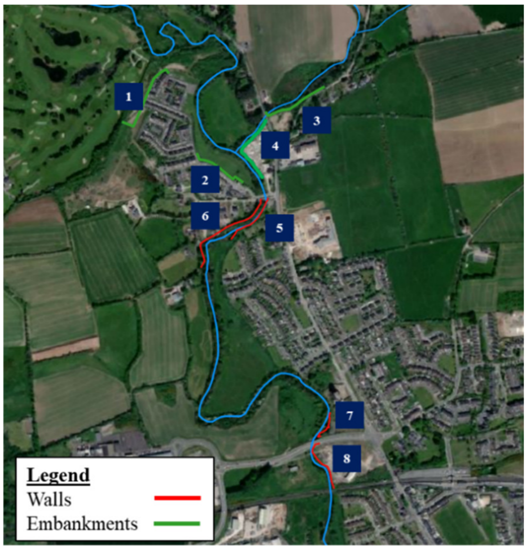

Figure 4: MRFS Option A - Areas 1 and 2

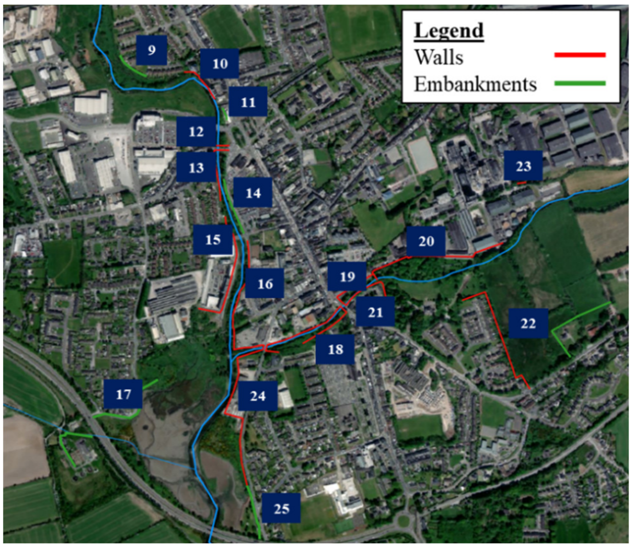

Figure 5 MRFS Option A – Area 3

The relative defence heights required to adapt the preferred option in the future to achieve the MRFS and HEFS SoP, are outlined in Table 4.

3.1.2 MRFS Option B- Direct Defences and Upstream Storage

This MRFS adaptation option utilises a potential upstream storage area. This reduces the need to adapt direct defences locally as the 20% increase in fluvial flows on the Owenacurra can be retained upstream during a fluvial event. However, in the tidally dominated area downstream, the 0.5m increase in tidal design flood levels require further adaptation of the direct defence to achieve the MRFS standard of protection. These adaptations will be of the same magnitude to those in MRFS Option A.

3.1.3 MRFS Option C- Direct Defences and Conveyance Improvements

This MRFS options considers bridge replacement and removal, and some dredging works downstream of the upper reaches. Similar to MRFS Option B, further adaptation of the direct defence in the tidal reach would still be required to achieve the MRFS standard of protection due to the increased flood risk caused by the rising sea level.

3.1.4 HEFS Option A, B, C and G- Combination of Alternative Options

HEFS Option A, B, C and G are made up of a combination of MRFS Options A, B and C presented above with further adaptation to the direct defences where required.

Table 4: Required Adaptation of Direct Defences to achieve Current, MRFS and HEFS Standard of Protection

Reference	Location Name	Direct Defence Height (m)		
		Current	MRFS	HEFS
1	Back of Tir Cluain	1.2	1.95	2.0
2	Small embankment Tir Cluain	0.4	1.10	1.35
3	Clohessy's Yard	2.0	2.35	2.45
4	Upstream Clohessy's Yard	2.0	3.05	3.15
5	Left bank south Moores Bridge	0.7	1.45	1.5
6	Right bank south Moores Bridge	1.1	1.85	1.9
7	Left Bank Lot 1	1.0	1.8	1.9
8	Left Bank Lot 4	1.0	1.85	1.95
9	Back of Millbrook	0.7	1.2	1.25
10	Back of The Courtyard	0.7	1.1	1.2
11	My Place	0.5	1.25	1.4
12	Right Bank North of Cork Bridge	0.8	1.25	1.4
13	Right Bank South of Cork Bridge	0.5	1.55	1.7
14	Left Bank protecting Thomas St	0.7	1.1	1.25
15	Right Bank beside Lidl	-	0.9	1.1
16	Left Bank Owenacurra Farrells	0.7	1.7*	2.2*
17	Riversfield Estate West of Est	0.8	1.8	2.3
18	Dungourney South Lewis Bridge	1	2.0*	2.65*
19	Baby’s Walk Wall	1.2	1.9*	2.5*
20	Peoples Park wall	1	2.0*	2.55*
21	Left Bank Baby’s walk	-	1.0	1.5*
22	GAA Development Defence	0.7	1.2	1.7
23	IDL Millrace	-	0.9	1.0
24	Dungourney right bank ESB site	1.2	1.7	2.5
25	Choctaw Park	0.8	1.6	2.5

*Indicates the required defence height is above the maximum height of 1.2m in public realm areas which might not be considered socially acceptable. It is considered likely that the required further defence heights may only be achieved using part demountable solutions, or alternatively that a lower design standard of protection may need to be considered in these areas. Higher permanent defences in rural/ low amenity areas are considered socially acceptable for the purpose of this study.

3.1.5 HEFS Option D, E, F and H- Tidal Barrier

HEFS Option D, E, F and H introduces a tidal barrier option in the Owenacurra Estuary. This measure is not considered viable in either the present-day case or the mid-range future scenario (MRFS) as it would not be cost beneficial in either scenario. However, it should be reconsidered as a HEFS Option due to the likelihood that direct defence heights would be excessive and the greater damages arising could generate a business case for a barrier. From our analysis to date, it is considered unlikely that a standalone barrier on the Owenacurra Estuary would be the preferred solution, as the need for and business case for a tidal barrier/barrage in the wider harbour could become potentially viable in the HEFS. Any such barrier could only work in conjunction with the direct defences proposed as part of the present day and MRFS solutions, to reduce the frequency of barrier closures to acceptable levels.

3.2 Findings

The approach assessed the damages for the Midleton study for each individual flood cell. Whilst recognising that individual properties and flood cells may have a positive or negative impact on the overall scheme based on their individual valuation of benefit and the cost, it was assumed that these differences will be aggregated across the scheme to give an overall Cost Benefit Ratio (CBR) for the

Scheme options. Comparison of options within each flood cell will therefore be differentiated by cost rather than CBR as all options will deliver the same SoP and thus, it is not proposed to present a CBR value per flood cell.

The analysis was carried out in accordance with the OPW guidance document "Lower Lee, Douglas and Glashaboy Flood Relief Schemes: Economic Damage Assessment and Cost Benefit Analysis (Rev B)". This guidance document sets out a common approach to the calculation of monetised economic flood damages and the economic benefits of flood risk management options, and for undertaking a cost-benefit analysis for Flood Relief Schemes. The guidance document was an evolution of the guidance document produced to guide the implementation of the National CFRAMS but amended to reflect the differing requirements between a Catchment Study and the delivery of an urban flood relief scheme.

Flood damage data was assessed from the "The Benefits of Flood and Coastal Risk Management: A Manual of Assessment Techniques (2019)" published by the Flood Hazards Research Centre at Middlesex University. This document is often referred to as the "Multi-coloured Manual" (MCM).

3.2.1 Economic Damages Calculations

The 2019 MCM damage curves were used to calculate the direct property damages at each property for the three epochs (Current, MRFS and HEFS). Table 5 outlines the baseline anchor points which are used to calculate the damages.

Table 5: Project Horizon

Epoch	Current	MRFS	HEFS	End point
Timeline	2020	2050	2080	2110

This assumes a project horizon of 90 years, 2020 to 2110. We would note that these assumed timescales are very conservative in the context of the latest IPCC projections and represents the likely worst-case scenario where carbon production continues unabated and indeed increases from present day levels.

In this context, we would note that sensitivity testing has also been undertaken as part of the project to consider the impact of alternative time horizons for climate change. This sensitivity ensured the approach was robust and the findings were not impacted by alterations to the project horizon.

An Annual Average Damage (AAD) was assigned to each of the intervening years between anchor points. It was assumed the AAD remained constant until the year at which the next epoch occurs, at which point the AAD would step up based on the increased boundary conditions. This is referred to as the "flat rate". A sensitivity analysis was carried out on this assumption where by the AAD for intervening years was based on a linear interpolation. A visual representation of these methods is illustrated in Figure 6.

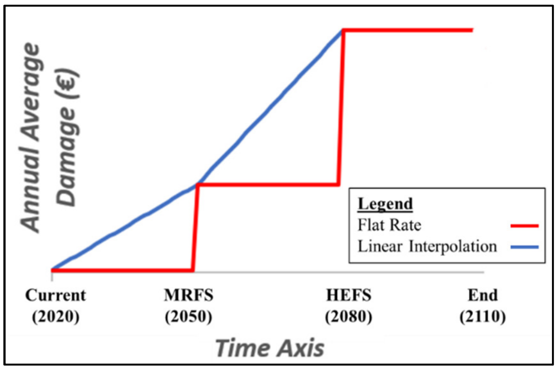

Figure 6: Linear interpolation vs flat rate - Annual Average Damage assumption

The baseline Present Value Damages (PVD) were calculated based on a baseline discount rate of 4%. Fluvial and Tidal PVDs included intangible damages for residential and family-owned commercial properties and uplifts factors to account for utilities (20%), emergency services (10.7%) and traffic (5%). Capping values for both residential and commercial properties were determined using the residential property price register and commercial leases register.

Based on the above assumptions, the baseline total combined fluvial and tidal undefended PVDs for Area 1, 2 and 3 over the project horizon was found to be in the region of €219 million.

3.2.2 Economic Benefit Calculations

The baseline benefit assumes the design SoP is achieved throughout the life of the project. This assumes that as fluvial flows and sea levels increase due to climate change, the chosen pathway will be adapted in time to continue to provide the design SoP. As per the OPW standard approach, the benefit is calculated by excluding all damages above the design SoP and therefore conservatively does not account for benefit provided by a scheme during exceedance events. These benefits are difficult to quantify and as they are achieved so infrequently, they would not be expected to make a significant contribution to the overall benefit.

The baseline total combined fluvial and tidal Present Value Benefit (PVB) of a scheme achieving the design SoP for Areas 1, 2 and 3 over the project horizon was found to be in the region of €202 million. This PVB does not account for future development and the subsequent benefits to such development.

3.2.3 Costings

The Present Value Costs (PVCs) of each adaptation pathway is based on a 90-year project horizon. The Capital Works Costs have been calculated at each epoch along each of the 12 adaptation pathways. The maintenance costs have been spread over the 90-year project horizon. As per the PVD, a baseline discount rate of 4% was applied to calculate the PVCs of each adaptation pathway. The CBR of each pathway is displayed in Table 6.

3.2.4 MCA Light

An ‘MCA Light’ approach was carried out on the viable adaptation pathways presented in Figure 3. The adaptation pathways were marked under cost-benefit, technical (operational robustness and health and safety), social and environmental impacts. These 4 categories were equally weighted and simply scored using a colour-coded 'score-card' as per the OPW MCA-Light- Rev B guidance.

3.2.5 Scoring of Pathways

The MCA Light scores and CBA of the 12 pathways are presented in Table 6 below.

Table 6: MCA Light Scores and CBA of each Adaptation Pathway

Pathway	Total MCA Light Score (Max 300)	Total MCA Light Score (%)	CBR	Rank
1	63	21%	5.8	1
2	24	8%	5.8	3
3	38	13%	5.8	2
4	-10	-3%	2.1	6
5	-35	-12%	2.1	9
6	20	7%	5.4	4
7	-36	-12%	2.1	10
8	-28	-9%	5.5	7
9	13	4%	5.8	5
10	-35	-12%	2.1	8
11	-51	-17%	5.8	11
12	-60	-20%	2.1	12

Based on the current assumptions, it is evident from Table 6 that Adaptation Pathway 1 is the best ranked using the MCA Light tool. This adaptation pathway consists of Direct Defences in the Current Options and then further increases of these defences heights in the MRFS and HEFS to achieve the required SoP. Pathway 3 is the 2nd most favourable pathway; this pathway consists of conveyance improvements as part of the HEFS adaptation. Due to the negative environmental impacts caused by dredging, this pathway was scored lower. Pathway 2 is the 3rd most attractive; it proposes utilising the area of Waterrock Golf Club for upstream storage as part of the HEFS Option. This pathway was deducted marks in the technical category of the MCA due to the increased operational and health and safety risk associated with operating and maintaining an upstream storage area. It should be noted that the defences in the tidal area for all 3 of these pathways are identical and, in several locations, the required defence heights to achieve the HEFS SoP exceed the socially acceptable defence height of 1.2m to 2m. In the future, in these areas, it is considered likely that significant aspects of part demountable solutions may be required.

Although a tidal barrier was not considered feasible as a MRFS Option, it was considered of part of the HEFS optioneering. The current MCA scores suggest pathways which propose a tidal barrier are not attractive from an MCA perspective due to the high capital, operation and maintenance costs, the construction in a Special Area of Conservation (SAC) and a Special Protection Area (SPA), and the operation robustness of a tidal barrier.

The cost estimate for the tidal barrier above assumes a smaller stand-alone barrier in the Owenacurra Estuary. However, if the HEFS were to materialise, it is considered more likely that a Cork Harbour Wide Tidal Barrier would provide a stronger CBR across the wider area as it would protect a much larger number of urban settlements. Ultimately, the trigger point for such a scenario is too far in the future to make an informed decision on a barrier at this point, but such a decision is not needed now and any barrier would rely on the direct defences proposed in both the current and mid-range future scenario. This is demonstrative of the key purpose of the CCAP and decision tree as it provides the evidence base to proceed with confidence with the direct defence solution knowing that the defences currently proposed form part of all future adaptation pathways.

3.2.6 Sensitivity on Discount Rate

Although the CBR in Table 6 is suggesting that all pathways are economically sound, caution should be taken when reading these results. HEFS adaptations such as the tidal barrier, were significantly discounted when estimating the PVCs of each pathway, essentially discounting the future costs to zero resulting in high CBR. In order to illustrate the impact the discount rate has on the Present Value Damages, Benefits, and Costs and therefore CBR, a 0% discount rate was applied. A comparison of the economic assessments with a 4% and 0% discount rate are presented in Table 7 and 8.

Table 7: Comparison of PVD and PVB with 4% and 0% discount rate applied

	4% Discount Rate Applied	0% Discount Rate Applied
Present Value Damages	€ 219 M	€ 730 M
Present Value Benefits	€ 202 M	€ 670 M

Table 8: Comparison of PVC and CBR with 4% and 0% discount rate applied

Pathway	Present Value Cost (4% Discount Rate)	Benefit Cost Ratio (4% Discount Rate)	Present Value Cost (0% Discount Rate)	Benefit Cost Ratio (0% Discount Rate)
1	€ 35 M	5.8	€ 87 M	7.7
2	€ 35 M	5.8	€ 89 M	7.5
3	€ 35 M	5.8	€ 87 M	7.7
4	€ 94 M	2.1	€ 766 M	0.9*
5	€ 95 M	2.1	€ 770 M	0.9*
6	€ 38 M	5.4	€ 95 M	7.0
7	€ 96 M	2.1	€ 771 M	0.9*
8	€ 36 M	5.5	€ 92 M	7.3
9	€ 35 M	5.8	€ 87 M	7.7
10	€ 94 M	2.1	€ 766 M	0.9*
11	€ 35 M	5.8	€ 89 M	7.5
12	€ 95 M	2.1	€ 770 M	0.9*

**BCR <1 therefore Pathway is deemed to be Economically Unacceptable at this time*

Further assessment is currently being carried out on this in which the CBR will be calculated at each trigger point to see if the tidal barrier remains cost effective. To test this, it is proposed to shift year 0 to 2080, when a tidal barrier may be constructed, benefits and costs will be discounted to this point in time and a CBR will be carried out to confirm this future adaptation is economically viable.

4. DISCUSSION

In this paper, we set out the climate change adaptation plan approach adopted in the development of the Midleton FRS, and how it proposes to deal with the uncertainty associated with predicting the effects of climate change on future flood flows and tidal levels. The CCAP approach advocates sequencing the flood risk management intervention based on a review of future trigger points, thus offering the economic benefit of managing flood risk in direct response to increase in flood risk as they arise in the future.

Based on a CBA and a detailed MCA, the preferred option for Areas 1, 2 and 3 of the Midleton FRS is direct defences. In this exercise, 3no. adaptation pathways were established to provide protection of up to the MRFS, which then further branched out to eight possible options to cater for the HEFS. Each pathway was analysed and scored using an MCA Light process.

The work has allowed a deeper analysis of the various options considered for the scheme and demonstrated that CCAP can be applied to better plan for and manage the risk of flooding from fluvial and tidal sources in the Midleton area both in the short and long term. The applicability of CCAP pathways and MCA Light scores is dependent on the accuracy of the available information, and it should be noted that pathways that scored poorly may become more attractive in the future, depending on the rate and extent of climate change and removal of uncertainty relating to key assumptions. As such, the CCAP should remain a live document and be reviewed and updated periodically.

To leverage the benefits of the CCAP approach, OPW proposes to apply it to other major Flood Relief Schemes whether the area is tidally dominant, fluvially dominant or a combination of the two. Our investigation illustrated that CCAP is relatively simple to apply in tidally dominant flood risk areas, but considerably more effort is needed in fluvial reaches.

4.1 Assumptions

There were a number of assumptions and as such, sources of uncertainties which had to be made when assessing CCAPs for the Midleton FRS including:

- The timing of future interventions and erosion of the SoP and resulting impact on benefit,
- The extent and timing of climate change,
- The impact discounting has on the PVC,
- Future developments and the additional benefit provided by a FRS,
- The potential additional benefit to carrying out a full MCA over the MCA Light, however it was not anticipated that this will have an impact on the outcome.

5. CONCLUSION AND RECOMMENDATION

This paper has found that the CCAP approach to assessing future adaptations of potential FRSs is advantageous as it mitigates against the risk of selecting an option now which may be difficult/ costly to adapt in the future. Unlike the traditional approach to FRSs which focused solely on the present-day option, the CCAP approach considerers the entire project horizon and what potential measures a future scheme may consist of. A major benefit of the CCAP approach is that we can proceed with increased confidence with the existing direct defence solution knowing that the defences currently proposed from part of all future adaptation pathways and will not result in a "regrets scenario" in the future.

Over time, the MCA scores of the pathways may change due to updated knowledge on Climate Change, technological advances (e.g., designing out risk or construction, operation, and maintenance costs of tidal barriers), policy change (e.g., socially acceptable height of defences, development in an SAP/ SAC) and approach to flood risk (e.g., a Cork Harbour wide tidal barrier). For this reason, it is recommended that the CCAP is an evolving plan which is reassessed on a regular basis. This review may be based on a set period (say, every 5 years) or after a significant event (say, 50-year) based on the original FRS scheme hydrology).

This study's methodology assumed the design SoP would be achieved at every stage across the project horizon. It was decided that further analysis should be carried out to test the sensitivity of this assumption and what impact climate change will have on the design SoP and in turn what impact this will have on the benefits of a scheme. This further work is ongoing at the time of writing this paper.

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