

Flood Risk Management and Climate Adaptation in Ireland

Wolfram Schlüter, Mark Adamson

The Office of Public Works, 52 St Stephen's Green, Dublin, Ireland

Abstract. It is likely that climate change will have significant impacts on flood risk in Ireland due to rising sea levels, increased rainfall and more intense storms. While it is important that causes of climate change are addressed, Ireland must also adapt to such changes. Ireland is well advanced in its preparations to tackle flood risk now and into the future. In May 2018, the OPW completed the most extensive and comprehensive study on flood risk in Ireland and through the National Catchment Flood Risk Assessment and Management programme identified 118 flood relief schemes to be carried out over the next decade. The measures contained in the Flood Risk Management Plans (FRMPs) that have been developed took due account of the impact that climate change would have on future flood risk. In this way, the assessment of potentially viable measures took into account how adaptable a proposed measure might be to cope with the potential impacts of climate change. The FRMPs will address flood risk to a total of 23,500 properties through a €1b investment in flood relief measures. Climate change adaptation for future projections of climate change impacts will be a critical aspect of the design and construction of these schemes. Public and stakeholder engagement is a vital component in the development of sustainable long-term strategies for adapting flood risk management for climate change, and extensive consultation was undertaken throughout the process for preparing the FRMPs, and in the preparation of the Climate Change Sectoral Adaptation Plan for Flood Risk Management (2019-2024) that was prepared and adopted by Government as part of the Climate Action Plan in October 2019. The overall goal of the Adaptation Plan is to promote sustainable communities and support the environment through effective management of potential impacts of climate change on flooding and flood risk. This paper provides an overview of flood risk management in Ireland and details potential impacts of climate change as well as the approach to adaptation.

1 Background

Flood risk management is a relatively new area of work in Ireland, with the Arterial Drainage (Amendment) Act, 1995, permitting the Office of Public Works (OPW) to develop and implement local flood relief schemes. Prior to this, activity on managing excess water quantity was aimed primarily at agricultural land protection and drainage to improve agricultural production, initially through the construction of embankments and then the implementation of Drainage Districts and Arterial Drainage Schemes under various Drainage Acts.

Following a series of severe flood events in the early 2000's, a review of the national flood policy was undertaken by an inter-departmental group that produced a report that was approved and adopted by Government in September 2004 (OPW, 2004). This decision set the national policy that is applicable today, and that is in line with the requirements of the EU 'Floods' Directive (EU, 2007) that came into force in November 2007.

The OPW, as the lead agency for flood risk management in Ireland, is responsible for coordinating

and, with respect to many aspects, implementing the National Flood Policy and the EU 'Floods' Directive; details of which are outlined in the following subsections.

1.1 Preliminary Flood Risk Assessment

The Preliminary Flood Risk Assessment (PFRA) is a requirement of the EU 'Floods' Directive that is aimed at identifying through a national screening exercise the Areas of Potentially Significant Flood Risk, or Areas for Further Assessment (AFAs) as they were referred to in Ireland. The AFAs are the areas where, under the 'Floods' Directive, detailed flood maps need to be produced and for which flood risk management measures need to be assessed to reduce and manage the risk.

In Ireland the first cycle PFRA¹ involved:

- Reviewing records of floods that have happened in the past (the historic assessment);
- Undertaking analysis to determine which areas might flood in the future, and what the impacts might be (the 'predictive' assessment); and,

¹ <https://www.gov.ie/en/publication/1c7d0a-preliminary-flood-risk-assessment-pfra/>

^a Corresponding author: wolfram.schluter@opw.ie
DOI 10.3311/ FLOODRisk2020.16.4

- Consulting with the Local Authorities, Government Departments, other public agencies and members of the public.

The assessment has considered all potentially significant types of flooding such as from rivers, the sea and estuaries, heavy rain and groundwater, and also from man-made sources, such as the failure of built water retaining infrastructure. It has included the impacts flooding can have on people, property, businesses, the environment and cultural heritage.

The first cycle PFRA identified 300 AFAs. Under the Catchment-based Flood Risk Assessment and Management (CFRAM) Programme and other location-specific projects, detailed flood hazard and risk assessments were subsequently undertaken for these areas, as described below.

The ‘Floods’ Directive is cyclical and as part of the second and subsequent cycles, the OPW and other relevant authorities are required to review, and if necessary update, the PFRA in relation to the potential sources of flooding they have responsibilities for. This review builds on the work of previous cycles, taking into account floods that may have occurred at the time of the reviews.

1.2 The CFRAM Programme

Completed in 2018, the objectives of the CFRAM Programme were to:

- identify and map the existing and potential future flood hazard and flood risk in the areas at potentially significant risk from flooding, called Areas for Further Assessment (AFAs), as identified through the PFRA,
- identify feasible structural and non-structural measures to effectively manage the assessed risk in each of the AFAs, and,
- prepare a set of FRMPs, and associated Strategic Environmental and Habitats Directive (Appropriate) Assessments that set out the proposed feasible measures and actions to manage the flood risk in these areas and their river catchments.

The CFRAM Programme covered those areas, in each county, where, based on initial analysis, the flood risk was determined to be potentially significant. The 300 communities studied are home to two thirds of the population and approximately 80% of properties potentially at risk in Ireland from rivers and the sea, the primary sources of flooding in Ireland. Ninety of these communities are coastal areas. While the CFRAM Programme assessed flood risk in all of the large urban areas in Ireland, approximately one quarter of communities assessed have populations of less than 500 people and half have less than 2,000 people.

The detailed work involved engineering analysis of the river systems, estuaries and coastal areas, including their hydrology and involving detailed hydraulic modelling. This included surveying and modelling of 6,700 km of watercourse and 9,400 km² of floodplain, including 4,500 km of High Priority Watercourses (HPWs) in the AFAs

that were modelled using dynamically linked 1D2D river models, using DHI Mike Flood, ISIS Tuflow or Innovyze ICM. The 300 AFAs and other modelled watercourses are shown in Figure 1.

Through the CFRAM Programme and other location-specific projects, the OPW has assessed and mapped the flood extents, hazard and risk for the 300 communities assessed for a range of eight flood event magnitudes from frequent, minor flood events (50% Annual Exceedance Probability (AEP) event) up to rare (1% AEP event) to extreme events (0.1% AEP event). The flood maps were developed for two future scenarios taking account of the potential impacts of climate change as well as for current conditions (See Section 2.1 below).

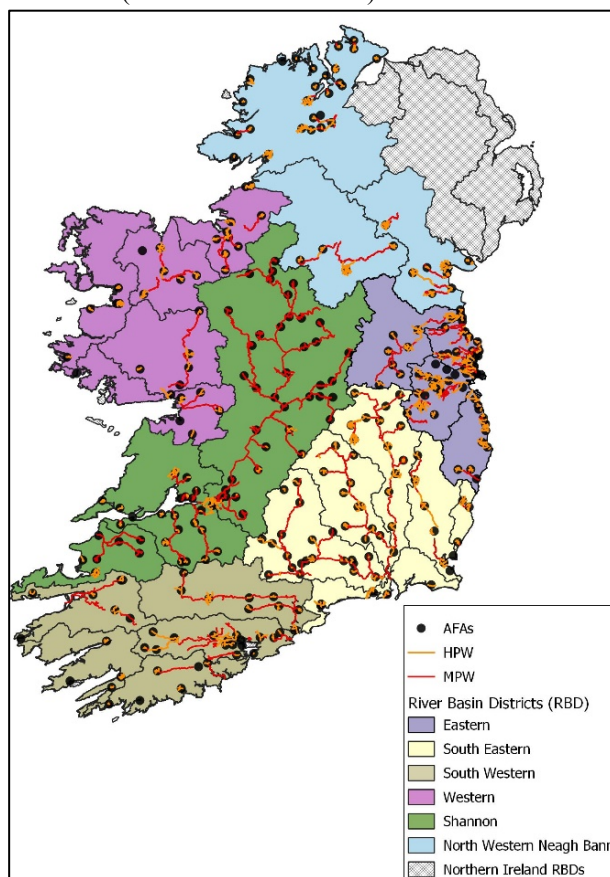


Figure 1: Six CFRAM Study Areas and 300 AFAs

These maps and assessments provide valuable information for the OPW, local authorities and other sectors in planning for adaptation against increasing flood risks due to climate change, as well as informing future planning decisions, emergency response planning and helping communities and people to plan for and respond to a flood event.

The CFRAM Programme has identified measures that, in combination with the measures already completed or that were previously at construction or under design, will provide protection to 95% of the properties at risk within the 300 areas. These measures are set out in the FRMPs that were published in 2018, along with information on the properties and assets at risk.

The flood maps and the FRMPs are available to view through the OPW flood portal; www.floodinfo.ie.

1.3 National Indicative Fluvial Mapping

The National Indicative Fluvial Mapping (NIFM) project was commissioned in order to provide improved flood mapping outside the AFAs (now covered by the CFRAM maps) and, in addition, take climate change into account. The NIFM project has produced second generation indicative fluvial flood spatial data that are of a higher quality and accuracy than those produced for the first cycle PFRA.

This national-scale modelling project has been delivered through extensive automation of the modelling processes, including hydrological calculations, the creation of the 2D model mesh, roughness and boundary files, running the models in sequence and post processing the model outputs. The modelling covers sub-catchments of 5km² or larger, 27,000 km of river reaches, separated into 37 drainage areas and consisting of 509 sub-catchments. Rigorous quality assurance techniques have been automated and applied throughout the modelling chain.

The hydrological inputs to the 2D hydraulic models, notably the index flood (QMED) values, growth curves and hydrograph shape, were derived following the Flood Studies Update (FSU) methodology². The gauged flow data at pivotal sites for estimating the index flood and growth factors was updated with an additional seven years of observed data, during which period some significant flood events had occurred (notably in December 2015 – the largest event of the observed record at many locations across Ireland).

The automated build of the 2D hydraulic models for each catchment uses the digital river network, 5m horizontal resolution IfSAR DTM, FSU flow nodes, the presence of arterial drainage improvements and flood defences, the location of river crossings and land cover data to build the 2D mesh. The river channel is enforced within the mesh using a set of rules that take into account the size and slope of the river and any man made adjustments such as drainage improvements and flood defences.

The mapping procedure has established flood hazard areas; these are the areas that are liable to flood with Annual Exceedance Probabilities (AEPs) of 0.1%, 1%, and 5%, for the current scenario and two potential future climate scenarios; the Mid-Range Future Scenario (MRFS), and High-End Future Scenario (HEFS) (See Section 2.1 below).

A core objective of the NIFM Project was ‘replacing the very indicative first cycle PFRA flood maps with spatial data of better quality / accuracy as the point of reference for areas of flood risk outside of the CFRAM modelled areas. The improved quality has been tested through comparison of both the PFRA and NIFM with CFRAM flood maps, demonstrating a significant improvement in accuracy (Galvin, 2020).

The NIFM data set will enable improved flood risk assessment for areas outside those zones designated as AFAs.

1.4 ICPSS and ICWWS

The Irish Coastal Protection Strategy Study (ICPSS) is a national study that was commissioned in 2003 with the objective of providing information to support decision making about how best to manage risks associated with coastal flooding and coastal erosion. The Study was completed in 2013 and provides strategic current scenario and future scenario (up to 2100) coastal flood hazard maps and strategic coastal erosion maps for the national coastline. This major study provides invaluable and essential information required to inform policy in this area, particularly for local authorities in relation to the proper planning and development of coastal areas. The ICPSS hazard mapping produced is available on the OPW website³.

The Irish Coastal Wave and Water Level Modelling Study (ICWWS) was commissioned in 2011 with the objective of providing information to facilitate the assessment of flood risk due to wave overtopping around the coast of Ireland. The Study was completed in 2013 and provides detailed nearshore water level and wave condition information for the current and future scenario (up to 2100) at 63 locations identified as being potentially vulnerable to wave overtopping and where this may contribute to significant coastal flooding both now and in the future.

In 2018, the OPW commissioned a further Study to update the extreme water level and wave analysis completed as part of the ICPSS and ICWWS by incorporating any additional data available from tide gauges and records of more recent storm events.

1.5 Adapting to Climate Change

Ireland’s first National Climate Change Strategy was published in 2000, followed by the second strategy in 2007. The National Climate Change Adaptation Framework (NCCAF) was subsequently published in December 2012. Under the NCCAF, the OPW, as lead agency for flood risk management in Ireland, prepared the Sectoral Adaptation Plan for Flood Risk Management, which was approved in December 2015 (OPW, 2015).

National policy in relation to climate adaptation was formalised in the National Policy Position on Climate Action and Low Carbon Development, published in April 2014. The policy was then put on to a statutory footing through the Climate Action and Low Carbon Development Act, 2015 (No. 46 of 2015).

Under Section 5 of the Act, the Minister for Communications, Climate Action and Environment published the National Adaptation Framework (NAF) in January 2018 (DCCAE, 2018), which compliments the National Mitigation Plan published in July 2017 (DCCAE, 2017). The following section details potential impacts of climate change on flooding including three case studies.

² <https://opw.hydronet.com/default.aspx?page=11>

³ <https://www.gov.ie/en/publication/eed0fb-irish-coastal-protection-strategy-study-icpss/>

2 Climate Impacts on Flooding

Ireland has suffered from some severe flood events over recent decades, including the winter of 2015-2016 when many thousands of properties were flooded, cut-off or at risk from flooding.

Human activities are estimated to have already caused approximately 1.0°C of global warming above pre-industrial levels, and global mean sea level has risen about 20 cm since the beginning of the 20th century, and is rising at approximately 3.5 cm per decade at present. The Intergovernmental Panel on Climate Change (IPCC) has reported that for a 1.5°C rise in temperature, the global mean sea level could rise by up to approximately 1m by 2100, and projections of more intense Atlantic storms could potentially increase surge events and wave heights. Met Éireann has predicted that in Ireland the autumns and winters may become wetter, with a possible increase in heavy precipitation events of approximately 20%.

The assessments under the National CFRAM Programme indicate potentially very significant increases in the flood impact and the number of properties that could become at risk from flooding. The impact on both the extent and depth of flooding, as well as on the potential damages caused is however site specific and varies significantly from community to community.

Climate change will also impact on different aspects of the national flood risk management programme. These impacts, and the need to take adaptive action to address them, vary across the different programmes of work within flood risk management, with the highest priority impacts being on flood protection, spatial planning and development management. Non-structural flood risk management measures (e.g., preparedness measures) tend to be more inherently adaptable to changes in flood frequency and severity, and ‘green’ measures, such as natural water retention measures also facilitate adaptation while providing benefits to other sectors (e.g., improve water quality and biodiversity, contribute towards carbon mitigation).

2.1 Development of Climate Change Scenarios

There is a wide range of projections of future changes in the climatic drivers of flooding due to a number of factors, including:

- different emission scenario projections into the future,
- different models used to simulate how the emissions projections will impact the future climate, and,
- different parameter sets used in each of the models.

While there is a very high level of confidence that the mean sea level is rising and that the rate of rise has accelerated over recent decades, and that mean sea levels will continue to rise over the coming decades and probably centuries, it is not known at what rate this ongoing rise will occur over this period. There is also considerable uncertainty over the potential changes into the future in local, short-duration extreme rainfall patterns, which are most relevant to the fluvial and pluvial flooding.

Given this uncertainty, it is clearly not possible to state with confidence exactly what the future will look like in

terms of the frequency or severity of flood events. To decide on selecting one single scenario, i.e., a specific degree of sea level rise and a defined increase in peak flood flows and rainfall intensities, and to design flood defences for this specific scenario could well give rise to ‘maladaptation’. This is where excess funds are invested to cater for a worse future than actually occurs, or where works are undertaken that prove to be inadequate, due to a worse than expected future, and which cannot be amended to cater for the worse-than-foreseen future. It is equally not feasible to assess the potential impacts and implications of all of the future climate projections on flooding in Ireland.

For the purposes of the CFRAM Programme, the OPW adopted two indicative potential futures for flood risk assessment; the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS). These were selected to reflect, based on information available at the time, a future in the latter part of the century that would be:

- typical or near to the general average of the future climate projections (MRFS), and,
- a more extreme future based on the upper end of the range of projections of future climatic conditions and the impacts such changes would have on the drivers of flood risk (HEFS).

The MRFS and HEFS provide potential futures that permit flood hazard and risk assessments to be undertaken to identify possible impacts of climate change on flooding, which, in turn, enables an assessment of the vulnerability of different communities and areas around the country to such possible changes. This will inform how flood risk in these communities should be managed now and into the future, in terms of policy and approach as well as the design of any proposed infrastructure, taking account of the potential changes in flood hazard (i.e., extents, levels, depths, etc.) and the sensitivity of the community to climate impacts.

The changes in flood-related parameters under each scenario are set out in Table 1.

Parameter	MRFS	HEFS
Extreme Rainfall	+ 20%	+ 30%
Depths		
Peak Flood Flows	+ 20%	+ 30%
Mean Sea Level Rise	+ 500 mm	+ 1000 mm
Land Movement	- 0.5 mm / year ¹	- 0.5 mm / year ¹
Urbanisation	<i>Review on Case-by-Case Basis</i>	<i>Review on Case-by-Case Basis</i>
Forestation	- 1/6 Tp ²	- 1/3 Tp ² / + 10% SPR ³
Note 1: Applicable to the southern part of the country only (Dublin – Galway and south of this) Note 2: Reduction in the time to peak (Tp) to allow for potential accelerated runoff that may arise as a result of drainage of afforested land Note 3: Add 10% to the Standard Percentage Runoff (SPR) rate: This allows for temporary increased runoff rates that may arise following felling of forestry.		

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

The allowances were not derived from, nor are linked directly to, a specific sub-set of projections from within the modelling that informed the IPCC reports. They were, rather, based on the range of potential impacts from sources available at the time, including research outputs from down-scaling climate impact projections by Sweeney and Fealy (2006), the EPA Report on climate change impacts (2003), and the guidance at that time from the UK, the Flood and Coastal Defence Project Appraisal Guidance (CDPAG3) (DEFRA, 2006).

It is important to reiterate, however, that the MRFS and HEFS are not intended to represent specific projections and model outcomes, but rather provide potential, or 'representative' futures; an approach based on the theory of representative futures (Whetton et al., 2012). This approach informs indicative or possible futures developed from an overview of the ensemble of future projections, and as such, they are not specifically time-bound, but could be taken, where a time-line is required, to represent possible futures up to 2100.

It can be seen that the allowances for the MRFS and HEFS for mean sea level rise would be close to the average and the top end of the projections from the IPCC 5th Assessment Report (IPCC, 2013) respectively. The scenarios also lie mid-range and at the upper end of the projections of sea level rise in the IPCC 1.5°C report (IPCC, 2018). Irish research on the application of the scenario-neutral approach for flood risk management (Broderick et al., 2019) indicates that MRFS and HEFS allowances for change in peak flood flows also cover the significant majority of projected changes (based on the Coupled Model Inter-comparison Project 5, or 'CMIP5' ensemble) for the catchments tested and across the four RCPs. The comparability of the two future scenarios adopted for the CFRAM Programme against current international projections gives confidence that they are acceptable as plausible futures for use in assessing potential requirements for adaptation.

Ongoing and future research may provide revised projections of potential impacts, which in turn may necessitate revised hazard and risk assessments. In this instance, use will be made in so far as possible of the mapping and risk assessment work done to date based on the MRFS and HEFS, e.g., through interpolation. The ICWWS for example involves the assessment of more extreme change, i.e., for projections of changes beyond the HEFS, in terms of mean sea level rise.

2.2 Case Study 1: Fluvial Flood Risk – Climate Impact Assessment for Ballinasloe, Co. Galway

A climate impact assessment for fluvial flood risk has been carried out for Ballinasloe. This is based on the Shannon CFRAM Study using the Present Day Scenario in comparison to the MRFS and HEFS. Figure 2 presents flood extent maps showing the Present Day Scenario and the HEFS for the 1% AEP event.

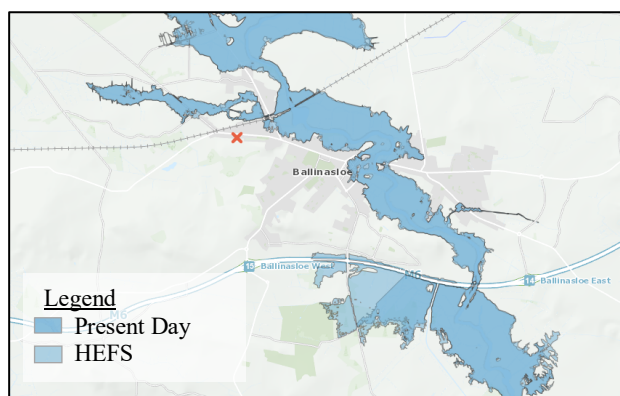


Figure 2. Fluvial Flood Extents – 1% AEP Event

Table 2 provides details on the number and type of risk receptors, as well as the estimated event damage cost for the Present Day Scenario and HEFS.

Type of Risk	1% AEP Present Day	1% AEP HEFS
Event Damage (€)	10,244,554	19,262,669
No. Properties at Risk	51	68
No. Major Utilities and Transport Assets at Risk	6	9
No. Social Infrastructure Assets at Risk	4	7
No. Environmental Assets at Risk	0	0
No. Potential Pollution Sources at Risk	63	127

Table 2 – Comparison of Present Day Scenario and HEFS

This shows that there is an estimated 51 properties currently at risk from flooding during the 1% AEP event. Under climate change condition, which is estimated as a flow increase of 30% under the HEFS, the number of properties is predicted to increase to 68 in comparison to the current condition. The cost of flood damage at Ballinasloe is currently estimated at over €10 Million for the 1%AEP event and this is predicted to almost double under climate change condition.

2.3 Case Study 2: Coastal Flood Risk – Climate Impact Assessment for Limerick City

A climate impact assessment for coastal flood risk has been carried out for Limerick City and Environs. This is based on the Shannon CFRAM Study using the Present Day Scenario in comparison to the MRFS and HEFS. Figure 3 presents flood extent maps showing the Present Day Scenario and High End Future Scenario for the 0.5% AEP.

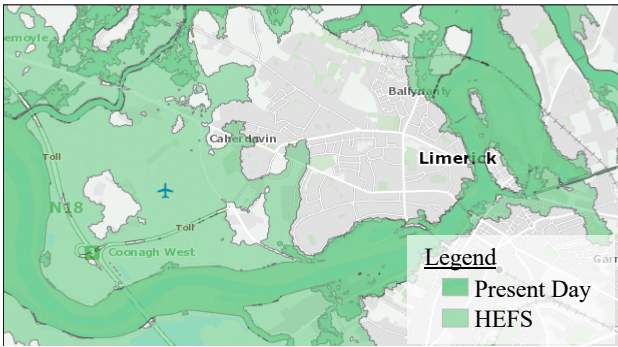


Figure 3. Coastal Flood Extents – 0.5% AEP Event

Table 3 below present details on the number and type of risk receptors, as well as the estimated event damage cost for the Present Day Scenario and High End Future Scenario.

Type of Risk	0.5% AEP Present Day	0.5% AEP HEFS
Event Damage (€)	83,149,253	1,035,710,958
No. Properties at Risk	1370	3146
No. Major Utilities and Transport Assets at Risk	49	71
No. Social Infrastructure Assets at Risk	10	18
No. Environmental Assets at Risk	4	6
No. Potential Pollution Sources at Risk	0	1

Table 3 – Comparison of Present Day Scenario and HEFS

This shows that there is an estimated 1,370 properties currently at risk from flooding during the 0.5% AEP event. Under climate change condition, which is estimated as sea level rise by 1m under the HEFS, the number of properties at risk is predicted to increase by more than double in comparison to the current condition. The cost of flood damage at Limerick City and Environs is currently estimated at over €83 Million for the 0.5%AEP event and this is predicted to rise to over €1 billion under climate

change condition. This corresponds to an increase of 12.5 times in comparison to the current condition.

2.4 Case Study 3 – Coastal Flood Risk – Climate Impact Assessment for Ardfry to Kilcolgan, County Galway

A climate impact assessment for coastal flood risk has been carried out for the study area from Ardfry to Kilcolgan. The assessment is based on the Irish Coastal Protection Strategy Study (ICPSS) flood extent maps using the Present Day Scenario in comparison to the High End Future Scenario (HEFS).

The ICPSS flood extent maps showing the Present Day Scenario and HEFS for the 0.5% AEP event are presented in Figure 4.

Table 4 below presents details of the number and type of risk receptors for the Present Day Scenario and HEFS. The table shows that there is an estimated 28 properties currently at risk of coastal flooding during the 0.5% AEP event.

Type of Risk	0.5% AEP Present Day	0.5% AEP HEFS
No. Properties at Risk	28	117
No. Major Utilities and Transport Assets at Risk	21	26
No. Social Infrastructure Assets at Risk	41	56
No. Environmental Assets at Risk	5	5
No. Potential Pollution Sources at Risk	0	0

Table 4 – Comparison of Present Day Scenario and HEFS

Under the HEFS, more than 4 times the number of properties (117 no.) are predicted to be at risk in comparison to the current condition.

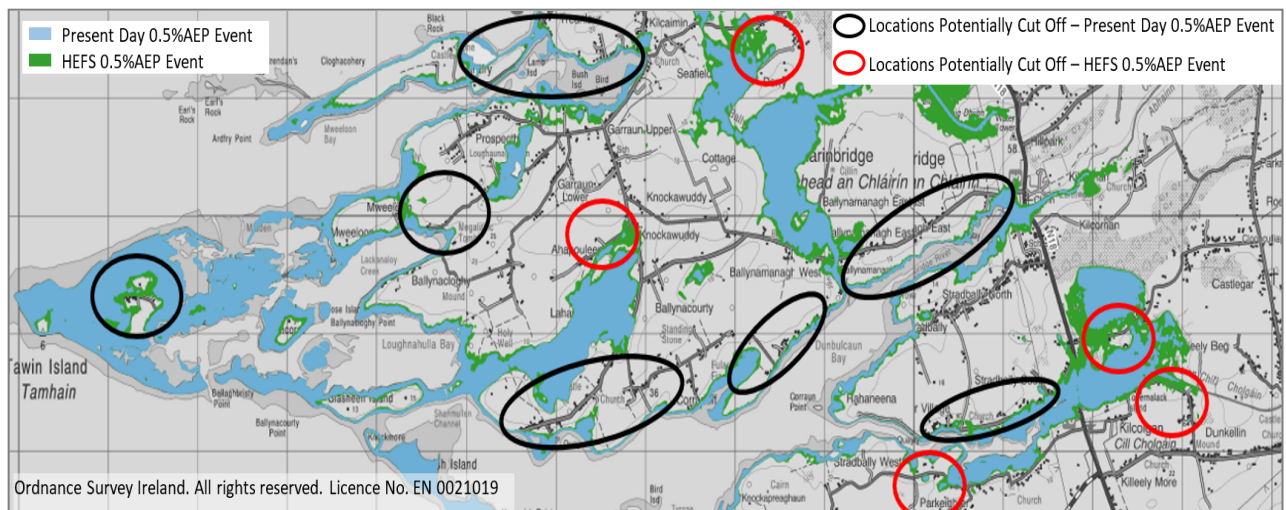


Figure 4. Locations where Access is Potentially Impacted

There are a number of environmental assets located within the study area including European designated sites, an OSPAR Marine Protected Area (MPA) and a Ramsar Site which may be negatively impacted under the HEFS. For example, coastal habitats in the intertidal zone will be at risk from rising sea levels and may be permanently under water in the future resulting in many coastal habitats being lost or irreversibly altered.

In addition to the increased number of properties and assets at risk in the future climate change scenario, rising sea levels will likely increase the frequency of properties being isolated or “cut off” during extreme coastal storm events. Figure 4 below illustrates the locations where access may be impacted during Present Day and HEFS 0.5% AEP events.

2.5 Potential Climate Impact Nationally

The national CFRAM study entails a very detailed risk assessment using the hydrodynamic modelling, as outlined in Section 1.2, and covering 300 AFAs that contain almost 35,000 at-risk properties; approximately 80% of those currently at risk from flooding from rivers and the sea in Ireland. Data from this risk assessment has been analysed to provide an indication of the potential climate change impact for Ireland nationally.

The total number of at-risk properties was estimated for the 10%, 1% and 0.1% AEP events under three scenarios (Present Day, MRFS and HEFS). Each data set was standardised against the equivalent AEP for the Present Day condition to indicate the potential impact of Climate Change. This analysis was undertaken separately for fluvial and coastal risk and results are presented in Figure 5.

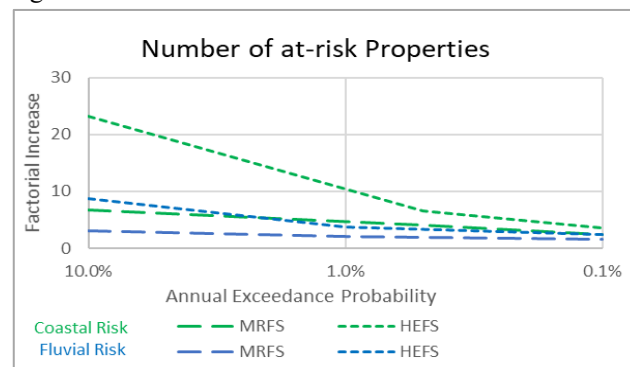


Figure 5. Increase in properties at risk – Standardised data for Present Day Condition using corresponding AEP

Results suggest that the factorial increase is significantly higher for the more frequent events (10%AEP) than it is for the extreme events, such as the 1%AEP and 0.1%AEP event.

Comparing fluvial and coastal risk would also suggest a more significant factorial increase in coastal risk, which is estimated to increase by a factor of 7 for the 10%AEP event and MRFS, and a factor of 23 for the 10%AEP event and HEFS. It should be noted that this significant increase in factorial increase in properties at risk from flooding is due to some degree to the relatively low number of properties currently at risk during the 10%AEP event.

The data for each scenario and AEP event was also standardised against the 10% AEP Present Day condition. This analysis was undertaken separately for fluvial and coastal risk and results are presented in Figure 6.

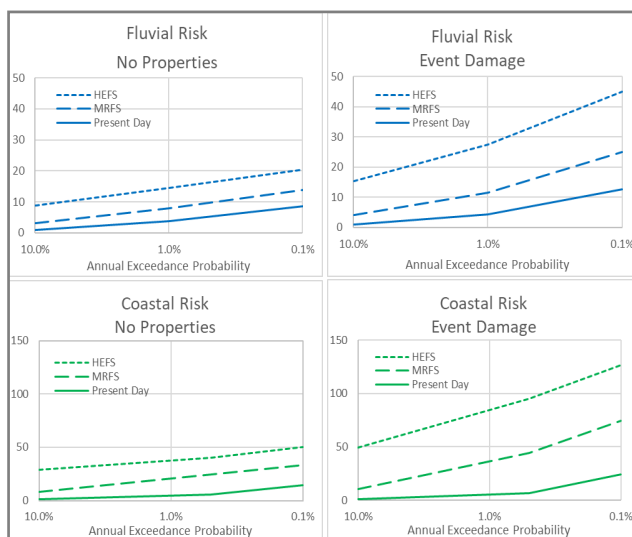


Figure 6. Increase No Properties and Event Damage – Standardised data for 10% AEP event and Present Day Condition

Results show a significant factorial increase in the number of properties at-risk under climate change conditions, and an even higher factorial increase in the Event Damage. The higher increase in Event Damage is due to the fact that most properties that are currently at risk (Present Day) will also incur further increase in Event Damage, due to increased flood depth under climate change conditions. This increase in event damage, combined with the substantial increase in the number of properties at risk in more frequent events, will create a significant increase also in the annual average flood damages that communities may experience.

When comparing fluvial and tidal risk, it is evident again that the factorial increase in risk is significantly higher for coastal flood risk than it is for fluvial flood risk.

The potential impacts of climate change can also be considered in terms of changing frequency for a given severity of events, i.e., what will the 0.1%AEP Present Day event become under climate change conditions. Findings for both fluvial and coastal risk suggest that under climate change conditions, there would be a shift in frequency for a given event severity, i.e. a 0.1%AEP Present Day event would become approximately a 1%AEP event under the MRFS climate change conditions. Similarly, a 1% AEP Present Day event would become approximately a 10% AEP event under the MRFS. For coastal flood risk, the number of properties at risk in the 10% AEP HEFS event will be approximately double the number currently at risk in the 0.1% AEP event.

Table 5 shows the approximate expected future frequency of extreme flood levels for recent coastal floods in Dublin, Cork and Limerick under both the MRFS (0.5m rise in mean sea levels) and the HEFS (1.0m of mean sea level rise), indicating a similar shift in frequency.

Event	Present Day	MRFS	HEFS
Dublin - Feb 2002	1 - 2%	50%	Very Frequent
Limerick - Feb 2014	1 - 2%	5 - 10%	50%
Cork - Feb 2014	1 - 2%	50%	Very Frequent

Table 5 – Potential Future Frequency of Recent Coastal Flood Events under the Current Scenario, the MRFS and the HEFS

It is clear from this national summary and demonstrated at three case studies that, without the ongoing and future investment in flood risk management, the impact of the MRFS and HEFS on flooding and flood risk in terms of increased damage for a given event frequency would be very significant.

For flood events that would occur relatively frequently (those with a 10% AEP event), the number of properties that would potentially become at risk increase very significantly in percentage terms, with a commensurate rise in potential damages.

It should be noted however that:

- many of these properties are to be protected against such events by flood relief schemes that are currently in construction or under design, or that are planned as set out in the FRMPs.
- For rare flood events (those with a 1%AEP), the number of properties at risk increase significantly. For example, the number of properties that could become at risk in the MRFS approximately doubles for fluvial (river) flooding and approximately quadruples for coastal flooding. However, climate change is taken into account in the design and implementation of flood relief schemes currently in construction or under design, or that are planned as set out in the FRMPs, and so many of these additional properties will also be protected.

3 Climate Change Adaptation

The draft Climate Change Sectoral Adaptation Plan (CCSAP) for Flood Risk Management was published on the 19th July 2019 for the purpose of public consultation for a period of four calendar weeks. Consultation Guideline Notes were made available for making a submission.

A total of twenty-eight submissions were received in response to the public consultation from a range of bodies including state bodies; academia; industry interest groups; private individuals and others. A summary of the issues frequently raised within the submissions are as follows.

- Importance of a whole of government response and collaboration across sectors to address climate change impacts.
- Interest in capacity building in relation to impacts of climate change on flood risk and possible adaptation opportunities.

- Emphasis of the importance of working with nature, the consideration of water quality and biodiversity and of natural flood management as part of the adaptation response to climate impacts.
- Concerns in relation to planning and planning guidelines.
- Concerns associated with a specific flood relief scheme and associated local issues.
- Concerns in relation to the causes of, and mitigation measures for, climate change.
- Concerns in relation to climate predictions and the science of climate change.
- Concerns in relation to coastal erosion.
- Proposals for the provision of further information or greater detail on particular topics / sections within the Plan.

All submissions were comprehensively reviewed with careful consideration given to the issues raised and the final Plan was adopted by Government in October 2019. The long-term goal adopted by the OPW on climate adaptation for flooding and flood risk management is:

Promoting sustainable communities and supporting our environment through the effective management of the potential impacts of climate change on flooding and flood risk.

To deliver on this goal, the OPW has identified the following adaptation objectives:

- Objective 1: Enhancing our knowledge and understanding of the potential impacts of climate change for flooding and flood risk management through research and assessment
- Objective 2: Adapting flood risk management practice to effectively manage the potential impact of climate change on future flood risk
- Objective 3: Aligning adaptation to the impact of climate change on flood risk and flood risk management across sectors and wider Government policy

A number of actions have been identified under each adaptation objective across the areas of activity in flood risk prevention, protection and preparedness and resilience, as well as in further research and capacity building.

3.1 Flood Risk Prevention

The National Flood Policy Review of 2004 identified flood risk prevention (i.e., the avoidance of creating new flood risks) as an area needing further development in Ireland. At the core of 'prevention' as a flood risk management strategy is sustainable development.

Shortly after the adoption of the Policy Review, the OPW and the Department of Environment, Heritage and Local Government (DEHLG) began developing guidelines to assist planners in taking flooding into consideration in planning and development management. The guidelines were published for consultation in 2008, and then adopted and published under Section 28 of the Planning Act in November 2009 (DEHLG/OPW, 2009).

These Guidelines provide a clear framework for sustainable planning taking a risk-based approach whereby flood-sensitive development should avoid flood-prone areas, based on classifications of land-use vulnerability and flood zones. On an exceptional basis, town centre development in flood prone areas may be appropriate (subject to a justification test), providing the risk is managed. The Guidelines apply to developers, as well as the planning authorities, and so public bodies, semi-state companies and private developers, should apply the principles and approach set out, including avoiding development in areas prone to flooding where possible.

The Guidelines have been in effect, at the time of publication, for over ten years, and have achieved widespread application. The successful and effective implementation of the guidelines is critical for the sustainable management of flood risk in Ireland in the long-term.

3.1 Protection

As of the end of 2019, the OPW had completed 46 flood relief schemes. As sea levels continue to rise, and if river flood flows and levels rise as a result of the impacts of climate change, the standard of protection offered by these flood relief schemes will be reduced.

The potential impacts of climate change on the standard of protection of the existing, completed flood relief schemes was assessed under the CFRAM Programme. As the potential impacts of climate change evolve over the coming decades, this assessment can in time inform planning for how the potential decrease in standard of protection can be managed, where no provision for climate change was made during design or construction. Options for adaptation of existing schemes include:

- Enhance or amend the existing scheme to maintain the standard of protection,
- Introduce other measures to maintain the standard of protection, and
- Maintain the existing scheme, accepting that standards of protection will fall, and introduce other measures to manage or reduce the increasing flood risk.

Examples of such future adaptation actions might include Natural Water Retention Measures (NWRMs) for upland and smaller communities and tidal barriers for some of our large towns and cities situated on the coast or estuaries, or upstream storage for communities prone to fluvial risk. These future adaptation actions may not be required, viable or environmentally or socially acceptable at this time, with alternative viable and effective measures applied in the interim, but will need to be assessed in the future in relevant areas as the flood risk increases.

The need for such interventions will be triggered through the 6-yearly review cycle of flood risk, as required under the EU 'Floods' Directive. These regular reviews will be informed by observations of sea level rise and changes in rainfall patterns and flow regimes through the hydrometric monitoring programme and the climate projections current at that time. The trigger points can be

identified in a timely manner to allow for the analysis, design and construction processes.

For the new flood relief schemes, a requirement has been set to assess the adaptation options to the potential impacts of climate change as part of the detailed scheme development, design and implementation, and for a Scheme Adaptation Plan to be prepared for each Scheme on foot of these assessments. The assessment and Scheme Adaptation Plan should determine the most robust, 'no regrets' strategy and design for short-term investment in flood risk management measures, taking account of the range of mid- to long-term future investments that may be necessary. This will help ensure that future flood relief works are sustainable and resilient to change.

The assessment of alternative adaptation approaches and options may be done making use of methods such as decision-tree analysis in conjunction with multi-criteria analyses and economic cost-benefit assessments. There is no 'one-size-fits-all' approach to applying adaptation to a flood relief scheme. A range of factors can influence what the preferred option or range of options might be, including:

- Changing degrees of risk for changing flood flows or levels into the future;
- the costs of works to address current risk, and of taking different approaches to dealing with the potential impacts of climate change, taking account of the need to maintain a positive benefit-cost ratio for any proposed scheme;
- what is most appropriate now to deal with the existing risk;
- the location of the works and how they might impact on local amenity and the environment;
- the nature of the works and whether they can be adapted in the future, or would need full replacement;
- what alternative steps might be available in the future to address rising hazard and/or risk.

Possible adaptation measures for a new scheme could include:

- a) The Assumptive Approach, where an allowance is built into a scheme now (e.g., additional height to a defence or additional capacity to a channel or culvert).
- b) The Adaptive Approach, whereby the measure is designed and built now to permit future changes (e.g., future increases in height of a defence or increases of conveyance capacity of a channel). Note that future increases in height of a defence may be demountable where it would not be acceptable / appropriate to install higher permanent defences.
- c) The adoption of alternative or additional measures in the future to address changes in risk patterns (e.g., building a new defence to cut off a new flow path arising from increases in flood flows / levels, implementation of catchment runoff control measures (e.g., storage or NWRMs) or removal of assets from the at-risk areas).
- d) Acceptance of rising flood probabilities and enhancing non-structural responses to flooding (improved flood forecasting, emergency response and/or resilience).

A Scheme may adopt two or more of the above approaches for different elements of the scheme, as appropriate to the context of each, and/or for different time horizons / degrees of climate change impact.

Each scheme will therefore be subject to an assessment of adaptability for future climate change within its particular context, and, as appropriate, provisions will be made in the design and construction of the schemes to cater for potential future changes. The Brief for the detailed development of the schemes includes a requirement for a Scheme Adaptation Plan that will set out how climate change has been taken into account during the design and construction, and what adaptation or alternate measures might be needed and when into the future. Ongoing monitoring of climate change indicators and projections will be required to identify when ‘trigger points’ may be reached necessitating the need for further investments or action.

3.2 Preparedness and Resilience

Flood risk preparedness, response and resilience is an area of work that was identified for development by the National Flood Risk Policy Review. The Interdepartmental Flood Policy Coordination Group, that is led by the OPW, was established to consider the extent that non-structural solutions could inform the implementation strategy of the Flood Risk Management Plans and to ensure that policies that can benefit communities and individuals directly – to be prepared for and respond to or live with flood risk – are carefully considered.

Measures that been advanced, or are under development, in Ireland that can help build community preparedness and resilience for future floods include:

- Provision of real-time data on water levels on www.waterlevel.ie and historical flood data on www.floodinfo.ie,
- Provision of a coastal surge forecasting service which allows Local Authorities and other relevant stakeholders up to three days advance notification of impending coastal storm surge events,
- The 'Plan, Prepare, Protect' initiative booklet was prepared in 2014 that provides practical advice to the public on how to prepare for potential flooding <https://assets.gov.ie/40603/37e2ec17800e4e9a812678edb31024d7.pdf>
- The provision of the national past flood event database (now available via www.floodinfo.ie) to promote awareness of flooding.
- The guidelines and templates for flood event emergency response plans prepared by the OPW and Department of Environment, Heritage and Local Government under the Framework for Major Emergency Management in 2008 have been revised.
- The Government decided in 2016 to establish a National Flood Forecasting and Warning Service. The service will deal with flood forecasting from river and

coastal sources and when fully operational will involve the issuing of flood forecasts and general alerts at both national and catchment scales.

- The Government agreed in November 2016 to introduce a targeted and prioritised once off Voluntary Homeowner Relocation Scheme for those primary residential homes that were flooded during the flooding event in winter 2015/2016. This is a once-off national scheme of humanitarian assistance, targeting aid at those residential homes worst affected by that flood event for which there are no alternative feasible measures.
- Supported communities’ preparedness by working with the Irish National Flood Forum.
- The OPW has undertaken a study to look at the potential support by Government of Individual Property Protection.

The Interdepartmental Flood Policy Coordination Group will continue its work and build partnerships, greatly informed by the wealth of knowledge and output from the CFRAM Programme. The Group will bring forward further feasible proposals for Government’s consideration to support and assist households and communities through non-structural flood risk management and mitigation measures.

3.3 Implementation of CCSAP

To ensure progress and continual improvement in adaptation, the implementation of the CCSAP will be monitored and reviewed through current structures. An annual review of progress will be undertaken to inform the Annual Sectoral Adaptation transition Statement for Flood Risk

The review and evaluation will need to be informed by indicators to enable critical assessment and to measure progress. The National Adaptation Framework notes that a priority for Ireland will be a project to develop a range of adaptation indicators to enable progress in preparing for the long-term effects of climate change to be monitored.

A research project considering ‘selecting and using indicators of climate resilience’ has commenced under the EPA’s climate research programme^d. Pending the completion of this project and/or the adoption of a national set of adaptation indicators, consideration has been given to the use of an interim set of indicators specific to flooding and flood risk management.

It is preferable to measure outcomes rather than outputs, but outcomes in relation to climate change adaptation will often take many years or decades to realise and may be difficult to quantify. Process-based indicators, that seek to monitor key stages that lead to choices about end points or outcomes can hence be used to ensure that defined actions are being implemented to promote a culture of, and capacity for, adaptation, and that adaptation is embedded in flood risk management processes.

^dhttp://www.epa.ie/pubs/reports/research/climate/Research_Report_263.pdf

The reporting of progress, will track the implementation of each of the actions set out in the Plan, and so only a limited number of indicators are defined to measure progress in key areas where quantitative measurement is possible and meaningful. The adaptation indicators to be measured are:

- The length and percentage of coastline for which flood mapping has been prepared and published for two or more future scenarios
- The length and percentage of river reach (with a catchment area greater than 5km²) for which flood mapping has been prepared and published for two or more future scenarios,
- The number and percentage of completed flood relief schemes for which appropriate adaptation options have been assessed and/or for which Scheme Adaptation Plans have been prepared,
- The number and percentage of flood relief schemes under construction for which appropriate adaptation options have been assessed and/or for which Scheme Adaptation Plans have been prepared ,and
- The number of properties (residential and commercial) benefitting from a flood relief scheme for which appropriate adaptation options have been assessed and/or for which Scheme Adaptation Plans have been prepared (Outcome Indicator).

4 Conclusion

This paper demonstrates the approach to flood risk management and climate change adaptation in Ireland. It provides an overview of the Sectoral Climate Change Adaptation Plan, which is based on the three pillars of flood risk management; Prevention, Protection and Preparedness and its overall goal is ‘Promoting sustainable communities and supporting our environment through the effective management of the potential impacts of climate change on flooding and flood risk’.

A significant amount of work was undertaken as part of the national CFRAM study, which entails very detailed risk assessments using hydrodynamically linked 1D2D modelling for 300 AFAs and containing almost 35,000 at-risk properties that were assessed for climate change impacts.

It is clear from this national assessment and demonstrated at three case studies that, without the ongoing and future investment in flood risk management, the impact of climate change on flooding and flood risk would be very significant. It should be noted however that the many of the properties potentially at risk in Ireland are to be protected against such events through the current flood relief investment programme.

Each scheme will be subject to an assessment of adaptability for future climate change within its particular context, and provisions will be made in the design and construction to cater for climate change, which will be detailed in the Scheme Adaptation Plan. This Plan will set out how climate change has been taken into account during the design and construction, and what adaptation or alternate measures might be needed and when into the future.

5 References

1. Broderick, C. Murphy, C., Wilby, R. and Matthews, T. (2019). Using a scenario-neutral framework to avoid potential maladaptation to future flood risk, *Water Resources Research*.
2. DCCAE (2018). *National Adaptation Framework*.
3. DEFRA, (2006). *FCDPAG3, Flood and Coastal Defence Project Appraisal Guidance: Economic Appraisal*.
4. DEHLG/OPW (2009). *Guidelines for Planning Authorities on the Planning System and Flood Risk Management*.
5. EU (2007). Directive 2007/60/EC on the Assessment and Management of Flood Risk. *Official Journal of the European Communities* L288 of 6th November 2007.
6. Galvin, C., Adamson, M. (2020). National Flood Mapping - Indicative fluvial flood map for Ireland. Paper for consideration at *FLOODrisk 2020*, Budapest.
7. Government of Ireland (1995). Arterial Drainage Amendment Act, Dublin: Stationary Office.
8. IPCC, 2013: *Summary for Policymakers*. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
9. IPCC, 2018: *Summary for Policymakers*. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.
10. OPW (2004). *Report of the National Flood Policy Review Group*.
11. OPW (2015). *Climate Change Sectoral Adaptation Plan for Flood Risk Management*.
12. Sweeney and Fealy, 2006. *ICARUS, Downscaling Global Climate Models for Ireland: Providing Future Climate Scenarios*.
13. Whetton, P, Hennessy, K., Clarke, J., McInnes, K., and Kent, D., 2012. Use of Representative Climate Futures in Impact and Adaptation Assessment, *Climatic Change* (2012).