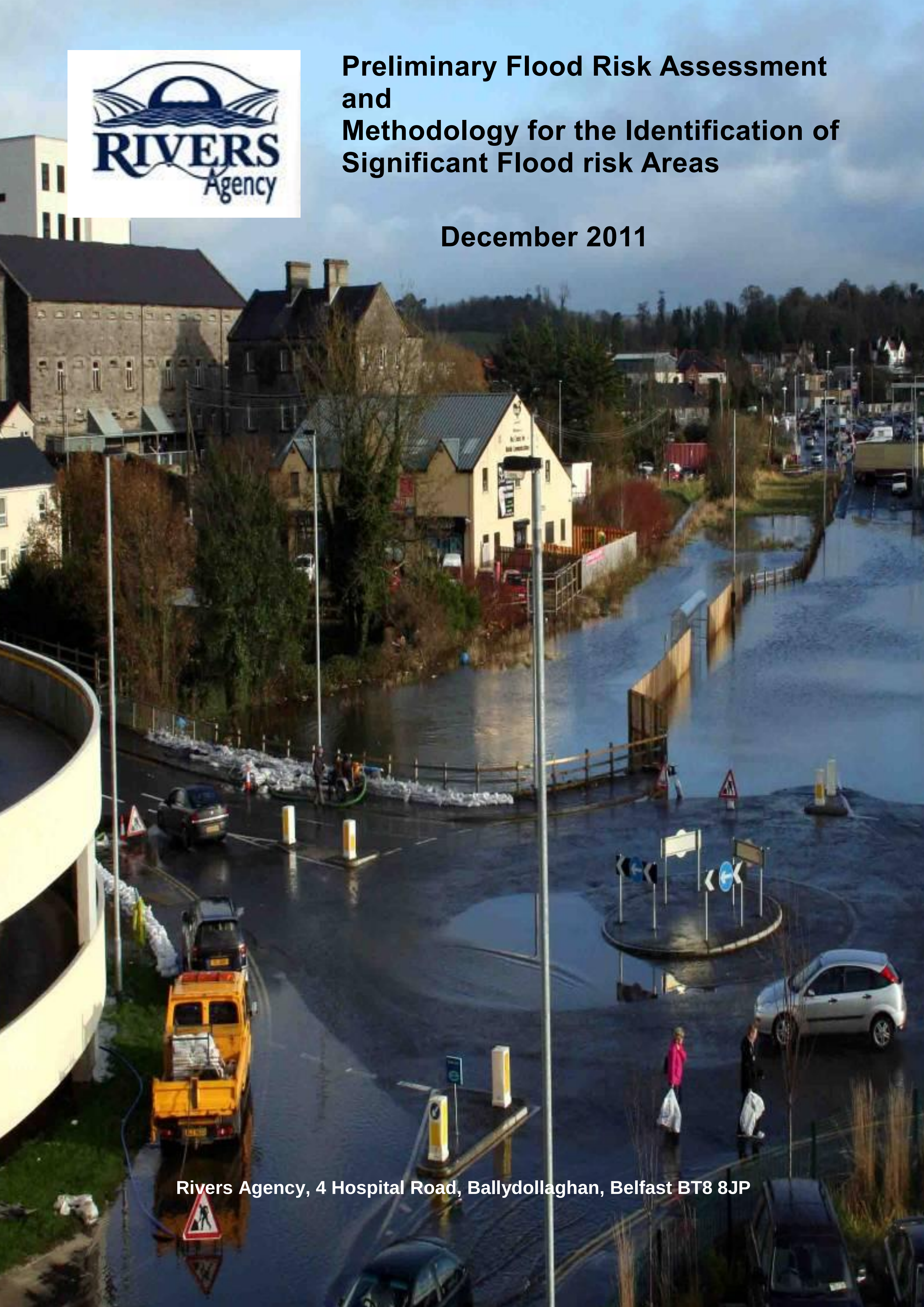
Preliminary Flood Risk Assessment and Methodology for the Identification of Significant Flood risk Areas

December 2011



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Contents

Abbreviations

AAAD	Aggregated Annual Average Damages
ACE	Association of Consulting Engineers
AKSF	Annual Key Services Flooded
ALC	Agricultural Land Classification
ASSI	Areas of Special Scientific Interest
BCR	Benefit Cost Ratio
DCLG	Department for Communities and Local Government
DDF	Depth-Duration-Frequency
DEM, DTM	Digital Elevation Model (unfiltered topography) Digital Terrain Model (bare-earth or filtered topography)
FEH	Flood Estimation Handbook
GAI	Geomorphological Activity Index
IPPC	Integrated Pollution Prevention Control sites
MCM	Multi-Coloured Manual from the Flood Hazard Research Centre manual assessing flooding damages
MDSF	Modelling and Decision Support Framework
NI	Northern Ireland
NINIS	Northern Ireland Neighbourhood Information Service
NISRA	Northern Ireland Statistical Research Agency
OPW	Office of Public Works, Republic of Ireland
OSNI	Ordnance Survey Northern Ireland
PFRA	Preliminary Flood Risk Assessment
SFRA	Significant Flood Risk Area

Executive Summary

The principal aim of this report is to deliver the Preliminary Flood Risk Assessment (PFRA) for Northern Ireland as required by Article 4 of the EU Floods Directive. The European Commission requires that the PFRA is completed by December 2011, is based of available or readily derivable information and assesses the potential adverse consequences of future floods on human health, economic activity, cultural heritage and the environment taking into account long term developments such as climate change. The PFRA considers flooding from all of the main flood sources including rivers, the sea, surface water runoff (also known as pluvial flooding) and impounded water bodies (such as dams and reservoirs).

The assessment of flood risk from impounded water bodies is not conclusively addressed within this report as there is currently insufficient 'available or readily available' information to conduct a robust assessment of the risk from this source. The reason for this lack of information is that, unlike the rest of the UK, Northern Ireland does not have legislation for the management of reservoir safety and as a consequence the owners of impoundments have not been required to collate such information as would be necessary to assess the potential risk of their failure. To bridge this information gap, Rivers Agency produced a separate strategic assessment, *Flooding from Impoundments – Northern Ireland (June 2010)* to scope the potential adverse consequences from flooding by impounded water bodies. This report has revealed that there are at least 156 large impoundments and that the risk to human health from their potential failure is 'significant'. Rivers Agency proposes to address the assessment and management of this risk through the introduction of new reservoir safety legislation and work to progress this legislation has commenced. Therefore, as the potential flood risk from impoundments has already been determined to be 'significant' and shall be effectively managed through a legislative mechanism the assessment of the flood risk from this source is not specifically covered within this report.

The PFRA report also provides Rivers Agency with information to comply with Article 5 of the Directive which requires each Member State to use the PFRA as the basis to *'identify those areas for which they conclude that potential significant flood risk exists or might be likely to occur.'* The identification of the Significant Flood Risk Areas (SFRA) is a critical milestone in the implementation of the Directive as these are the only areas for which the later requirements to produce detailed flood maps and flood risk management plans apply. This report does not seek to identify the SFRA as the decision as to what is considered 'significant' is yet to be finalised. A summary description of the Rivers Agency's methodology for the determination of significant flood risk areas can be found in Section 7. However it is important to note that the methodology may be revised up until the date at which the EU is formally notified of the SFRA for Northern Ireland. The current version of the Methodology for the Determination of SFRA is also available on the Rivers Agency's website at http://www.dardni.gov.uk/riversagency/

This report contains a narrative which describes the adverse consequences of major floods which occurred in the past and perhaps more importantly; it focuses on the quantification and measurement of the potential adverse consequences of floods that may occur in the future.

Flood risk is a measure of the statistical probability that flooding will occur combined with the adverse consequences of the flooding. The assessment of future flood risk therefore requires a detailed understanding of the flood mechanisms for each source of flooding, the magnitude and statistical probability of flood events and the scale of the potential adverse consequences arising from these events. The extent of the potential future flood hazards for each source of flooding for a range of return periods was determined using predictive flood inundation models developed by Rivers Agency for rivers, sea and surface water. Although strategic in nature these models have been developed using best practice methodologies that utilise the available topographical and land use data.

The predictive flood models used for the assessment ignore the presence of existing flood defences and therefore represent the worst case scenario. This precautionary approach has been taken because there is currently a degree of uncertainty about the level of protection that each of the defences provides. By adopting this approach, urban areas that are located behind existing major flood defence structures shall feature as SFRA by default. This will provide the opportunity to undertake the detailed structural assessment and hydraulic modelling necessary to establish the actual level of protection offered by these defences and the extent of the areas which they benefit.

From the information gathered for PFRA it is estimated that 46,000 or 5% of the 830,000 properties in Northern Ireland are located within the un-defended 1 in 100yr (1% AEP) fluvial floodplain or 1 in 200yr (0.5% AEP) coastal floodplain (Rivers Agency, 2008). Approximately 15,500 of these properties are protected to some extent by flood defence systems and the culvert network. In addition, the surface water flood map indicates that around 20,000 or 2.5% of the properties in Northern Ireland are sited in an area that is shown to be at risk of flooding from a 1 in 200yr (0.5% AEP) pluvial event with a depth greater than 300mm, however, many of these properties would already be at risk of flooding from fluvial and/or coastal flooding.

To support the PFRA process a GIS application was developed to combine the flood outlines for each of the sources with a wide range of receptor datasets. A description of the data used in the assessment can be found in Section 2 of the report and include for example, building polygons (for residential and non-residential property), transportation infrastructure (road, rail, air and sea ports) and key infrastructure assets (electricity, gas, water supply/waste, hospitals, GP Practices, Care Homes, Police Stations, Fire Stations etc). Embedded within the application is a Flood Risk Query Tool which applies algorithms to the data to quantify the flood risk in terms of flood risk indicators. A broad range of flood risk indicators have been generated to measure the adverse impact of potential flooding on groups of receptors and these quantitative indicators are used in whole or in part to assess the potential flood risk in the broad categories required by the Directive; i.e., human health, economic activity, cultural health and the environment.

The flood risk indicators have been ‘annualised’ by using flood events with different return periods to estimate the long term annual average impacts. For example, the flood risk indicator, *Aggregated Average Annual Damage (AAAD),* is the estimated average economic damages arising from all sources of flooding which, taken over the very long-term, is likely to occur on an annual basis. Similarly, the Aggregated *Annual Average Key Service Flooded (AAAKSF)* is an estimate of the number of key services assets that may be flooded in an average year from all sources.

As the principal objective of the PFRA is to assist in the identification of those geographical areas where flood risk is most significant within the national context the suite of flood risk indicators are measured in 1km grid squares. By computing the flood risk indicators at this spatial level it is possible to use them to compare and contrast the risk across the province at a broad community scale. The methodology for the determination of significant flood risk areas describes how appropriate threshold values for key flood risk indicators are used to establish draft SFRA and how these were refined by the responses from a major stakeholder consultation exercise to finalise and ‘determine’ the SFRA.

1. Introduction

1.1 Background to the Preliminary Flood Risk Assessment

The European Directive on the Assessment and Management of Flood Risks (2007/60/EC) came into force on 26 November 2007 and was transposed into local legislation by The Water Environment (Floods Directive) Regulations (Northern Ireland) 2009. Article 4 of the Directive requires that each member state undertakes a Preliminary Flood Risk Assessment (PFRA) for their respective territories by 22 December 2011. The PFRA shall be based on available or readily derivable information and shall assess the adverse consequences of flooding on human health, economic activity, cultural heritage and the environment from all of the potentially significant sources of flooding which for Northern Ireland have been determined to be rivers, sea, surface water and impounded water bodies. However, the assessment of flood risk from impounded water bodies is not conclusively addressed within this report as there is currently insufficient 'available or readily available' information to conduct a robust assessment of the risk from this source. The reason for this lack of information is that, unlike the rest of the UK, Northern Ireland does not have legislation for the management of reservoir safety and as a consequence the owners of impoundments have not been required to collate such information as would be necessary to assess the potential risk of their failure. To bridge this information gap, Rivers Agency produced a separate strategic assessment, *Flooding from Impoundments – Northern Ireland (June 2010)* to scope the potential adverse consequences from flooding by impounded water bodies. This report has revealed that there are at least 156 large impoundments and that the risk to human health from their potential failure is 'significant'. Rivers Agency proposes to address the assessment and management of this risk through the introduction of new reservoir safety legislation and work to progress this legislation has commenced. Therefore, as the potential flood risk from impoundments has already been determined to be 'significant' and shall be effectively managed through a legislative mechanism the assessment of the flood risk from this source is not specifically covered within this report.

Article 5 of the Directive requires member states to use the PFRA as the basis on which to *'identify those areas for which they conclude that potential significant flood risk exists or might be likely to occur.'* The methodology used to determine the location and extent of these areas which the Agency refers to as Significant Flood Risk Areas (SFRA) must be reported to the EC with the PFRA or a short time thereafter. Detail of the Rivers Agency's methodology for the determination of SFRA is included in Section 7.

The identification of the areas that are potentially at risk of flooding now and in the future requires, at the very least, a strategic understanding of the national flood risk from the various flood sources. Fortunately, the importance for such information has been long recognised by Rivers Agency and through its Flood Mapping Strategy, strategic flood models had already been completed for the fluvial and coastal flood risk before commencement of this project. As the management of the risk from pluvial flooding is not within the Rivers Agency's statutory remit, flood models for this source were not available. Damage from pluvial flooding has been a major factor in recent significant flood events within Northern Ireland and therefore could not be ignored. In the 2007 and 2008 flood events it is estimated that 84% and 60% of the respective damages are attributable to this source. In the absence of a single authority with responsibility for surface water, Rivers Agency in partnership with Roads Service, NI Water and Planning Service developed a strategic pluvial (surface water) model and this completed the suite of models necessary to conduct a national assessment of flood risk from all sources. The flood models for each of the flood sources were updated throughout the life of the project as new information or improved methods became available.

To generate the information necessary for the PFRA in general and for the identification of SFRA in particular, this national assessment focused on the measurement of adverse impacts using flood risk indicators. This approach was recommended in a report from the Republic of Ireland's Office of Public Works (OPW, 2008) and more recently, the Environment Agency's guidance on undertaking a PFRA in England and Wales (EA, 2010). This guidance included a CD which contained a suite of flood risk indicators that are based on counts of receptors that are located within the flood outlines depicted on the EA national flood map. The use of quantitative indicators has been recommended as a means by which to *'.. facilitate a transparent assessment of whether or not a particular location is subject to significant flood risk'* (OPW, 2008) and have also been included within various planning guidelines (see DCLG, 2006). Additional drivers for the use of flood risk indictors are that they provide an effective means by which to describe and communicate current and future levels of flood risk and that they can serve to identify high-risk locations in order to determine the appropriate levels of flood warning (Adamson et al., 2008)

Through this assessment Rivers Agency has reviewed and refined the 'available and readily derivable' datasets for a broad range of receptors, derived new or improved historical and modelled flood outlines for the various sources of flooding and generated a suite of flood risk indicators which have been measured on a regular 1km grid for the whole of Northern Ireland. The measurement of risk within a 1km grid has also been adopted in England and Wales (EA, 2010) and is widely considered to be an appropriate scale for a national flood risk assessment that is aimed at identifying individual communities at risk of significant flooding. Each of the flood risk indicators are a measure of the adverse impacts of flooding on human health, economic activity, cultural heritage or the environment and can be used to highlight the spatial variation in the level of risk within each of these categories.

Throughout the course of this assessment the methodologies used to assess and measure the flood risk have been shared with the Republic of Ireland through various workshops and dissemination events, including the Irish National Hydrology Conference. In addition there are formal arrangements that have been established between Rivers Agency and OPW to ensure compliance with Article 4(3) of the Directive which requires Member States to *'ensure that exchange of relevant information takes place between the competent authorities'* for trans-boundary catchments.

1.2 Report Structure

As the report shall provide 'supporting information' for the formal reporting sheets required by the EC, important information is referenced to the relevant articles of the Directive.

Section 1 of the report introduces the background to the main flooding issues in Northern Ireland, describes historical flooding and identifies key topographic and land-use features.

Section 2 focuses on the data used in the assessment which is categorised in terms of the flood sources, pathways and receptors and their associated vulnerabilities. It also describes how the output from the predictive flood models for each source of flooding can be combined with the receptor datasets to derive the long-term annual average impacts of potential future floods. It explains how the annualisation of adverse impacts is used to derive the quantitative flood risk indicators and how these are used to measure the spatial variation in the long term annual average flood risk on a regular 1km grid across the country.

Section 3 provides a detailed methodology for the derivation of flood risk indicators which describes how these have been calculated using automated GIS queries. It explains how a bespoke software application known as Flood Risk Lab, is used to generate the underlying flood risk metrics from which the flood risk indicators are calculated and how a results geo-database is used to present the data in a highly flexible user friendly manner. For example, it is possible to compute the flood risk indicators by flood source (or any combination of sources) using historical flood outlines or predictive flood outlines (with or without the predicted affects of climate change) and by defined spatial area.

Section 4 is designed is to satisfy the main requirements of the Directive's Article 4 and includes summary descriptions of the adverse consequences of past and possible future flooding and how flood risk may increase with climate change. The summary descriptions are supported by a collection of tables which contains a broad range of quantitative flood risk indicators that illustrate the extent of the risk at a national level and how this is distributed across each of the seven proposed Sub-plan areas (see Section 1.3). In addition, this flood risk data is visually represented using various graphs and charts which effectively communicate the distribution of the risk from each flood source at the scale of the 1km grid squares and also within the boundaries of the seven Sub-plan Areas.

Section 5 describes how the GIS based application and the embedded query tools can be used to generate a range of tables, maps and charts to represent the quantitative flood risk indicators and other relevant data in a highly visual manner.

Section 6 describes the PFRA conclusions.

Section 7 explains the methodology used by Rivers Agency to determine the location and extents of the Significant Flood Risk Areas to meet the requirements of Article 5 of the Directive.

1.3 Article (4)(a) – Maps illustrating topography, land use and boundaries of River Basin Districts and Sub-plan Areas.

This section meets the requirements of Article (4)(a) of the Directive which requires the production of appropriate scale maps to indentify boundaries of the River Basin Districts, river basins and coastal areas and illustrates the topography and land-use. Rivers Agency has determined that the River Basin Districts shall mirror those already established by the Department of Environment for the implementation of the Water Framework Directive. Therefore, within Northern Ireland there is one River Basin District (North Eastern RBD) and three International River Basin Districts (Neagh Bann IRBD, North Western IRBD and Shannon IRBD). The Directive requires that where river basins cross international boundaries, Member States shall refrain from taking measures or engaging in actions that significantly increase the risk of flooding in other Member States and shall coordinate their flood management activities. To secure compliance with this requirement Rivers Agency and the Office of Public Works have established formal structures to ensure the effective management of flood risk within the shared IRBDs. However, it is important to note that there are only a few square kilometres of the Shannon IRBD within Northern Ireland and as there is no flood risk concerns within or arising from this small area this IRBD is effectively excluded from this assessment. The Directive requires that Member States produce Flood Risk Management Plans coordinated at the level of River Basin District. At the commencement of this project Rivers Agency indicated that it was likely that the River Basin Districts would be sub-divided into seven Sub-plan areas which fit like a jigsaw within the boundaries of the RBDs. As illustrated in Figure 1-1, the North Eastern RBD will be covered by plans produced for the Antrim Coast, Belfast and the Down Coast; the Neagh Bann IRBD by plans for the Bann System and the South Armagh/Down & Louth and the North Western IRBD by plans for the Foyle System and the Erne & Melvin System. Each of the Sub-plan areas is a conglomerate of complete hydrological areas and therefore all of the individual river catchments and sub-catchments fit completely within the boundaries of a particular Sub-plan area.

The topographic representation used for the PFRA is shown in Figure 1-1 and is based on the Ordnance Survey 5m Digital Terrain Map for Northern Ireland. The land-use map is shown on Figure 1-2 and is based around the Land Cover Map 2000 (LCM2000) produced by the Centre for Ecology and Hydrology, Wallingford. The LCM2000 is produced from satellite imagery and provides the most up to date and accurate land coverage map for Northern Ireland. It illustrates, using a 'Broad Habitat' classification, the use of land on a field-by-field basis.

Figure 1-1 Topography, River Basin Districts & Sub Plan Areas

Figure 1-2 Land Use map of Northern Ireland

1.4 Background to flood risk in Northern Ireland

It is estimated that 46,000 or 5% of the 830,000 properties in Northern Ireland are located within the 1 in 100yr (1% AEP) fluvial floodplain or 1 in 200yr (0.5% AEP) coastal floodplain (Rivers Agency, 2008). Of these properties, approx 15,500 are protected to some extent by flood defence systems and the culvert network. The fundamental reason that people and property are at risk of flooding is that many towns and cities are located within the functional flood plains of rivers. The decision of our forefathers to select locations for settlement close to rivers was understandable and based on the need for drinking water, foul drainage, transport, commerce and fishing. The pressure for development within towns and cities that have a known flood risk has continued largely unabated until the introduction of relatively recent planning policies such as PPS 15 – Planning and Flood Risk. Properly implemented, this planning policy will limit future development that may be at risk of flooding or increase the risk of flooding elsewhere.

Apart from developing in flood prone areas there have also been broad scale changes to rivers and their watersheds that have resulted in an increased flood risk. Widespread deforestation together with drainage and land management practices designed to improve the productive potential of agricultural land have diminished the capacity of catchments to absorb storm-water. In addition, many rivers have been straightened and deepened and effectively separated from their flood plains by the construction of embankments and flood defences to prevent agricultural land and urban development from flooding. In many cases these human alterations to watercourses and their catchments have increased downstream flood risk to communities by increasing run-off rates and stream flow.

Much of our urban flooding is caused by rainfall overwhelming the drainage systems. This is an increasing problem that stems from an ageing drainage infrastructure that has not kept pace with the rate of development. Surface water runoff has increased due to development of the green spaces within, and expansion of our urban areas. Even the general permeability of our urban areas has changed as people build patios, pave gardens and build extensions. All of these factors have combined to intensify the surface water runoff and place additional pressures on the drainage network. It is important to note that even the most modern of our urban drainage systems are designed only to cope with a 1 in 30yr (3.3% AEP) rainfall event and that most of the older parts of the network will be operating to a much lower standard.

Looking forward, there is an almost universal acceptance within the scientific community that global warming is a reality and that as a consequence our climate is changing. The report, Preparing for Climate Change in Northern Ireland (SNIFFER 2007), states that Northern Ireland’s climate is already changing and that these changes are expected to accelerate over the coming century. Although the precise nature and extent of these changes is uncertain and continuously under review, most scientists agree that sea levels will continue to rise and that there will be an increase in the intensity of extreme rainfall events and in the overall winter precipitation. These changes to our weather patterns will increase the risk of flooding, both inland and along the coastline and possibly to the extent that floods which are currently considered to be ‘extreme’ will become more frequent in the future.

1.4.1 Fluvial flooding

Northern Ireland has one of the largest rates of run-off per unit area in the British Isles. Much of the country is low-lying and many of its rivers and streams have gentle gradients in their lower reaches. With lowland soils that are mostly clay rich and of low permeability there is the widespread potential for localised flooding.

Rivers Agency has an ongoing maintenance responsibility for more that 6800km of watercourses that have been ‘designated’ by the Drainage Council (a body set up under the NI Drainage Order (1973)). Many of these watercourses have been designated as a consequence of the associated flood risk to life and property.

1.4.2 Pluvial or surface water flooding

Pluvial or surface water flooding occurs as a result of rainfall which overwhelms natural or man-made drainage systems resulting in water flowing overland and ponding in depressions in the ground. It is a particular problem in urban areas which are often dominated by non-permeable surfaces (i.e. roofs, roads and car-parks).

As a consequence of the predicted increase in the frequency and intensity of extreme rainfall events due to climate change, urban areas are susceptible to an increasing risk of this type of flooding. Belfast has a long history of pluvial flooding and there are extensive newspaper reports of major flooding in the city as far back as the early 1900s. Recently, significant and widespread flood events occurred in June 2007 and August 2008 and it is estimated that 84 % and 60% of the respective total economic damages was caused by surface water. It is notable that on the 18th August 2008 the gauged daily rainfall totals across the province were recorded at between 80% and 100% of the average monthly average (Northern Ireland Assembly, 2008).

It is important to note that at the time of this report, no single statutory authority has an overarching responsibility for managing the risk of pluvial flooding and this is a policy gap which is currently under review by government. In the absence of a single responsible authority it was agreed by the NI Floods Directive Steering Group, the cross-departmental group established to ensure the effective implementation of the Directive, that Rivers Agency, NI Water, Roads Service and DOE Planning would cooperate in the development of a Surface Water Model for Northern Ireland. The surface water flood map was released to the public in December 2011 and indicates that around 20,000 or 2.5% of the properties in Northern Ireland are sited in an area that is shown to be at risk of flooding from a 1 in 200yr (0.5% AEP) pluvial event greater than 300mm deep. Many of these properties would already be at risk of flooding from fluvial and/or coastal flooding. The model also confirms the susceptibility of NI to the increasing threat from pluvial flooding as a consequence of climate change. Based on a range of flood risk indicators the model output for the climate change 2100yr epoch indicates that the pluvial risk to people, property and key services may increase by around 30%. A paper, Development of the Surface Water Flood Map for Northern Ireland was presented to the Irish National Hydrology Conference (Porter et al., 2010). The methodology used is detailed in the report, ‘A Surface Water Map for Northern Ireland – June 2010’.

1.4.3 Coastal Flooding

The coastline of Northern Ireland is approximately 650km long and is characterised by stretches of cliffs and rock, tidal inlets and sea loughs as well as stretches of long sandy beaches and dunes. Although significant coastal flooding is a relatively infrequent occurrence in Northern Ireland, Rivers Agency currently monitors and maintains 26km of sea defences and 2 tidal barriers that are designed to reduce the risk of the flooding to low lying coastal land, a significant proportion of which is reclaimed land that is now in agricultural production. Details of these structures, which are located at Lough Foyle and at various locations along the County Down coastline, can be found in the Rivers Agency’s Sea Defence Asset Management Plan (May 2008).

In 1902 a major storm surge coupled with an extreme rainfall event caused widespread flooding to homes and commercial properties throughout the greater Belfast Area. More recently in October 2004 there was flooding along the County Down coast as a result of an extreme tide and on the 10th March 2008 the River Lagan and Connswater River in Belfast were almost overtopped due to an extreme sea level of 2.28m OD in Belfast Lough (Rivers Agency, Storm Surge Report, March 2010). The UK Climate Projections 2009 (UKCP09) advises that climate change will cause an increase in relative sea levels around the NI coastline and that this coupled with an increase in the storminess of the weather will lead to more extensive and frequent coastal flooding.

As coastal flooding is often characterised by flows that are more rapid than for other sources of flooding the consequential risk to public safety is relatively high. Also, economic and environmental damage is generally higher due to inundation from saltwater than from freshwater. To reflect the relatively high potential impacts from coastal flooding the 1 in 200yr (0.5%AEP) flood event for this source is used as the medium probability event in the PFRA as opposed to the 1 in 100yr (1% AEP) event which is used as the medium probability event for assessing fluvial risk. This approach is similar to that used in Planning Policy Statement 15 (PPS15) – Planning and Flood Risk.

1.4.4 Groundwater flooding

Groundwater flooding is uncommon in Northern Ireland (Department of the Environment, 2006). This type of flooding generally occurs over and around aquifers where the underlying geology is highly permeable with a capacity to store rainfall (alluvial and fluvio-glacial aquifers). Other areas that could be prone to groundwater flooding include areas close to rivers that are underlain by bedrock aquifers, areas close to groundwater fed ephemeral streams and areas of groundwater rebound. Following a desktop review of the hydro-geology and flooding history there have been no areas identified as being at 'significant risk' of flooding from groundwater.

1.4.5 Geomorphological influence

There are many historical accounts of geomorphological activity influencing flood risk mainly through the deposition of sediments which can lead to blockages in channels, culverts and inlet structures. In a broad scale screening exercise (see Appendix H) the key datasets such as stream power, land-use and drift geology that are indicative of the risk of sedimentary deposition were used to identify specific reaches of watercourses that are most likely to be susceptible to this phenomenon. The index values used to identify watercourse sections that are potentially susceptible to deposition were reviewed and revised to give results which best fit with the sections that are known to contain depositional features and identified through aerial photography (Google Earth). Given the uncertainty associated with this approach and the difficulty in determining how flood risk may increase with the deposition of sediment for any particular watercourse, this flood risk indicator was not included in the methodology to identify SFRA. However, it is recommended that the future modelling studies that are undertaken to produce the detailed flood hazard and flood risk maps for SFRA take this geomorphology risk assessment into account. Maps illustrating the watercourses in which elevated geomorphological activity may have an impact on future flood risk have been produced an example of these is shown in Figure E-7.

1.4.6 Flooding from impounded water bodies

Unlike the rest of the UK, Northern Ireland does not currently have legislation for the management of reservoir safety. Initial indications are that there is around 156 impounded water bodies with a capacity greater than 10,000m3 within Northern Ireland. Approx one third of these are in private ownership with the remainder owned by public bodies and in particular by NI Water which owns around half. In the absence of legislation, the maintenance of impounding structures is unregulated. Consequently, it has not been possible to require the owners of impounded water bodies to produce such information as is necessary to determine the likelihood of failure and therefore a robust assessment of the flood risk associated with their potential failure was not possible. To bridge this information gap for the purposes of the PFRA, Rivers Agency undertook to estimate the scope of the potential adverse consequences of flooding from impounded water bodies and it produced inundation maps for each of the 156 reservoirs. Although these maps are based on a total dam failure, which is an extremely unlikely worst case scenario, they at least provide an indication of the potential adverse consequences of failure. This simplified approach has been necessary because detailed structural condition assessments for the impoundments are not available or readily derivable.

The scoping exercise has revealed that in excess of 66,000 people are located in areas which could potentially flood from a dam failure. Although the number of people within the dam failure flood outline is very high, it is not possible to estimate the likelihood of failure of any of the dams with any degree of accuracy and as a consequence there is no means to determine the actual 'significance' of the risk from this source. Given these shortcomings, Rivers Agency considers it appropriate to determine the impoundments as Reservoir Risk Areas (RRA) on the basis of potential flooding. It is the view of the Agency that the risk from this source would be most effectively managed through reservoir safety legislation similar to that which is in place elsewhere in the UK. Rivers Agency has commenced the process to make the legislation which, when introduced, shall place a legal responsibility on the owners and operators of impounded water bodies to effectively manage the associated flood risk. For the purposes of the PFRA, the flood risk from impounded waters will not be used in the determination of SFRA for the first six year planning cycle of the Directive.

1.4.7 Flooding from other sources

Flooding can arise from sewerage systems due to limited capacity, blockages, pump failures and high water levels at the outlets to receiving watercourses or the sea. However in transposing the EU Directive through The Water Environment (Floods Directive) Regulations (Northern Ireland) 2009, NI has exercised the permitted flexibility to exclude floods from sewerage systems that are caused solely by a system failure or blockage are therefore not considered in this assessment. Floods which occurs due to overloading of the sewerage systems as a consequence of extreme rainfall or higher than usual rivers levels are included within the terms of the Directive and have been assessed using the surface water flood model.

There have been a number of major flood events in urban areas in recent years due to extreme rainfall events and the inability of drainage systems to effectively vent the run-off is often a clear factor and cannot be ignored. The inability of the road drainage systems and storm drainage systems to cope with extreme events is limited as they are designed with the capacity to discharge the run-off from 1 in 1yr (100% AEP) and 1 in 30 yr (33.3% AEP) rainfall events respectively. As urban drainage systems and surface water flooding are inextricably linked it was decided that a notional sewer capacity should be included as a parameter in the development of the surface water flood map. Following current best practice in surface water modelling elsewhere in the UK it is assumed that the sewer network has the capacity to effectively vent rainfall up to 12mm/hr and therefore this figure is deducted from the rainfall profiles used in the model for high, med and low probability events. It is accepted that in some instances sewerage systems may have a larger or lesser capacity than the notional capacity and this assumption of itself is sufficient cause to treat the model outputs with a high degree of uncertainty. However, despite the limitations, the surface water flood map does serve to illustrate the areas in which this type of flooding may be a significant issue. This will enable the relevant drainage authorities to identify areas where a detailed examination of the sewerage systems may be required, perhaps using integrated flood models.

1.5 Historical flooding – Articles 4(2)(b) & (c)

This section addresses the principal requirements of Article 4(2)(b) of the Directive which requires *'A description of floods that have occurred in the past and which had significant adverse impacts … and for which the likelihood of similar flood events is still relevant, including their flood extent and conveyance routes and an assessment of the adverse impacts.*

An assessment of the adverse impacts of some of the most significant past floods was undertaken and is described in Section 4.8.

1.5.1 Historical flood data

Rivers Agency has been gathering data in regard to actual flood events for many decades, although much of the earlier information would be considered to be of questionable reliability by today's standards. Since the 1980s the Agency has been using aerial photography to capture the extents of major floods and this information supported by field officers flood reports has been invaluable in the production of accurate flood extents maps. Maps illustrating the location and extents of significant past flood events that have occurred in each of the proposed seven plan areas are contained in Appendix C. It should however be noted that most of the historical flood events that have been mapped are not identified with an event of a particular return period. Although the historical flood maps are useful insofar as they can serve as a strong visual reminder that the risk of flooding is very real, this information in itself is not sufficient to determine the likelihood of flooding now or in the future. In addition to the Agency's flood records, historical and fairly reliable records of flooding have been obtained through various newspaper articles and these have been a particularly useful source of information for floods that occurred as far back as the early 1900s.

1.5.2 Description of recent notable flood events

Given the quality of historical flood information and the relatively recent extensive urban development of Northern Ireland it has been determined that only the last 10 years of records will be used to fulfil the requirements of Article 4.

17 August 2004 – Derry City

August 2004 had an unsettled month with a number of heavy rainfall events affecting various parts of Northern Ireland. On the 17th a line on intense storms developed over Co. Tyrone during the day and became slow moving over the Derry City area during the late afternoon. It is estimated that 30mm of rain fell in the city centre area in less than an hour. The extreme rainfall overwhelmed drainage systems causing widespread flooding of the city centre. The floodwater inundated many commercial properties and homes mainly in the Dunluce Road, Strand Road and Shantallow area. It also trapped a number of motorists who had to be rescued from their cars by the emergency services.

1 December 2005 – Belfast

An active front moved east across Northern Ireland during the morning of the 1st December 2005. This produced several hours of heavy rain in parts of Armagh, Down and South East Antrim. The worst of the rain affected the Belfast Area were some parts in the south of the city received 25 to 30mm of rain in a 4 hr period which is estimated to be a rainfall event with a return period of around 20yrs. The worst area affected was the Lower Ormeau Road where around 40 homes were internally flooded. In addition 12 properties flooded in the Sydenham area and a small number in Downpatrick. All of these floods were related to surface water and/or out-of-sewer flooding. Although very wet, this type of rainfall is not uncommon and other factors appear to have played a part in the flooding on this occasion. For example, heavy rain had already fallen in the weeks prior to this event and the River Lagan was higher than normal and a high tide coincided with the period of the heaviest rainfall. In addition, a pumping station in the Lower Ormeau area failed which resulted in a much reduced ability for the local drainage infrastructure to cope with the run-off.

12 June 2007 – Widespread

Intense storms developed across central parts of Northern Ireland from late morning on 12 June 2007. The storms were typical intense and slow moving summer rainfall events. In the Omagh area 95mm of rain fell in the day and much occurred during a three hour period in the afternoon. This is the highest daily rainfall total recorded in that area since records began in 1872 and the event is estimated to have a return period in excess of 200 years. In the east of the province, 50mm of rain fell in the Belfast area in a 90 minute period.

The extreme rainfall caused widespread flooding with reports received by Rivers Agency of 48 separate flooding incidents, most notably in East Belfast where around 400 properties were adversely affected. Some of the worst flooding occurred at Ladas Drive when the Loop River, which rose by over 2m, burst its banks. The Knock River at Orangefield also overtopped its banks and caused serious flooding problems during which 80 residents of the Towel House old people's home on the Kings Road had to be evacuated after it was badly damaged by floodwater.

Although the greatest impact of the flooding was in East Belfast, serious flooding also occurred at Omagh and to a lesser extent at Lisburn, Cushendall, Antrim, Portrush and Dungannon. In total, more than 1000 households across the province received emergency flood relief payments of £1000 as a consequence of this event.

16 August 2008 – Widespread

A significant widespread rainfall event occurred on 16th and 17th August 2008 to the extent that the recorded rainfall on the 16th was typically between 80 to 100% of the normal monthly average. The rainfall depths were typically in the range 40 to 65mm with the greatest accumulation at Portglenone where 75mm was recorded. Although Belfast was worst affected by the flooding other areas in Antrim, Ballymena, Down, Newtownabbey, Craigavon, Banbridge, Beragh and Castlereagh were also significantly impacted. The newly completed Broadway underpass was flooded to a depth of around 4.6m when a grille blocked on the River Clowney and as a result the Westlink was closed for a period of 4 days. In addition, more than 100 roads were closed across the province and the Fire and Rescue Service had to rescue people from their cars and homes. There was significant damage to infrastructure, services and property and local councils received in excess of 1600 applications from householders for emergency flood relief payments. It was estimated that of the main source of flooding was surface water (pluvial) and that this may have contributed to around 60% of the total damage.

November 2009 – Fermanagh

The Erne Catchment experienced an unprecedented level of rainfall during November 2009. The Erne drainage system was incapable of venting the 337mm of rainfall which fell during this period and as a consequence Lough Erne rose to levels not seen since the 1950s. The rise in the Lough Erne levels caused extensive flooding of the surrounding lands particularly around the Upper Lough. There was severe and prolonged flooding of the Derrychara Link Road and Quay Pass which for a time denied access to the Erneside shopping complex car park and 9 adjacent retail units and caused severe traffic disruption throughout the town. The flooding presented very considerable challenges to the local population who had difficulties in accessing homes, shops, schools, farms and businesses. It also caused public health concerns, difficulties for the care of vulnerable groups and for the welfare of animals.

17 October 2011 – Widespread

Unlike the widespread August 2008 event the intense rainfall was confined to a relatively narrow band that runs diagonally across Counties Fermanagh, Tyrone and Antrim. The rainfall which amounted to around 30mm resulted in flooding at Fintona, Coalisland, Ballygawley, Ballinamallard, Kells, Sion Mills and Tempo. At the time of this reports publication information on the adverse affects of this flood event were still being collated. Investigations indicate that 26 dwellings and 11 businesses were inundated by floodwater. In Beragh, which has flooded in the past, houses and the local GAA clubhouse were inundated and emergency services had to rescue 18 residents trapped by the floodwaters from their homes. At Coalisland, flooding from the Canal Back Extension inundated at least 6 of the properties at Moor Close. There was flooding on the railway line between Newry and Belfast, South of Portadown and road culvert collapsed leaving a deep crater in a road near Fintona. Although there was no major flooding in Omagh it is estimated that the River Strule, which runs through the town, was considered to be at a 1 in 120 year water level which was extremely close to the top of the existing floodwalls.

1.5.3 Description of some major historical flood events

Belfast flooding - 1901/1902/1916

There are documented reports of flooding in Belfast as far back as the 1600s and there are detailed newspaper accounts of two major floods that occurred in 1901 and 1902. In November 1901 a severe rainstorm which lasted for two days coupled with an extreme high tide caused the River Lagan to overtop its banks at a number of locations and flood extensive low lying areas of the city. This flooding was reported in the Belfast Telegraph as *'beyond any like occurrence for 50 years.'*

Only a year later on 3rd Sept 1902, Belfast experienced even greater flooding. Many of the main rivers, including the Blackstaff River, Pound Burn, Connswater and the Farset surcharged and flooded much of the city centre. Again, this was due to a combination of heavy rainfall and high tides. The floods were described in the newspapers as unprecedented, with reports of enormous property damage and the closure of the majority of the mills and factories in the city. In addition to tidal and fluvial flooding, a dam burst on the Springfield Road and discharged to the nearby Blackstaff River and caused it to burst its banks. The newspaper estimates that due to the dam burst, a nearby street flooded to a depth in excess of 4m. In many other locations around the city the flood exceeded window levels and standing water ponded to a depth of 1.5m.

There is also evidence of a major pluvial flood that occurred in Belfast in 1916. Photographs of the flooding would indicate that this may have been similar in nature to the more recent 2007 event

Omagh flooding

The town of Omagh is situated at the confluence of the Drumragh and Camowen rivers which join to form the River Strule. The town has a long history of fluvial flooding and has suffered major flood events in 1909, 1929, 1954, 1956, 1969 and 1987. Many of these flood events have resulted in the inundation of hundreds of properties and it is reported that there was a loss of life due to a drowning as a consequence of the flood in 1929. Flood protection works, which included channel improvements, flood banks, and concrete flood walls, were commenced in the mid 1950s. When completed in 1961 it is estimated that the scheme provided protection to floods with a 50 year return period (2% AEP). These defences failed to protect the town from an estimated 1 in 100 year flood event which occurred in 1969 and as a consequence further works to improve the defences were undertaken in the 1970s. In 1987 the defences were breached yet again by the largest flood event on record which was estimated at the time to be a 170 year flood. Subsequent to this event a major scheme to upgrade the defences was undertaken in the early 1990s and since that time the defences have not been overtopped by the rivers although there has been some, albeit much reduced, flooding due to surface water drainage problems behind the defences, most notably in 1999 and 2007. In October 2001 there was an extreme flood event in the rivers running through the town that is estimated to have a return period of around 120 years and the defence systems performed very effectively.

2. Available datasets relating to flood risk

2.1 Introduction

This study delivers a Preliminary Flood Risk Assessment by examining the spatial distribution of flood risk through the use of flood risk indicators. These indicators, such as the long term annual average number of people at risk, are computed for discrete areas defined by a regular 1km grid. The range of flood risk indicators used and their quality is dependent upon 'available or readily derivable' base-data which this section sets out to describe. The base-data has been subject to continual improvement, so a flexible set of tools were developed to allow the spatial analysis to be updated when new or improved data became available.

The data has been divided into three categories associated with the 'systems based approach' to flood risk, which is adopted by Rivers Agency and described in its Flood Mapping Strategy (HR Wallingford, 2007). The approach is based on a Source-Pathway-Receptor model, the main elements of which can be described as follows:

- **Sources** of flooding addressed in the assessment are fluvial, coastal and extreme surface water runoff (truncated to pluvial flooding). Flooding from impounded water bodies has been considered in a separate report.

- **Pathways** to receptors require information on the topography, typically based on a Digital Terrain Model, but also includes knowledge of defence crest height data for defence failure. The modelled outlines are all based upon undefended flood risk, so generally reflect the worst case scenario. Defended area outlines have been estimated for the relatively few defences in Northern Ireland.

- **Receptor** data includes building polygons of different types, key road and rail infrastructure, key services of different classes (schools, hospitals, GP surgeries, emergency services etc.) and community vulnerability (e.g. based on Census data of the distribution of the elderly population).

Flood risk indicators were derived based on all of this information, and where possible the risk was quantified to give estimates of long term annual average risk. This was undertaken by integrating the damage versus the Annual Exceedance Probability (AEP) curve (see Section 2.3.2). Although used typically for economic damages, it is also a useful way of quantifying long term flood risk for other indicators.

A framework or ‘sub-area’ in which to compare and visualise the flood risk metrics had to be defined for the assessment. At the national (macro) scale, statistics such as ‘10% of properties are in the floodplain’ are often summarised based on broad-scale flood model outlines. At the micro scale, predicting which individual property floods would require a level of accuracy in hydrology and hydraulics that would be unaffordable for a national strategic assessment. A 1 km regular grid was considered as a practical scale at which to assess the national distribution of potential impacts.

A range of scales at which to disaggregate flood risk were considered, but the use of a 1 km grid was choosen as it enabled like-for-like comparison to be undertaken without the need for normalisation of flood risk indicators and the misconceptions that can arise from visualisation. To check if a 1km grid was appropriate a scale-sensitivity analysis was undertaken using a 100m grid for Belfast. This analysis revealed that similar high risk areas were identified and consequently it was determined that there was no benefit in assessing the risk at a grid scale smaller than 1km. The flood risk indicators were used to quantify the flood risk within each of the 1km grid squares and this information was used in the methodology for identifying Significant Flood Risk Areas (see Section 7).

2.2 Base-data

Table 2-1 summarises the base-data on sources, pathways and receptors (including the vulnerability of the receptors) that was obtained and used to generate flood risk indicators.

Table 2-1 Base-data used in derivation of flood risk indicators

Category	Description	Provenance	Main Use
Source	Fluvial flood outlines for AEP 10%, 1% and 0.1% (Present Day and Climate Change)	Rivers Agency Updated Sept 2010	Querying receptor data and annualisation
	Coastal flood outlines for AEP 10%, 0.5% and 0.1% (Present Day and Climate Change)	Rivers Agency Updated Sept 2010	Querying receptor data and annualisation
	Pluvial outlines of water depth > 0.1m for AEP 3.3%, 1% and 0.1% (Present Day and Climate Change)	Derived using strategic blanket rainfall approach Updated using new LiDAR Nov 2010	Querying receptor data
	Historical outlines for different events	Rivers Agency	Querying receptor data and validating technique against historical observation
	Newspaper clippings of historical events	Rivers Agency	For comparison with flood risk metrics and for historical documentation of severity of flooding
Pathways	OSNI 5m National DTM	Rivers Agency	Used for derivation of outlines
	2m LiDAR data	Rivers Agency Updated using holdings up to July 2010	Used for derivation of outlines
	Merged OSNI 5m and LiDAR re-sampled to 5m	Rivers Agency Updated to holdings Sept 2010	Used for derivation of outlines
	Defended areas	Rivers Agency	Imply possible pathways on defence failure
	Defence polylines attributed with consequence score	Rivers Agency	Calibration of SFRA - Strand 1.
Receptors	Building polygons	Rivers Agency, based on OSNI large-scale data Updated version Sept 2010	Understanding Flood Risk to
	Pointer Address	OSNI	Not used
	OSNI roads centreline under NIMA agreement	OSNI, but Rivers Agency provided advice on key roads	Understanding flood risk to key infrastructure
	Railway Line layer from Translink	Translink	Understanding risk to key infrastructure. The accuracy of this data was found to be poor, and its use would wrongly identify flood risk
	Sewage treatment works, pumping stations, Water Treatment works and water pumping stations	Northern Ireland Water	Understanding flood risk to key services
	Electricity substations	Northern Ireland	Understanding flood

	(Pole and Ground Mounted)	Electricity	risk to key services
	Integrated Pollution Prevention and Control sites (IPPC), and Integrated Pollution & Radiation Inspectorate sites (IPPR)	EHS website	Understanding risk to the environment from waterborne pollutants
	Emergency Services (fire, police head quarters, hospitals, GP surgeries) Ambulance depots	NINIS/NISRA websites and through contacting relevant authorities for police HQ, ambulance depots	Understanding flood risk to key services
	Pressurised gas pipeline	Premier Transmission	Understanding risk of flotation of pressurised gas main
	Listed buildings, Gardens, Sites and Monuments Records (SMR) and Sites of Archeological Interest	EHS	Understanding flood risk to cultural heritage
Receptor Vulnerability	Census Data	NISRA websites at Output Area level	The following community make-up data were used: Long term sick; Elderly; Lone parents; Unemployed; Overcrowding; Non-car ownership; Non-home ownership; Mobile household; Basement household.
	Census Data	Economic Deprivation index from NINIS website	Understanding economic vulnerability

2.3 Fundamental flood risk indicators

Each of the different flood risk indicators were measured using one the following indicator genre:

- **Count** of number of receptors (i.e. number of properties flooded)
- **Length** of linear receptor flooded (i.e. roads / railways)
- **Area** of receptor flooded (i.e. areas with environmental designations / building polygons)

Some of the basic flood risk indicators such as the numbers of properties flooded were combined with auxiliary data such as the damage incurred per square metre for each of the various property types to calculate other indicators such property damage costs. This process is described in detail below.

2.3.1 Supplementary data

Some additional parameters were required to derive flood risk indicators which relate to average annual economic damages, including for example:

- Damage per m^2 from flooding for different flooding probabilities. These were estimated based on the updated UK Flood Hazard Research Centre publication called the Multi-Coloured-Manual 2010 (see Section 2.5). Estimates of damages for a range of building types were derived for each modelled outline by assuming an average depth of flooding. The annual average damages were then corrected in line with the MCM210.

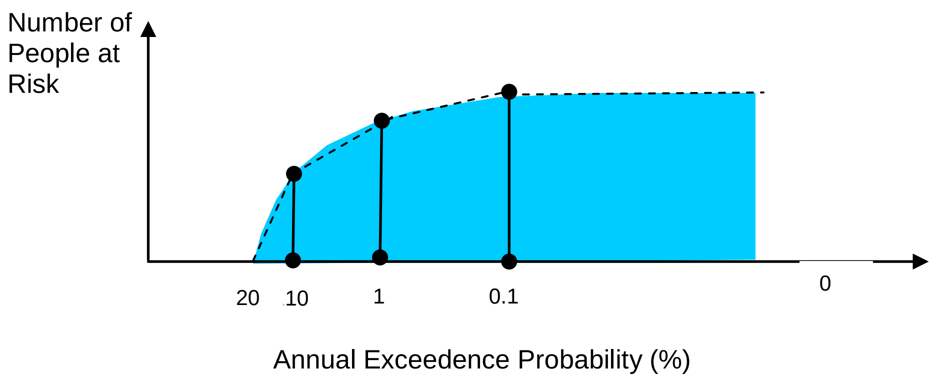
- Damage per hectare from flooding of different land cover types (see Section 2.8)

Additional information was also required to calculate a vulnerability index based on the make-up of communities from the census data (see Section 2.9)

2.3.2 Annual average estimates - overview

An appropriate flood risk assessment requires a holistic approach that considers the risk from each source of flooding and takes account of the cumulative affects of events with different periodicity (i.e. from frequent through to extremely rare) within a catchment area or grid square. By assessing the adverse affects in terms of flood risk indicators for a broad range of return periods it is possible to produce a damage–probability curve. The total area under this curve represents the annualised value of the flood risk indicator or to put it another away the long-term average annual value of the flood risk indicator. This is a vitally important concept as it provides a common basis for a rational comparison of the risk to areas in which, for example, a small number of properties are flooded on a frequent basis with those in which a large number of properties are flooded on an infrequent basis. In the example illustrated in Figure 2-1 the damage-probability curve shows the number of people whose properties are adversely affect by fluvial events in a catchment (or grid square). The data used to produce this graph can be obtained using the GIS based application by querying the number of domestic properties which are intersected by the 1 in 10yr (10% AEP), 1 in 100yr (1% AEP) and 1 in 1000yr (0.1% AEP) flood outlines as generated by the strategic (fluvial) flood model. A multiplier of 2.5 people per property is then applied to the number of flooded properties to calculate the number of people flooded for each of these events. In this example it is assumed that for the extremely rare events, the level of damages to domestic property (and therefore people) do not increase beyond that which occurs at the 1 in 1000yr (0.1% AEP) event and that the onset flood at which damage begins to occur is the 1 in 5yr (20% AEP) event. The AEP of the onset flood is extremely important as the occurrence of high frequency events have a significant bearing on the total area under the curve (and therefore the annual average value). An accurate estimate of the AEP for the onset flood for a particular watercourse can only be obtained through the production of a detailed flood model. However, as the PFRA is a national assessment based on strategic flood models with limited accuracy it is necessary to assume an AEP for the first onset flood event. As the majority of watercourses in the urban areas have been engineered to accommodate the flows from flood events with relatively high return periods and there are very few properties within the province which have a history of repeat flooding on a frequent basis it was decided that the first onset flood should be a 1 in 5yr (20% AEP) event. The calculation of annual average estimates is undertaken in a similar manner for all annualised flood risk indicators be that the number of people flooded, the number of properties flooded, the number of key services flooded or the economic flood damages.

Figure 2-1 Calculating annual average values (annualisation)



2.4 Property datasets

Two national property datasets were readily available:

- Building Polygons from the Basemap-NI (last updated October 2010) which identifies the location and extents of approximately 1.3 million buildings.
- Pointer-address data which identifies approx 800,000 buildings with information that typically dates from the mid -1990s.

The pointer-address data is supplied with many different attributes including building number, street name, townland, town, postcode and categorises buildings in terms of their constituencies, counties, councils and wards. Much of this information is superfluous to the task of assessing economic damage. A key limitation with the pointer address data is that it only covers addressable properties and there are many individual buildings which do not have a unique postal address for example, those located within an industrial estate. Due to the inherent limitations of this dataset it was considered to be unsuitable for the assessing the flood damage to property.

The Building Polygons dataset is considered by Rivers Agency to be more up-to-date than the pointer-address dataset and contains a geometrically correct representation of the building plan area for each property which is essential information for the estimation of potential flood damage. It also contains an attribute called 'FEAT-CODE' which allocates each building to one of 13 different property types. These feature codes fit well with the property information requirements of the Multi Coloured Manual (see section 2.5). Table A-1 in Appendix A lists the 13 feature codes used in the Building Polygons dataset. It was decided by Rivers Agency that the relatively inconsequential building receptors allocated to the feature codes 1054 and 1058 should be removed from the dataset and therefore the actual property dataset used in the assessment is shown in Table 2-2 below. The refined dataset reduces the total number of buildings from 1.3 million to 826,086 and of these 742,644 (around 90%) are residential properties.

Table 2-2 Property Types

Feature Code	Property description	Property Type Distribution across NI (%)	
		By Number	By Area
1042	LAW_ADMIN : COMMUNAL BUILDING FOR LAW AD	0.0	0.0
1043	HEALTH_B : COMMUNAL BUILDINGS ASSOCIATED	0.4	1.1
1044	EDUCATE_B : COMMUNAL BUILDING FOR EDUCAT	1.0	3.2
1045	RELIGION_B : COMMUNAL BUILDING ASSOCIATE	0.5	1.3
1046	SERVICES_B : COMMUNAL BUILDING FOR PUBLI	0.7	0.7
1047	RECREAT_B : COMMUNAL BUILDING FOR RECREA	0.3	0.9
1048	GOV_OFFICE : COMMUNAL BUILDING FOR GOVER	0.2	0.5
1049	COMM_OTH : ANY OTHER TYPE OF COMMUNAL BU	0.7	1.5
1051	INDUSTRY_B : GENERAL BUILDING ASSOCIATED	1.2	8.7
1052	COMMERCE_B : GENERAL BUILDING ASSOCIATED	4.9	12.0
1053	DWELL_HOUS : GENERAL BUILDING - ALL TYPE	90.1	70.0

2.5 Property damages

Estimation of flood damages to residential and non-residential property is normally carried out in accordance with The Benefits of Flood Coastal Risk Management: A Handbook of Assessment Techniques (Penning-Rousell et al., 2005) also known as The Multi-Coloured Manual (MCM). However a detailed assessment of flood property damage using the MCM requires the collection of depth / damage data for all properties that are located within flood prone areas. This is an onerous undertaking that is normally reserved for use on a single catchment for which a detailed fluvial flood model has been developed. However for this national assessment detailed flood models for each of the river catchments have not been undertaken and the depth of flooding for events with a range of return periods (which are essential for the annualisation of damages) cannot be established from the strategic flood models available. To work around this information gap a technique was developed by the EA to establish (from historical records) the 'typical' average depth of flooding to properties within the respective flood zones of fluvial events with specific return periods. The EA's methodology for determining average flood depths and how this information is used to estimate property damages using the MCM as a framework is fully described in Appendix A. The outworking of this process is to produce a 'typical' damage function that assigns an annual damage in £ per square m for each property which takes into account the property type, the flood source and its location within either the high, medium or low probability flood outline.

The damage function, which is shown in Table A-7, is an essential first step in the estimation of annual average damage to property. Algorithms within the Arc GIS application query the juxtaposition of the various flood outline for each source with the building polygon dataset to establish whether a building is at high, medium, low (or no) risk of flooding. Having established the level of risk to each property and its property type every property within the flood outlines is assigned with a 'damage per unit area flooded' value in accordance with the damage function table. The application then calculates the actual area of the ground floor plan of each building that is susceptible to flooding multiplies this by the appropriate damage value (£/m2) to estimate the annual average damage for each building and computes the sum total for all of the buildings within each 1grid square.

Updates to the Damage Function tables (which are based on 2010 figures) shall be required for future economic damage assessments. The Consumer Price Index 04.3 has been identified as the appropriate inflationary measure associated with property types for future updates.

2.6 Intangible damages

To account for the intangible health impacts arising from the distress to people at risk from flooding the Benefits of Flood and Coastal Risk Management Manual recommends that this can be monetised and valued at £200/property/year. This allowance was factored into the 'Aggregated Annual Average Damage' (AAAD) flood risk indicator that was used in the methodology to determine the Significant Flood Risk Areas.

2.7 Number of people at risk

This flood risk indicator was readily computed by assuming an average occupancy of 2.5 persons per residential household (using feature code 1053). In common with the other indicators, this was annualised in the manner described in section 2.3.2 to give the average annual number of people at risk of flooding from fluvial, coastal and pluvial flooding.

2.8 Land cover and agricultural damages

The Agricultural Damage for any given area was calculated by taking the sum of the areas flooded of each land cover type multiplied by unit damages for that land cover type. This follows a similar methodology used within the Modelling and Decision Support Framework (MDSF), Defra 2004, for valuation of agricultural damages in England and Wales but makes use of the land cover classifications available for Northern Ireland.

2.8.1 Land cover types in Northern Ireland

The MDSF methodology uses the Agricultural Land Classification (ALC) as a basis for predicting likely land use and farming practice and from this, the likely impact of a single flood event. The ALC grading system is based on the long-term physical limitations of the land for agricultural use, and takes into account the climate, site and soil characteristics. Unit damages for each ALC grade are calculated by taking the weighted sum of the damages for each land use class assumed to be present within land of that ALC grade. However, the ALC map is not available for Northern Ireland, so it has been necessary to make use of the face value of the Land Cover Map 2000 (LCM2000). LCM2000 is based on digital interpretation, with ground truth validation, from Landsat satellite imagery. This data is being updated, although classification will still be based on land cover, rather than soil characteristics, so will not provide scope for understanding the inherent potential of the land. It will incorporate the DARD fields dataset which contains details of field boundaries, but this update will only make use of the spatial information and will not incorporate information on usage based on claims for small farm payments owing to confidentiality. This latter information would still reflect current usage as opposed to inherent potential. In the absence of a detailed study of soil properties and the derivation of a version of ALC for Northern Ireland, LCM2000 provides the most *readily derivable* agricultural dataset for the purposes of the PFRA screening exercise.

There are uncertainties in the individual land cover class recognition at a detailed scale but these are less likely to be significant on a regional scale. To make use of the unit damages derived in the MCM, it was necessary to make a correspondence between the land-cover types of the LCM2000 and those used in the MCM. The correspondence made for this work is shown in Table 2-3, together with the unit damages used.

Table 2-3: Land Cover Damages						
LCM Sub-Class	LCM2000 Description	LCM_ Code (1)	Corresponding MCM Agricultural Land Use Type	MCM Description	Unit Flood Damage (£/ha/yr)	% Land cover of NI(2)
1.1	Broad-leaved / mixed woodland		N/A			1.7
2.1	Coniferous woodland		N/A			3.8
4.1	Arable Cereals	2	Extensive arable	Cereals, beans, oil seeds	£500	0
4.2	Arable horticulture	1	Horticulture / Intensive Arable	Incl sugar beet, potatoes	£1500	6.3
4.3	Non-rotational arable and horticulture		N/A			0
5.1	Improved grassland	3	Intensive grass	Improved grass, usually dairying	£50	49.9
5.2	Setaside grass	4	Extensive grass	Usually cattle and sheep	£20	0
6.1	Neutral grass	4	Extensive grass	Usually cattle and sheep	£20	7.2
7.1	Calcareous grass	4	Extensive grass	Usually cattle and sheep	£20	3.2
8.1	Acid grassland	4	Extensive grass	Usually cattle and sheep	£20	8.8
9.1	Bracken		N/A			0.1
10.1	Dense dwarf shrub heath		N/A			3.0
10.2	Open dwarf shrub heath		N/A			4.5
11.1	Fen/march/swamp		N/A			0.4
12.1	Bog (deep peat)		N/A			3.3
13.1	Inland water		N/A			0.5(3)
15.1	Montane habitats		N/A			0.0
16.1	Inland bare ground		N/A			0.3
17.1	Suburban/rural development		N/A			1.0
17.2	Continuous urban		N/A			5.7(4)
19.1	Supra-littoral sediment		N/A			0.1
20.1	Littoral rock		N/A			0.0
21.1	Littoral sediment		N/A			0.1
21.2	Saltmarsh		N/A			0.0
22.1	Sea/estuary		N/A			0.1(3)

Notes:
(1) The LCM_Code is a simplified classification introduced in this work to provide a one-to-one correspondence with unit damage values.
(2) Percentage areas calculated from LCM2000 (Landcover) map, modified to include the supplied urban development area outlines
(3) Percentage areas calculated from Landcover map clipped to supplied Northern Ireland outline, which excludes large inland waters such as Lough Neagh and Lough Erne, and all significant estuaries, hence low percentages for these LCM sub-classes
(4) Continuous urban sub-class comprises the LCM sub-class 17.2 plus the supplied urban development areas outlines

2.8.2 Derivation of Unit Damages for agricultural land

The unit damage values given in Table 2-3 are those used in a similar study for the Scottish Government[1] where, as here, the LCM2000 land cover classes were used as the ALC map was not available. The values should be regarded as indicative because although they are broadly in line with those derived for use in MDSF, there was no direct one-to-one correspondence between LCM2000 and ALC land cover classes. There are a number of key assumptions underlying the derivation of the MDSF unit damages that also apply here:

The unit damages given in Table 2-3 use MCM methodology and are consistent with those derived for use in MDSF. A number of key assumptions were made:

[1] http://www.scotland.gov.uk/Publications/2005/04/19110405/04121

- A flood is a single flood event in any one year lasting about one week in duration. The event can happen in any month of the year with equal probability;
- The flood destroys any arable crop which is occupying a field at the time of the flood;
- The estimates assume a complete loss of crop, less savings on uncommitted variable costs and uncommitted machinery costs, plus clean up costs;
- Arable cropping assumes typical rotations;
- It was assumed that flood costs are zero there when floods occur during periods when there are no arable crops on the land, e.g. in winter prior to the establishment of spring sown crops;
- Flooding on grassland was assumed to reduce energy from grass, which requires substitution by bought feed.
- Grassland assumes a mix of grazing and forage conservation, with allowances where relevant for relocation of grazing animals in the event of a flood, savings in forage conservation costs, and clean up costs.
- Grassland is classed as either intensive or extensive reflecting improved and unimproved grassland, with high and low animal stocking densities respectively.

2.8.3 Comparison of Land Classification with Agricultural Land Classification Grades for a test region

An estimate was made of the effect of using LCM2000 in place of ALC on overall agricultural damages by comparing the methodology used here with an MDSF-like treatment using the ALC map for a test region (North Wales) where both the ALC map and the LCM2000 were available. The resulting total agricultural damage for the test region using the two methodologies is given in Table 2-4.

Table 2-4: Agricultural Damage Calculated in Test Region compared to that calculated using MDSF Methodology

Agricultural Damage	Using LCM2000 Land Classes	Using ALC grades (MDSF)
Total over Test Region	£ 2,394,790	£ 2,945,329
Mean per hectare flooded	£ 58.51	£ 71.96

Table 2-4 shows that the use of LandCover2000 land classes results in total values of agricultural damage which are about 20% lower than those which would have been calculated by MDSF, for a test region of similar land cover to Northern Ireland. Given the approximations and uncertainties involved in both methods, it is judged that the methodology used in this report is equally valid to that of MDSF and gives rise to similar values of total agricultural damage. A scaling factor of 1.2 could be applied to compensate for this difference.

Finally, it was realised that the LCM2000 classes covered urban areas, whereas agricultural damages should really only encompass rural areas. For this reason, only LCM2000 data was used to estimate agricultural damages outside of the development limits provided by the Rivers Agency.

2.9 Vulnerability Index for Northern Ireland

The Social Flood Vulnerability Index (Penning-Rowsell, 2004) combined four flood risk metrics that include representation of elderly population, lone parents, the long term sick and financially deprived households. Recent National studies of vulnerability mapping (JBA, 2006) have shown that this can result in adding together negatively correlated variables. The Northern Ireland data was examined before constructing indices, to ensure that it satisfactorily reflected local correlations between key vulnerability factors.

Three indicators of vulnerability were used for this study. Two described in this section take into account negative correlations between core variables from the Census Output Area data, and the economic deprivation index described in the next section. The first two indicators were based on techniques developed for the National Vulnerability Map and the Thames Estuary Vulnerability Baseline Project (EA, 2006, 2007) using principal component analysis. The indicator improves upon the simple addition of individual components since it also considers interaction (correlation) based on local variables. The approach has the disadvantage that different classes of people are given different weights without considering the implications, but it is used here since it gives the most discerning weighted combination of these factors so relative vulnerability in Northern Ireland can be assessed.

The census outputs (NISRA - http://www.nisra.gov.uk/) that make up the vulnerability indicators are percentage by census output area population or number of properties (see below for more details of normalization). These factors were used in the national vulnerability map (JBA, 2006), and contain the key groups used in the Social Flood Vulnerability Index (Penning–Rowsell et al., 2004)

- Long term sick;
- Elderly;
- Lone parents;
- Unemployed;
- Overcrowding;
- Non-car ownership;
- Non-home ownership;
- Mobile household;
- Basement household

A correlation matrix was produced for all these factors that might influence vulnerability. This was used to help understand which variables are strongly related, and where these should be taken into account in building an overall index. A non-parametric version of principal component analysis was then undertaken of these factors at the census output area level. The first principal component (V1) gives the greatest variance over Northern Ireland, and includes strong weights for Long Term Sick (0.37), Lone Parents (0.35), Overcrowding (0.38), Non car ownership (0.47) and non home ownership (0.46). A second index is simply based on percentage elderly by census output area.

Within the MCM there is a clear acknowledgement that vulnerability analysis is an important tool that can be used to ensure that an increased priority can be given to schemes that offer protection to more vulnerable people, so that the gain to society is greater from the expenditure of resources. However, it also recognises that vulnerability analysis remain experimental in nature and there is advice against formalising the presentation of results as there is a possibility of making the analysis appear more precise than it deserves. Moreover, the MCM does not recommend that vulnerability analysis is necessary for national level analysis of flood risk (such as the PFRA) and advocates their use only for meso-scale analysis such as Catchment Flood Management Plans. As a consequence, it is considered that the vulnerability flood metric should be used only for the purposes of visually illustrating the contrast in the vulnerability of people to flooding across the province. Therefore, although the vulnerability flood index is not used in the methodology for determining SFRA it is anticipated that the social vulnerability of people that are exposed to flooding will be taken into account in the development of the Flood Risk Management Plans.

2.10 Economic Deprivation index for Northern Ireland

The Economic Deprivation Measure at the level of Output Area was constructed by the Social Disadvantage Research Centre at the University of Oxford. This was based on three Domain Measures with the following weights:

- Income (41.7%)
- Employment (41.7%)
- Proximity to Services (16.6%)

More details can be found on the NINIS website, although for this study, the indicator is referred to as V3, and is used alongside V1 and V2, in order to derive a further flood risk metric in Section 4. However, the number of flooded propertied weighted using V1 and V3 were found to be very strongly correlated, so this was taken into account when combining the metrics in Section 4.

2.11 Flood risk to the environment

A basic indicator of the potential flood risk to the environment is to measure the area of important habitats that are prone to inundation by flooding from each of the flood sources. This approach was cited in a report and paper delivered by the OPW at the DEFRA Conference (OPW, 2008, Adamson et al., 2008). The indicator is the estimated plan area of the designated Areas of Special Scientific

Interest (ASSI) that is prone to flood inundation. ASSIs are the country's very best wildlife and geological sites and include all of the internationally important designated areas such and Special Areas of Conservation (SAC), Special Protection Areas (SPA), RAMSAR sites and also some of the National Nature Reserves.

Of the 226 ASSIs in Northern Ireland, 147 were found to be at least partially within the predicted 1 in 100yr (1% AEP) fluvial or 1 in 200yr (0.5% AEP) coastal floodplains. Of the 147 flood prone sites,, 29 are designated solely for their Earth Science (i.e. geological) features and are not likely to be adversely affected by flooding. Therefore, 118 ecologically important sites are estimated to be prone to inundation to some degree from coastal and or fluvial flooding. This figure does not include inundation from surface water as it is assumed that ponded rainfall is unlikely to represent a 'significant' risk to habitats or features.

It is considered that potentially significant risks to the designated environment sites may arise from the release of pollutants from flooded Integrated Pollution Prevention and Control (IIPC) installations. The number of these sites that are located within any of the flood outlines has been computed and is highlighted in the summary tables in Appendix B. Another environmental flood risk metric as described in section D.5 combines the area of flooded ASSIs with the number IIPC sites, waste water treatment works and pumping stations at risk of inundation. The variation of this combined environmental metric is illustrated on coloured coded maps on a 1km grid and an example of these can be seen in Fig 4-3.

Although these environmental metrics may help identify specific areas where flooding could potentially cause some adverse affects to the environment, they are not a reliable indicator of the actual level of risk. In some cases the flooding of an ASSI may be a damaging, neutral or even a beneficial event. There is very little literature available on the environmental vulnerability of designated environmental sites to the affects of flooding. The main conclusion to be drawn from a literature search is that an assessment of the vulnerability of environmental sites is complex and needs to be undertaken on a site by site basis. To ensure that there was a robust assessment of the flood risk to the environment, Rivers Agency consulted with NI Environment Agency which has a responsibility to conserve and protect our natural environment and built heritage. The Environment Agency, as experts in this field, undertook to advise Rivers Agency if the flood risk to any of the ASSIs was likely to be considered significant. The conclusion of the EA was that for the purposes of the PFRA, habitats and species located within ASSIs are not vulnerable to flooding to the extent that this would be considered a 'significant' risk.

2.12 Flood risk to cultural heritage

NI Environment Agency provided four key datasets which were used in the assessment of flood risk to cultural heritage. These included Listed Buildings, Gardens, Sites and Monuments Records and Sites of Archaeological Interest. A dataset that included listed bridges could not be used to develop a meaningful flood risk indicator because there is no readily available means to establish the structural efficacy for some of the bridges and more importantly, as there is no depth/velocity data available for the various flood outlines it is not possible to determine the scale of the flood hazard. Therefore although these bridges are, by their very nature, always located within a flood outline, there is no reason to conclude that they are likely to be adversely affected by flooding. Furthermore, although 'listed', the majority of these bridges are publicly owned and therefore inspected, assessed, maintained and improved by Roads Service in accordance with current best practice.

Rivers Agency provided NIEA with the information necessary to determine the likelihood of flood inundation to all of the 'listed' cultural heritage assets and invited NIEA to identify any assets for which flooding would be considered to a significant risk within a national context.

Important to note that outside of the consultation with NIEA on the 'significance' of flooding to listed buildings from a heritage perspective the potential economic damage to listed buildings is included (as with all other buildings) in the calculation of annual average property damage as described in section 2.5.

2.13 Flood risk to key / critical services

For the purposes of this assessment, key services includes assets such as hospitals, GP surgeries/health centres, care homes, fire stations, police station headquarters, electricity substations (ground mounted) and water supply/sewerage facilities. A basic indicator of the flood risk to key services is the sum of individual key services assets that are prone to flooding within a 1km grid. As with other flood risk indicators these figures have been annualised for each of the flood sources. Although the number of key services that may be disrupted due to flooding within a particular grid square is easily computed using the automated GIS based query tool, this indicator of itself has clear limitations. Quite obviously the potential adverse affects on the wider public from flooding to a hospital is likely to be much more significant in comparison to those from the flooding of a small care-home or GP surgery. Therefore the number of key services assets flooded of itself cannot fully reflect the 'significance' of the potential disruption to key services within a national context. For the purposes of determining the SFRA using the methodology described in Section 7, Rivers Agency consulted with all of the owner/operators from the key services sector. The main purpose of this consultation exercise was to enable the owner/operators to provide such information as is necessary to:

- conduct a robust assessment of the potential economic damages for high value specialist assets that may otherwise have been undervalued using the rationalised approach in the multi coloured manual, and

- identify those 'critical' assets which if flooded would have a significant impact on the delivery of essential services leading to loss, or disruption, of service to tens of thousands of people or affecting whole counties or equivalents i.e., Category 2 or greater according to the Cabinet Office's criticality scale.

2.14 Flood risk to key infrastructure

The flood risk indicator for key infrastructure relates solely to the combined length of major roads and rail lines that are located within the flood outlines. In urban areas, other important infrastructure such as gas mains and telephone networks are considered to be highly correlated to the road and building infrastructure which are already considered in the risk assessment. Consequently, it was decided that including the length of flooded gas mains and telephone lines within this flood risk metric would not result in any significant change to an assessment of the overall relative flood risk between the grid squares.

However, an exception to this premise is highly pressurised gas transmission pipelines which, for safety reasons, are purposely set away from buildings and roads. Gas pipelines located within flood plains must be adequately anchored to prevent the risk of flotation and possible rupture due a stress failure. It was decided that this unique flood risk should be considered separate from this generalised flood risk assessment and the authorities responsible for the gas pipelines have been advised of the potential risk so that they may take appropriate measures to mitigate the risk.

3. Methodology: Design of flood risk indicators

3.1 Introduction

The wide range of flood risk indicators described in Section 2 were computed using an automated ArcGIS query tool to allow flexibility in applying updates. This undertakes spatial queries on the different flood outlines (fluvial, coastal, pluvial, historical and defended) against all the readily available base-data for Northern Ireland. The large number of flood outlines for different design events (with and without climate change) coupled with the large volume of receptor data resulted in the computation of metrics with over 100 attributes which are combined in various ways to produce the flood risk indicators. This section summarises the indicators and how they are computed. Section 4 describes the spatial distribution of the flood risk indicators and their visualisation and Section 7 describes how the most important of these flood risk indicators are used within the methodology for the determination of Significant Flood Risk Areas.

3.2 Flood risk indicators

There are numerous ways of classifying the different flood risk indicators, and Table 3-1 considers the impact in terms of the nature of the receptors that are flooded. The long term annual average value of the indicators was computed according to the methods outlined in Section 2 for all flood sources, with and without climate change.

Table 3-1: Flood risk indicators

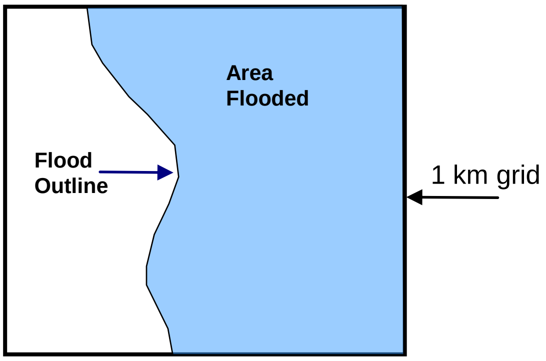
Receptors at risk	FRM	Explanation figure	Detail
Community Economy and environment	Flooded area inside outline in grid square	Figure 3-1	This gives a 'boxed' version of the main flood outlines
Community	Number of flooded residential buildings * 2.5	Same approach as for Figure 3-3	Assumes 2.5 people per residential dwelling, Feature code 1053.
Key infrastructure	Flooded road length of any type in grid square	Figure 3-2	Sub query on road type possible
Key infrastructure	Percentage railway length	Figure 3-2	
Key Services	Number of key services in flooded outline for grid	Figure 3-3	Schools GP Practices Hospitals Fire stations Police Stations Key Northern Ireland Water assets including sewerage (pump and stations), drinking water pumping stations and water treatment works. Electricity sub-stations (ground mounted)
Economy	Number of flooded buildings in outline including breakdown into 5 building types	Same approach as for Figure 3-3	Uses centroid of building polygon in 1km grid All Res Health Education Industry Commerce
Economy	Area of building polygon flooded including breakdown of building types into 3 (Residential/industrial/commercial)	Figure 3-4	Used area flooded of part of building in the 1km grid
Economy	Property damages for each	Figure 3-4	

	return period		
Economy	Annual Average Damages using 3 return periods	Figure 3-4	3 design events for fluvial and coastal used
Rural Economy	Agricultural Damages based on Land Cover Map and MCM	Figure 3-5	The Agricultural Land Classification associated with the quality of the land and its potential was unavailable for NI
Environment	Percentage flooded area of ASSI	Figure 3-6	
Environment Pollution	Percentage flooded area of ASSI site within an urban area	Figure 3-6	Sensitivity index
IPPC Count	Count of flooded IPPC sites	Same approach as for Figure 3-3	
IPRI area flooded	Area of IPRI site flooded	Figure 3-4	IPRI dataset was reportedly more accurate (and contains site outlines) for pollution and radioactivity permit sites.
Cultural heritage sites	Count of cultural heritage sites flooded.	Same approach as for Figure 3-3	This includes: Listed buildings, Gardens, Sites and Monuments Records (SMR) and Sites of Archeological Interest.
People Vulnerability	Vulnerability index from first principal component (V1); percentage elderly (V2), Economic Deprivation index (V3).	Figure 3-7	These 3 indicators are used as likelihood measures that weight the number of properties flooded in census output areas.

3.2.1 Flooded Area

This is the area of the 1km^2 grid square that is flooded, as shown in Figure 3-1.

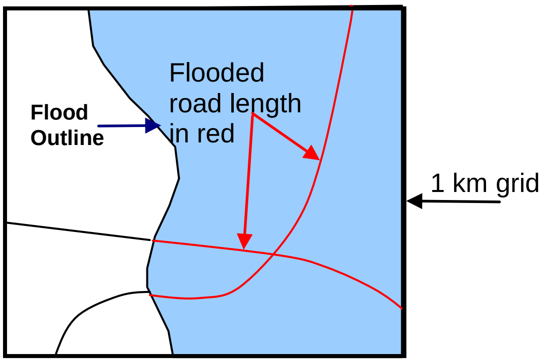
Figure 3-1: Area Flooded



3.2.2 Key infrastructure flooded

This is the sum of the length of major roads or rail that is within the flood outline (Figure 3-2). The query tool computes both the total length flooded and the percentage of length flooded for each type of infrastructure (roads or rail). The absolute values were used in this study, since percentage values can be misleading especially when grid squares only contain a small length of road in the flood outline. Road disruption costs were estimated using the MCM 2010, although there are large uncertainties in traffic volumes and little guidance on UK disruption costs for historical events. Therefore the length indicator was used to influence the combined economic activity flood risk metric (See Appendix D), rather than a disruption cost.

Figure 3-2: Flooded length of key infrastructure



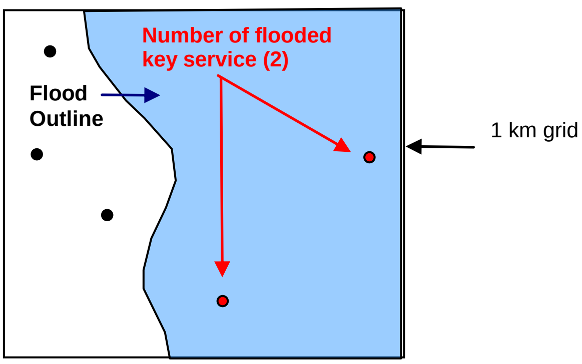
3.2.3 Key Services flooded

Key Services cover a wide range of specific building types from data downloaded from the NISRA website or provided by utility groups (Northern Ireland Electricity and Northern Ireland Water). For this study Key Services include:

- Schools
- GP surgeries/ health centres
- Hospitals and ambulance depots
- Fire stations
- Police Station Head Quarters
- Core NIW assets (including Water Treatment, water pumping stations, waste water treatment works and pumping stations
- Electricity Sub stations (categorised as ground mounted - GM)
- Flooded IPPC sites (IPRI polygons were also used)

Figure 3-3 shows how the flooded key services metric queries count individual service types. A total number of key services flood risk indicator was also determined, this being the sum of all the individual flooded services. Where the building polygon layers have been used to establish the number of a particular type of building, the centroid of the building polygons were first computed, and only counted if they were within the flooded area of the test 1km grid square.

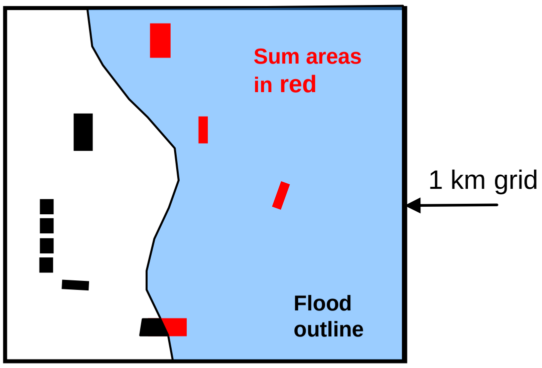
Figure 3-3: Flooded key services



3.2.4 Area of building polygons flooded and damage calculations

This query measures the actual floor of each building that is prone to flooding (Figure 3-4) and uses the feature codes (described in Table 2-2) to calculate the sum total of the flooded floor area for the various property types. These figures are used in combination with derived damages for each property type (Table A-7) to calculate the total damages by property type and then summed to give the total property damages within the grid square.

Figure 3-4: Building polygon area flooded



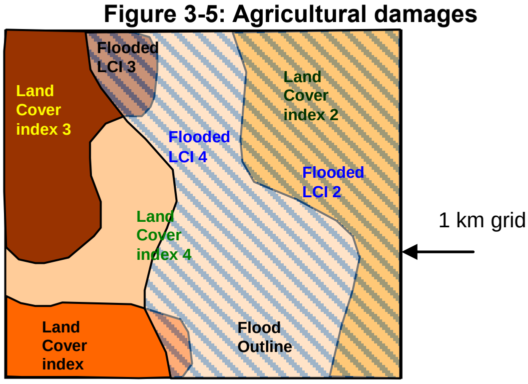
3.2.5 Agricultural damages

Agricultural damages were related to the Land Cover Map 2000 as described in Section 2.8.3, and damages per unit area for the different land classes was used with the respective area of flooded land, as shown in Figure 3-5, using Equation 3-1:

$$V = \text{Flooded Area}_1 {*} D_1 + \text{Flooded Area}_2 {*} D_2 \quad + \ldots. \qquad \text{(Equation 3-1)}$$

Where D_1 is the damage per square metre for land cover type 1, etc

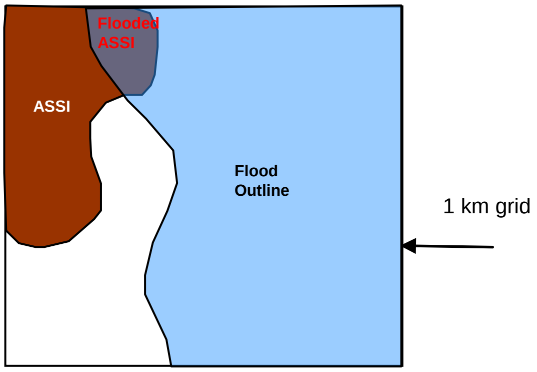
Figure 3-5: Agricultural damages



3.2.6 Flood risk to the environment

The area of flooded ASSI was calculated as shown in Figure 3-6. To understand flood risk to the environment, a combined indicator that counted potential pollution sites flooded within the same grid square were used.

Figure 3-6: ASSI flooded

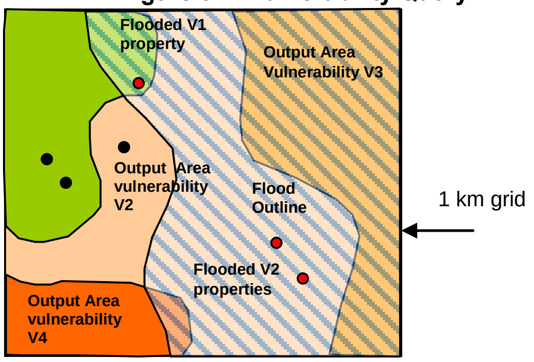


3.2.7 Vulnerability Factor

The vulnerability flood risk metric for any given area was calculated by taking the weighted average of the number of flooded residential buildings in each Census Output area using the vulnerability index ascribed to the Output Area in which the flooded property lies (Equation 3-2). A similar weighted index was constructed for the Economic Deprivation index.

$$V = (n_1V_1 + n_2V_2\ ) / (n_1 + n_2) \qquad \text{(Equation 3-2)}$$

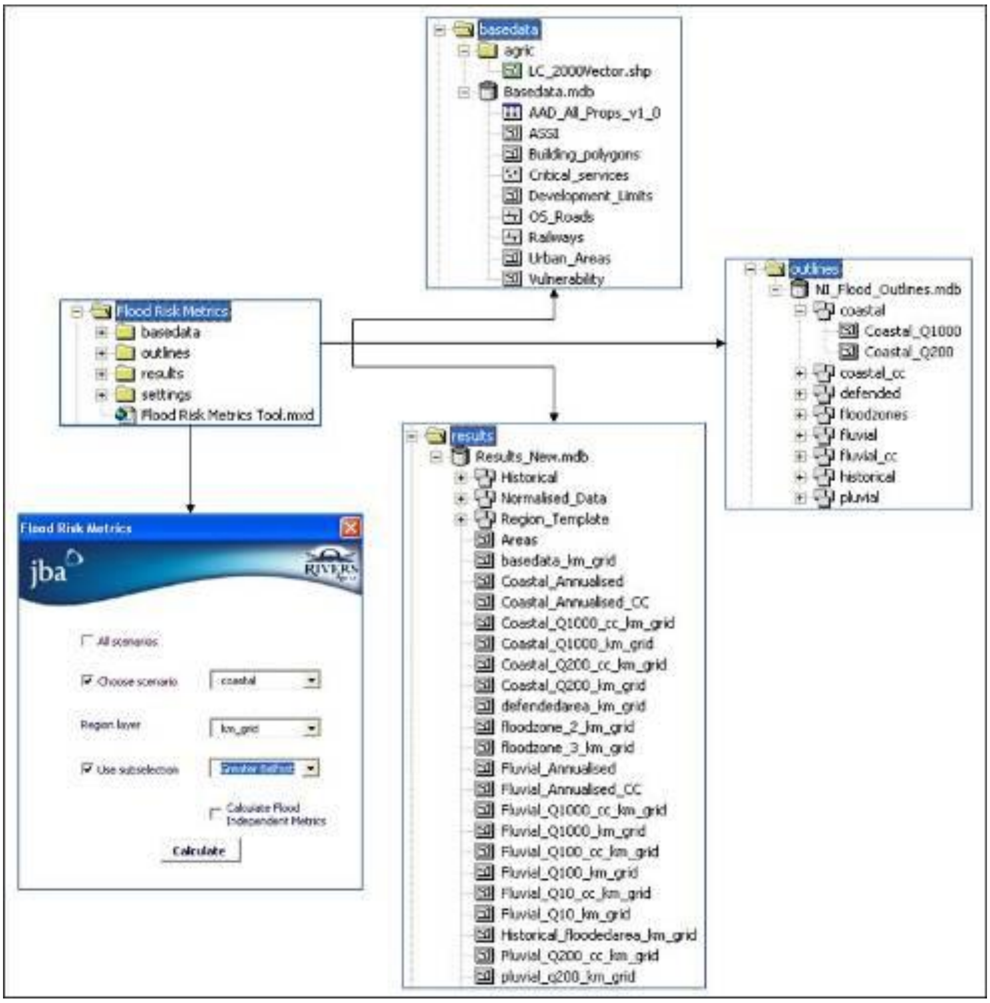
Figure 3-7: Vulnerability Query



3.3 Automated GIS queries

The structure of the automated GIS query tool, along with key geodatabases is outlined in Figure 3-8. The queries are run from a bespoke application called ‘Flood Risk Metrics.mxd’ which has two simple user forms launched from a new menu item called ‘Flood Risk Lab (metrics)’. The first user form is shown in Figure 3-8, and this generates all of the flood risk metrics listed below in the results folder. The second menu item, Annualisation Tool (not shown) produces annual average quantities for the three sources of flooding.

Figure 3-8: Structure of Flood Risk Lab (metrics)



3.4 Results geo-database and computation of flood risk metrics

The Results geo-database structure is illustrated in the left hand side of Figure 3-9. It contains the results for all the significant historical outlines for the three pilot areas (Belfast, Newtownards and Omagh) and also for the different fluvial, coastal, pluvial and defended outlines. The right hand side gives the meta-data for one of the historical events, and this is the same as that for any of the other outlines (Figure 3-10). The results database is considered to be a very valuable resource for consultation that can readily be updated as new or improved data becomes available.

Figure 3-9: Results Meta-data for 2 example flood outlines

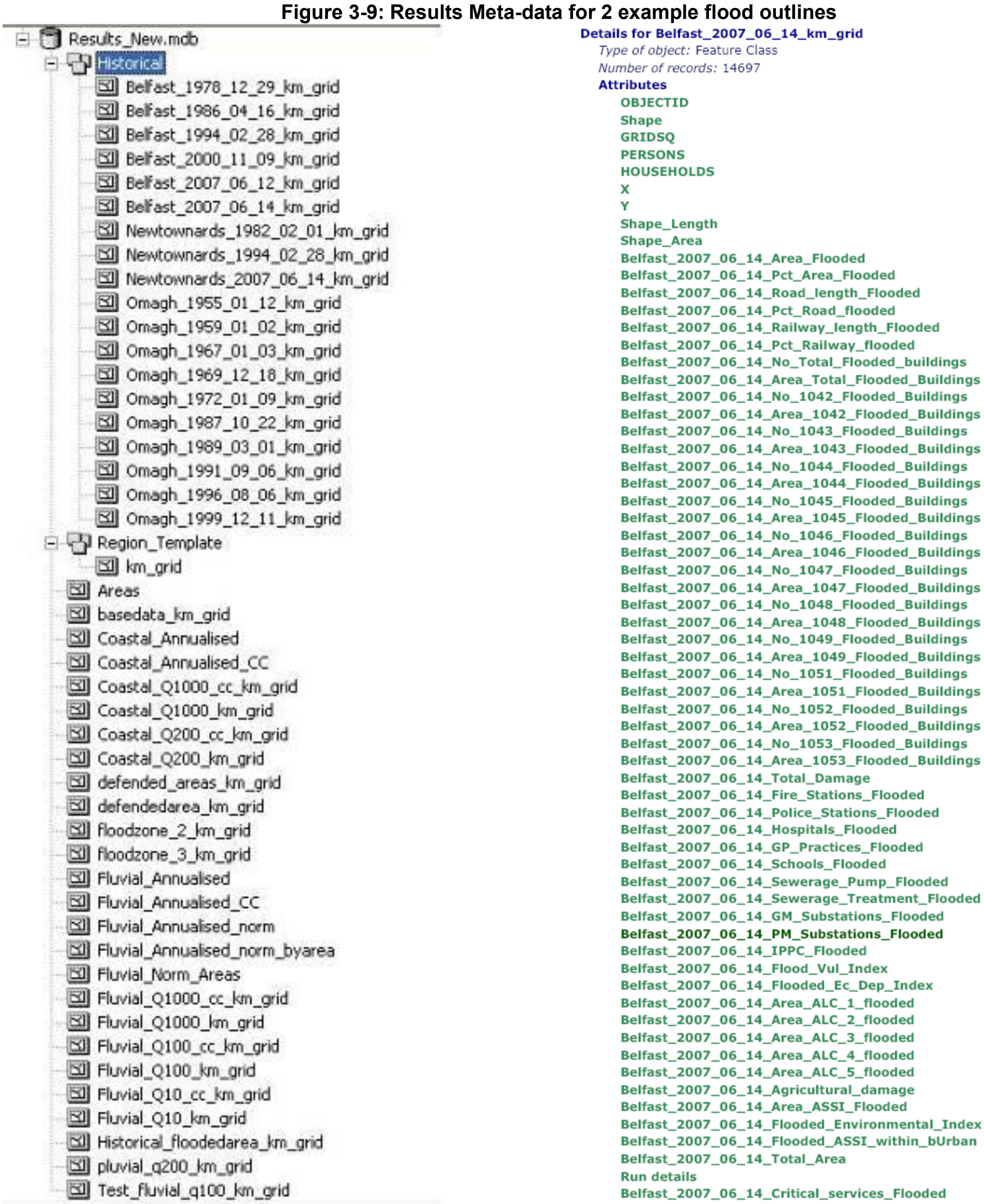


Figure 3-10: Results Meta-data for 2 example flood outlines

Details for Fluvial_Q100_km_grid

Type of object: Feature Class
Number of records: 14697

Attributes

- OBJECTID
- Shape
- GRIDSQ
- PERSONS
- HOUSEHOLDS
- X
- Y
- Shape_Length
- Shape_Area
- Fluvial_Q100_Area_Flooded
- Fluvial_Q100_Pct_Area_Flooded
- Fluvial_Q100_Road_length_Flooded
- Fluvial_Q100_Pct_Road_flooded
- Fluvial_Q100_Railway_length_Flooded
- Fluvial_Q100_Pct_Railway_flooded
- Fluvial_Q100_No_Total_Flooded_buildings
- Fluvial_Q100_Area_Total_Flooded_Buildings
- Fluvial_Q100_No_1042_Flooded_Buildings
- Fluvial_Q100_Area_1042_Flooded_Buildings
- Fluvial_Q100_No_1043_Flooded_Buildings
- Fluvial_Q100_Area_1043_Flooded_Buildings
- Fluvial_Q100_No_1044_Flooded_Buildings
- Fluvial_Q100_Area_1044_Flooded_Buildings
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- Fluvial_Q100_Area_1047_Flooded_Buildings
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- Fluvial_Q100_Area_1051_Flooded_Buildings
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- Fluvial_Q100_Area_1052_Flooded_Buildings
- Fluvial_Q100_No_1053_Flooded_Buildings
- Fluvial_Q100_Area_1053_Flooded_Buildings
- Fluvial_Q100_Total_Damage
- Fluvial_Q100_Fire_Stations_Flooded
- Fluvial_Q100_Police_Stations_Flooded
- Fluvial_Q100_Hospitals_Flooded
- Fluvial_Q100_GP_Practices_Flooded
- Fluvial_Q100_Schools_Flooded
- Fluvial_Q100_Sewerage_Pump_Flooded
- Fluvial_Q100_Sewerage_Treatment_Flooded
- Fluvial_Q100_GM_Substations_Flooded
- Fluvial_Q100_PM_Substations_Flooded
- Fluvial_Q100_IPPC_Flooded
- Fluvial_Q100_Flood_Vul_Index
- Fluvial_Q100_Flooded_Ec_Dep_Index
- Fluvial_Q100_Area_ALC_1_flooded
- Fluvial_Q100_Area_ALC_2_flooded
- Fluvial_Q100_Area_ALC_3_flooded
- Fluvial_Q100_Area_ALC_4_flooded
- Fluvial_Q100_Area_ALC_5_flooded
- Fluvial_Q100_Agricultural_damage
- Fluvial_Q100_Area_ASSI_Flooded
- Fluvial_Q100_Flooded_Environmental_Index
- Fluvial_Q100_Flooded_ASSI_within_bUrban
- Fluvial_Q100_Total_Area
- Run details
- Fluvial_Q100_Critical_services_Flooded

Details for pluvial_q200_km_grid

Type of object: Feature Class
Number of records: 14697

Attributes

- OBJECTID
- Shape
- GRIDSQ
- PERSONS
- HOUSEHOLDS
- X
- Y
- Shape_Length
- Shape_Area
- pluvial_q200_Area_Flooded
- pluvial_q200_Pct_Area_Flooded
- pluvial_q200_Road_length_Flooded
- pluvial_q200_Pct_Road_flooded
- pluvial_q200_Railway_length_Flooded
- pluvial_q200_Pct_Railway_flooded
- pluvial_q200_No_Total_Flooded_buildings
- pluvial_q200_Area_Total_Flooded_Buildings
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- pluvial_q200_No_1053_Flooded_Buildings
- pluvial_q200_Area_1053_Flooded_Buildings
- pluvial_q200_Total_Damage
- pluvial_q200_Fire_Stations_Flooded
- pluvial_q200_Police_Stations_Flooded
- pluvial_q200_Hospitals_Flooded
- pluvial_q200_GP_Practices_Flooded
- pluvial_q200_Schools_Flooded
- pluvial_q200_Sewerage_Pump_Flooded
- pluvial_q200_Sewerage_Treatment_Flooded
- pluvial_q200_GM_Substations_Flooded
- pluvial_q200_PM_Substations_Flooded
- pluvial_q200_IPPC_Flooded
- pluvial_q200_Flood_Vul_Index
- pluvial_q200_Flooded_Ec_Dep_Index
- pluvial_q200_Area_ALC_1_flooded
- pluvial_q200_Area_ALC_2_flooded
- pluvial_q200_Area_ALC_3_flooded
- pluvial_q200_Area_ALC_4_flooded
- pluvial_q200_Area_ALC_5_flooded
- pluvial_q200_Agricultural_damage
- pluvial_q200_Area_ASSI_Flooded
- pluvial_q200_Flooded_Environmental_Index
- pluvial_q200_Flooded_ASSI_within_bUrban
- pluvial_q200_Total_Area
- Run details
- pluvial_q200_Critical_services_Flooded

4. Results: Assessing the potential adverse consequences of flooding

4.1 Introduction

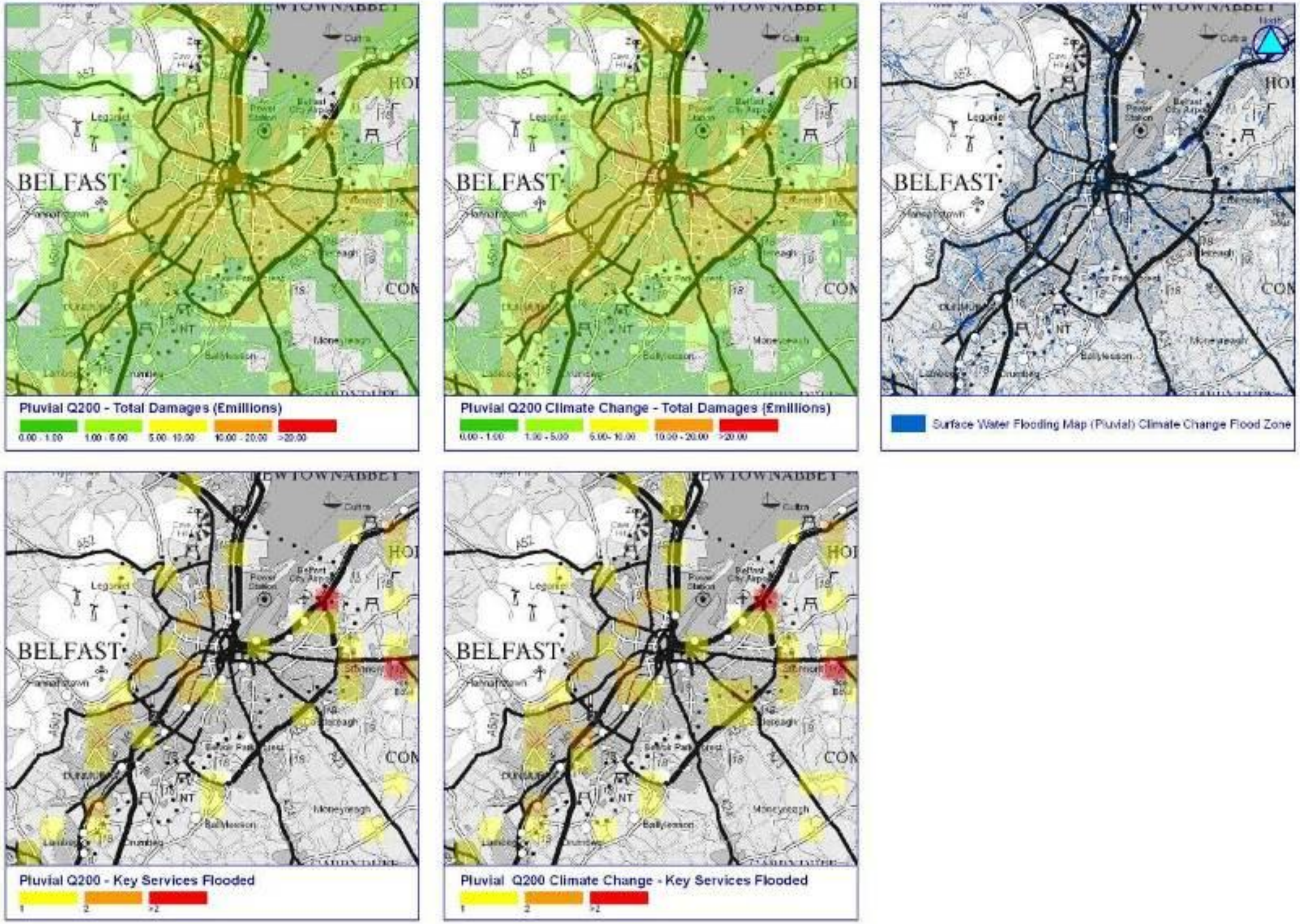
This section describes the outputs from the flood risk indicators calculations based on modelled and historic outlines to improve the understanding of the potential adverse consequences from flooding in each Sub-plan Area. The contribution to flood risk from fluvial, coastal and pluvial flooding according to a range of indicators are summarised for each Sub-plan Area to meet with the requirements of Article 4. The key indicators summarised include the core flood risk indicators used in the identification of Significant Flood Risk Areas in Section 7. Details of the important risks are drawn out for each Sub-plan Area and compared with records from historic flooding accounts. The contribution to each flood risk indicator from fluvial, coastal and pluvial flooding is also visualised and discussed to help understand source apportionment. This section therefore forms an essential part in understanding the distribution and scale of flood risk in Northern Ireland. It should be considered that all modelled flood outlines are based on the worst case - undefended flood risk, and that the values represent estimates of the long term annual average risk.

Finally, this section explores different combinations of the flood risk indicators to help appraise flood risk in a sustainable framework. In the first instance, different metrics were normalised and combined into groups associated with Human Health, Economic Activity, Environment and Cultural Heritage.

4.2 Example flood risk indicator outputs

The flood risk metric query tool populates the results geo-database described in Section 3 and provides the base data by which to create any number of visualisations for the spatial distribution of flood risk using the indicators (or combinations thereof). Figure 4-1 demonstrates how the indicators can be used to produce maps that illustrate the distribution of various aspects of flood risk. The figure shows the sensitivity of pluvial impacts (key services and damages) to climate change. Numerous other indicators (summarised in Section 3) can also be visualised in this way.

Figure 4-1: Total pluvial economic damages and key services flooded (with and without climate change)



4.3 Summary of key annualised flood risk metrics

Table 4-1 summarises the flood risk indicators for the whole of Northern Ireland. These have been calculated separately for each of the flood sources so that it is possible to quickly establish the extent to which each of the sources contributes to the overall national flood risk. In addition, the flood indicators have been computed for the current climate conditions and also for those which are predicated to occur by the year 2030 due to global warming. The percentage change in the indicators as we move from the current to the future (2030yr) scenario provides a broad scale measure of Northern Ireland's sensitivity to climate change.

It is important to note that the flood risk indicators are annualised to reflect the adverse consequences from the whole spectrum of floods that may occur over the very long (i.e. infinite) term. In other words, in a lot of years there may be no damages at all and in others there may be damages that are very much higher than the quoted figures but taken over the very long term these are the average damages that we can expect in a year.

Table 4-1: Summary of the annualised flood risk indicators for Northern Ireland

Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change (2100yr)	All sources combined without climate change
AAAD with intangibles	£116.8m	£123.7m	£33.4m	£36.4m	£140.5m	£181m	£290.9m
		5.9%		8.8%		28.8%	
All Property and Agriculture (AAAD)	£116.2m	£123m	£33.3m	£36.2m	£140m	£180.2m	£289.5m
		5.9%		8.8%		28.8%	
Property Damage	£115.6m	£122.4m	£33.2m	£36.1m	£139.7m	£179.9m	£288.6m
		5.9%		8.8%		28.8%	
Agricultural Damage	£0.55m	£0.57m	£0.11m	£0.11m	£0.25m	£0.30m	£0.91m
		3.3%		4.4%		21.3%	
Key Services	17.61	18.36	4.70	4.95	12.80	16.41	35.11
		4.3%		5.4%		28.2%	
Key Infrastructure	20.3k	21.7k	9.6k	10.3k	18.7k	24k	£48.6k
		6.6%		7.2%		28.6%	48.7k
ASSI Area	2696ha	2706ha	1352ha	1358ha	2400ha	2930ha	4289ha
		0.4%		0.5%		22.0%	
Number of IPPC Sites	0.98	0.99	0.81	0.86	1.08	1.68	2.87
		0.6%		6.1%		56.2%	
Number of People at Risk	8100	8600	1800	2000	6700	9100	16,800
		6.3%		10.2%		35.7%	
Vulnerability	5k	5.2k	0.6k	0.7k	7.7k	8.7k	13.3k
		5.0%		7.9%		12.5%	
Economic Deprivation	3.5k	3.7k	0.3k	0.4k	5.5k	6.3k	9.5k
		5.1%		8.3%		15.1%	

Similar tables for each Sub-plan Area are provided in Appendix B. These tables help place the relative risk in each Sub-plan Area within the context of the overall flood risk in Northern Ireland and show how each of the flood sources contribute to the total risk and how this may increase with climate change. This information is also represented visually using the pie-charts described at Section 4.5.

4.4 Climate change sensitivity

The climate change sensitivity for fluvial and coastal flood risk was assessed by calculating the values of key flood risk indicators for the 2030yr flood outlines (with climate change), contrasting these with the values for the present day flood outlines and expressing the difference as a percentage.

The climate change sensitivity for pluvial risk was assessed in a similar manner, except that the 2100yr (climate change) outline was used and not the 2030yr. The reason for this difference is that the pluvial flood outlines have been generated using a relatively new and largely untested surface water modelling technique. Although the surface water model used is currently the best available for a broad scale strategic assessment and similar to the models used by the other flood authorities within GB and ROI, the results should be treated with a degree of caution due to uncertainties in the methodology. For example, there is some difficulty in establishing an appropriate extreme rainfall event storm profile for specific return periods; there are deficiencies in the topographical data which can markedly affect the flood routing within the model and broad assumptions have been made in relation to the capacity of existing drainage systems which affect the estimates of net surface water flows, particularly in urban areas. As a consequence the flooded area maps derived from the model should be treated with caution and viewed as indicative rather than accurate or precise. Given the imprecise nature of the surface water maps it would not be appropriate to assess the sensitivity of surface water flood risk to climate change by comparing a present day map with a 2030yr map as the differences in the outlines would be subtle and possibly outweighed by the uncertainties arising from the methodology.

For this reason, the sensitivity of the surface water flood risk to climate change has been assessed by assuming an average 20% increase in the volume of rainfall across the province. As 20% is at the higher end of UKCIP09 estimates for rainfall increase for the end of the century, the pluvial risk sensitivity has in effect been assessed by reference to the year 2100 and not 2030 (as used for fluvial and coastal flood risk). In reality the increase in rainfall intensity is likely to be spatially and seasonally variable and highly uncertain. Although the 20% increase in volume may be an overestimate (between 10% and 20% is typically used) and the estimated change in flood risk is nonetheless very significant. Table 4-1 shows that pluvial damages are estimated to increase by around 29% by the year 2100 if the upper-bound prediction of a rainfall increase of 20% is realised. This very significant increase can be attributed to two main reasons:

- The pluvial outline operates on depths above a threshold of 0.1m, so as more rainfall is added, more of the area that was already flooded to just less than 0.1m becomes classified as flooded without the surface water actually having to spread to new dry areas before it gets counted.

- As more rainfall is added, a bottleneck effect comes more into play in urban areas where buildings restrict water from leaving flooded areas, more so than for fluvial, where the extra increase in flows are better conveyed within a slight widening of the non-climate change flood outline.

Table 4-1 shows that nationally, the economic damages attributed to fluvial flooding are estimated to rise by around 8% by the year 2030. However, the Tables in Appendix B indicate that there is a wide variation in this increase across the province. For example, the increase is most pronounced (13%) in the Foyle System Sub-plan Area while the increase in the other Sub-plan Areas is typically in the 3-6% range.

Nationally, the economic damages from coastal flooding are estimated to increase by around 9% by the year 2030. The Foyle System Sub-plan Area is again the most sensitive climate change with a predicted increase in economic damages of around 14.2% which is closely followed by the Belfast Area with almost 11%. However, in real (monetary) terms the increase in the Belfast is much more significant and more than 8 times higher than the Foyle System Area. The Erne and Melvin Sub-plan Area has no coastline and consequently there are no economic damages now or in the future and similarly, in the Bann System Area the length of coast is very short and therefore the economic damages are fairly insignificant. Although the Antrim Coast Sub-plan Area has a substantial length of coastline the costal damages are very small and despite the fact that these damages may rise by around 10% with climate change the damages are still relatively low within the national context. Coastal damages in the South Armagh and Down & Louth Sub-plan Area and the Down Coast Sub-plan Area are substantial and expected to rise by 5% and 8% respectively by 2030.

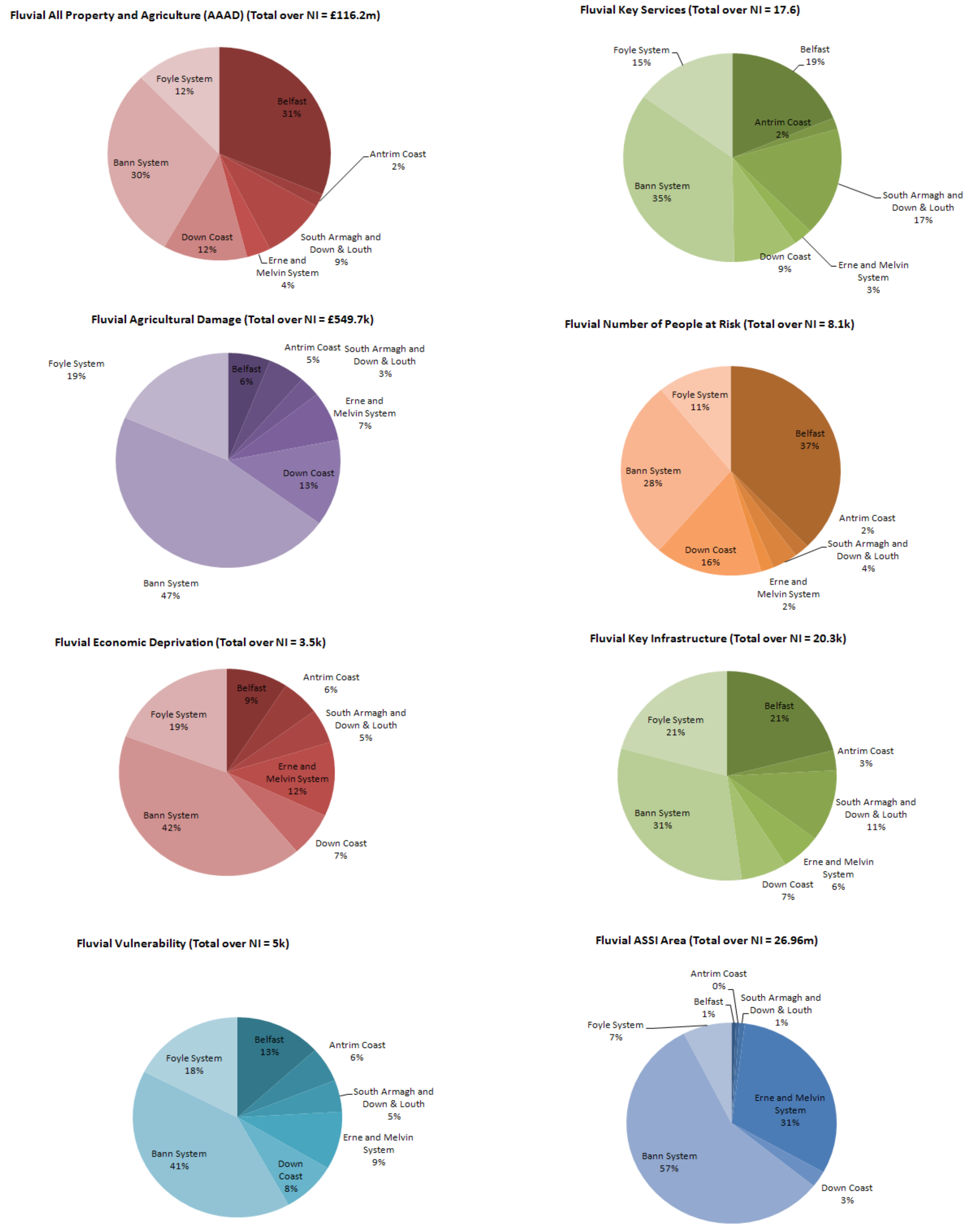
Bearing in mind that the pluvial risk sensitivity has (for the reasons stated above) been assessed over a 100 yr time frame and not the 20yrs used for both fluvial and coastal risk, a direct comparison between these sources is not possible. However, regardless of the extended timeframe it is clear from the data in Table 4-1 that pluvial risk is likely to increase significantly if climate change predictions are realised. The figures show that for that by the year 2100 the economic damages from pluvial flooding may increase by around 30% and increases in many of the other flood risk indicators fall within the range 20-50%. Unlike the risk from other sources, the magnitude of the increases due to climate change is fairly consistent across all of the Sub-plan Areas and in the range 20-34%.

4.5 Summary charts illustrating distribution of flood risk

The pie-charts in Figure 4-2 provide a useful visualisation that illustrate and effectively communicate the geographical distribution of flood risk throughout Northern Ireland for each of the flooding sources. These have been produced by comparing the ‘fluvial’ flood risk indicator values for the whole of NI contained in Table 4-1 with the respective values that are contained in summary tables for each of the Sub-plan Areas (Appendix B). Clearly, the broad-scale land-use characteristics and dominate flood sources vary between one Sub-plan Area and another and this has a marked influence on the nature of the flood risk. For example, the Bann System Sub-plan Area is largely rural and therefore it is no surprise that it contributes a large proportion on the total agricultural damages (green chart) and a relatively small proportion of the number of people at risk when compared to Belfast (purple chart).

A complete series of the pie-charts that illustrate the distribution of flood risk by Sub-plan Area for each of the flood sources (with and without climate change) is included in Appendix B.

Figure 4-2: Contribution to fluvial flood risk from all Sub-plan Areas



4.6 Potential adverse consequences for each Sub-plan Area

This section summarises the headline flood risk factors on a Sub-plan Area basis.

4.6.1 Belfast

Belfast has a long history of flood events and major damages are known to have been caused by both fluvial and pluvial events. The potential adverse consequences to human life in Belfast are predicted to be a large proportion of the Northern Ireland total (i.e. 37% fluvial, 57% coastal and 34% pluvial). The estimated long-term annual average number of people potentially exposed to fluvial, coastal or pluvial flood risk is approx. 6800 in the Belfast Sub-plan Area.

The potential for fluvial property damages in Belfast also forms a large contribution to flood risk in Northern Ireland (31%), corresponding to long term annual average damages of over £36m. The coastal and pluvial flood risks are both sensitive to climate change, with estimated increases to property damage of 11% and 37% respectively. There are a large number of key services at risk, with over 7 (increasing to 9 with climate change) likely to be affected on an annual average basis by some type of flooding. It is therefore not surprising that Belfast accounts for a large proportion of the total geographical area that is estimated to be at ‘Significant’ risk of flooding.

4.6.2 Antrim Coast

The historical flooding of County Antrim includes the extreme rainfall event of 2008, when Portglenone was subjected to 62mm of rain in 12 hours. In the 2007 flood event, roads were blocked by landslides around Ballygally and the International Airport was affected. However, within a national context there are relatively few people potentially exposed to extreme pluvial flooding (600 as compared to 6,500 in Belfast), but the flood risk metrics suggest that the climate change impact of coastal flooding of key infrastructure is relatively important (7% in Antrim).

4.6.3 The Bann System

The Bann system is the largest geographical area, and contributes substantially to the flood risk in Northern Ireland. It is estimated that around half of Northern Ireland’s total agricultural damages (annual average £0.4m from all sources) come from this system. In addition, the system also accounts for 28% percent of the fluvial flood risk to people and 31% fluvial flood risk to key infrastructure. Although the annual average fluvial property damages (£34m) are of a similar order of magnitude to Belfast (£36m) the coastal damages are relatively insignificant for geographical reasons.

Analysis of the potential adverse consequences to key services show that 11 key services are likely to flood from any source on a long term annual average basis, as opposed to 7 for Belfast, whereas there are much fewer people at risk (4,000 as opposed to 6,800 in Belfast) in this large rural system. The smaller coastal flood risk, and general rural aspect results in relatively fewer core SFRAs than might be expected from its geographical extent alone.

4.6.4 Down Coast

Approximately half the potential agricultural damages in Northern Ireland from coastal flood risk come from this Sub-plan Area, with a large proportion of the potential people at risk (30%), key infrastructure (19%) and area of ASSI at risk (59%) all from coastal flooding. Although there is predicted to be less fluvial damages (£14m) than for Belfast (£36m), a relatively large proportion of the fluvial flood risk to people (16%) is estimated to come from the Down Coast System. All this combined results in relatively large number of core SFRAs occurring within this Sub-plan Area.

The 2007 flooding gave rise to severe adverse affects within the Sub-plan Area with numerous incidents recorded at Saintfield, Crossgar (in which shops in the town centre were flooded), Ballynahinch, Newtownards and Comber. There are also a relatively high number of key services predicted to be at risk and this was underlined recently when flooding of the Fofanny water treatment plant left many people without a drinking water supply.

4.6.5 The Erne and Melvin System

The Erne and Melvin system contributes a relatively small proportion of the fluvial flood risk with only 4% of the national economic damages (approx. £4m AAAD), but the analysis shows that a relatively large proportion of the flood risk to ASSI (31%) stems from this Sub-plan Area.

From analysis of the geology of the region (BGS, 1994 and GSNI, 1991, 1997), the area most likely to suffer groundwater flooding is the Viséan limestone outcrop between Upper Lough Erne and Lower Lough Erne. In this area a major aquifer (Viséan limestone) is in contact with the lakes and with the river that connects them. However, there are no records of significant flooding by this mechanism.

4.6.6 The Foyle System

The historical flood risk in Omagh has been described at length in section 1.5.3, and the summary tables confirm that the flood risk is expected to be high, with over 2000 people at risk from fluvial flooding. However it is important to note that this represents the undefended flood risk and that flood defences have been built in Omagh that will substantially mitigate this risk. In addition to problems with fluvial flooding, around half of the coastal agricultural damages come from this system, together with a large proportion of flood risk to key infrastructure (21%) and key services (15%).

Within this Sub-plan area their may be a risk from groundwater flooding as the following systems are at locations were the river may be in hydraulic contact with alluvial and fluvio-glacial aquifers:

- River Foyle (Strabane) in the Ballymagorry area
- Fairy Water northwest of Omagh
- Owenreagh southwest of Omagh

However, there are no historical records of groundwater flooding at these locations. Consequently there has been no attempt made within this assessment to quantify the flood risk from groundwater as there is no readily derivable information available to support an assessment and the potential risk is estimated to be very low.

4.6.7 South Armagh and Down & Louth

There is a significant coastal flood risk within this Sub-plan Area which accounts for approx. 24% of the total national economic damages and 41% of the total risk to key infrastructure. On the other hand the area is generally at relatively low risk from pluvial flood in comparison to other areas.

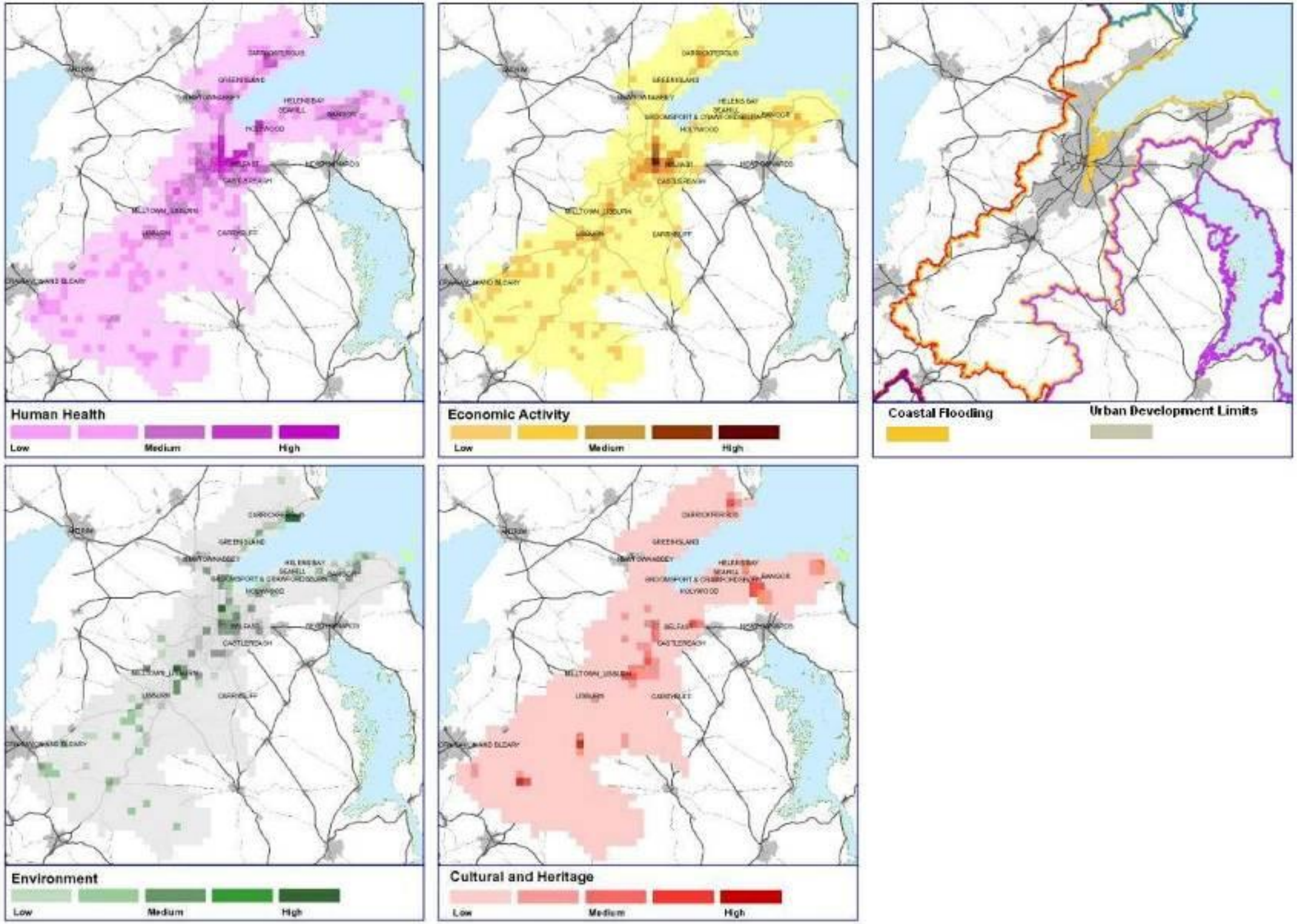
4.7 Combined flood risk indicators

The flood risk indicators described above were also combined to provide integrated measures of potential adverse consequences to Human Health, Economic Activity, Cultural Heritage and the Environment, called the Floods Directive Metrics. The combination of indicators into these Floods Directive categories can be useful (Adger et al, 2004), since the four different groupings have different vulnerabilities and help to understand where to target to raise particular types of resilience (Figure 4-3). Importantly, this combined analysis is not used to define significant flood risk areas, but rather to help with the broader assessment and to aid the consultation process.

The different flood risk indicators described so far can be grouped into the four categories, for instance flooding of key services and flooding of people’s homes are all potential adverse consequences for human health. Table 3-1 contains a list of metrics which reflects current thinking (Parker, 1999) on which factors should be included for assessing social, economic and environmental flood risk. However as the Floods Directive introduced a category specific to human health the grouping of the metrics has been adapted to reflect this addition. Different sensitivity analyses of the metric combination approach were undertaken, with more details reported in Appendix D.

These different indicators were not weighted (i.e. they were given the same weights), unless there were strong reasons for doing so (Rygel et al., in press). A key consideration is whether some of the metrics contain the same information, and so by adding them together, the same thing would be measured twice. This was found to be the case for three of the indicators for the Human Health Metric, so the weights were reduced accordingly. Further details of the combination methods are reported in Appendix D.

Figure 4-3: Example combined flood risk indicators for sustainable flood risk appraisal



4.8 Assessment of potential adverse consequences based on historical flood outlines

An estimate of the adverse consequences of some significant recent historical floods, including the 2007 and 2008 events, was undertaken by applying the flood risk metric query tool to their respective flood outlines. Examples of the flood risk indicators for two of these events are shown in Figure 4-4 and Figure 4-5.

In total 16 historical flood events were queried and a summary of the estimated adverse impacts using receptor data sets for the present day scenario is presented in Table 4-2. The estimated values in Table 4-2 should be treated with a high degree of uncertainty because in many instances it is unlikely that the complete flood outline has been accurately recorded.

As can be seen from Table 4-2 many of the most damaging events have occurred in the Omagh area. The parliament record, Hansard (1987), records that the damage arising from the worst of the Omagh floods, which was caused by the River Strule overtopping existing flood defences, was estimated at the time to be around £10m (see Figure 4-5 for the extents). The present day estimate of the economic damages for this event, calculated using the flood risk query tool is much higher at around £34m. However, given that £10m in 1987 is probably worth around £20m-£25m at today's prices and that the relative value of typical home contents has increased significantly during this period, there is a reasonable correlation between these estimates. Following the 1987 event the Omagh flood walls were raised and therefore fluvial flooding to the extent of that which was recorded in 1987 is an unlikely scenario. However, the flood defence scheme hasn't completely removed the risk of flooding and in October 2011 a major flood event on the River Strule, estimated to have a return period of 1 in 120yr saw floodwaters rise to within 0.5m from the top of the river walls.

According to the query tool the most recent flooding in June 2007 (described in section 1.5.2) is estimated to have caused economic damages of in excess of £13m of which around £10m is attributed to the Belfast area. However these damage figures do not include the monies paid to the victims of flooding by local councils in flood relief payments, which in this instance exceeded £1m.

Table 4-2: Relative impacts of historic events using Flood Risk Metric tool based only on available surveyed flood outlines (post 1971 only)

Flood	Area Flooded (m2)	Road Length (m)	Damage (£)	Key Services Flooded	Agricultural Damages (£)	Area ASSI Flooded (m2)	No. Buildings Flooded
Omagh 1987	3,722,714	5,678	33,767,916	6	16,824	13,334	350
East Belfast 2007	214,182	36	9,791,523	0	1,728	0	333
Omagh 2007	135,999	2,492	3,309,566	0	62	0	86
Lisburn 1978	791,222	3,407	2,313,977	2	2,966	0	10
Widespread 2008	1,381,714	836	2,198,097	0	8,631	0	43
Omagh 1972	1,612,102	382	546,109	0	7,895	0	12
Comber 1982	552,533	491	223,214	0	9,646	0	8
0magh 1991	557,892	259	65,897	1	3,726	0	0
Lagan/Upper Bann 1986	1,011,628	789	59,561	0	3,680	0	1
Widespread 2007	21,652	0	57,706	0	96	0	1
Omagh 1999	813,985	683	11	0	5,512	0	0
Omagh 1996	279,576	52	0	0	1,048	0	0
Newtownards 2007	42,025	0	0	0	422	0	0
Newtownards 1994	20,500	0	0	0	530	0	0
Widespread 2000	264,289	0	0	0	1,032	0	0
Widespread 1994	451,505	36	0	0	1,728	0	0

Figure 4-4: Example flood risk indicators for Belfast Region Historic Flooding 2008

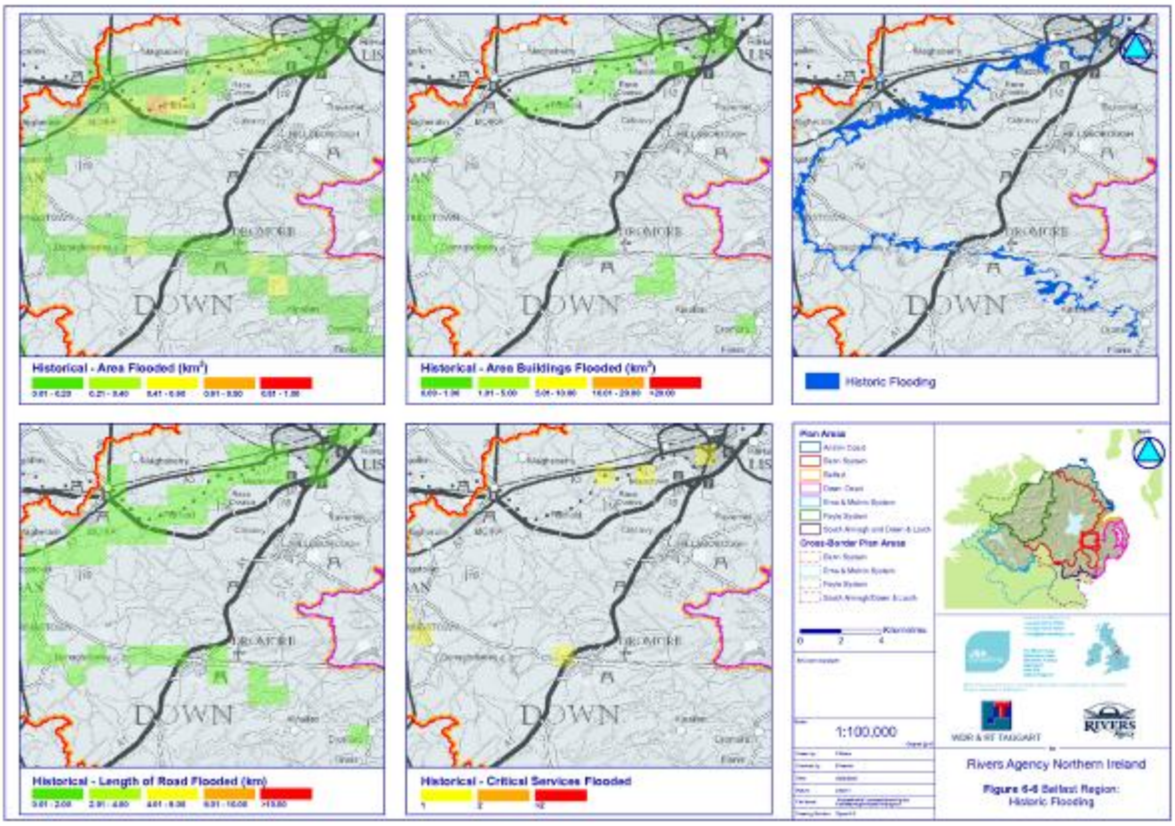
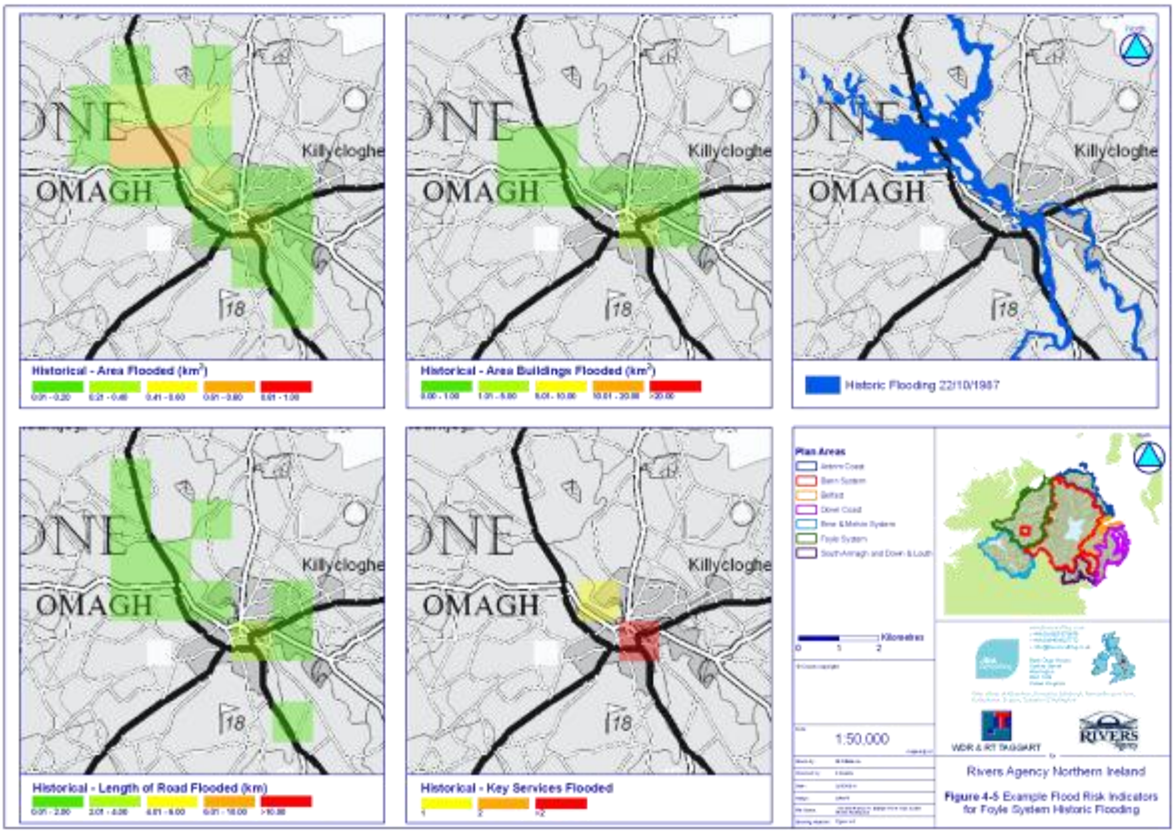


Figure 4-5: Example flood risk indicators for Foyle System Historic Flooding



5. Visualisation of Assessment Output Data

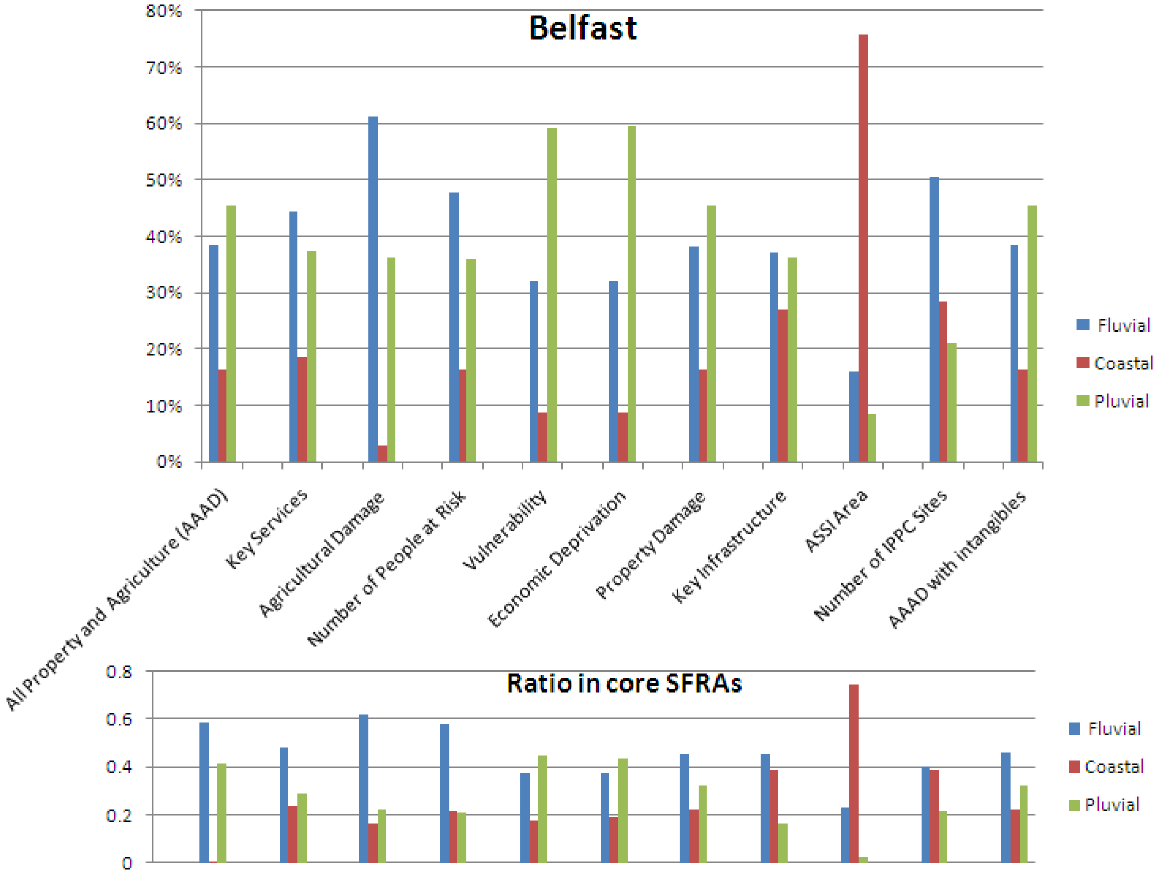
The GIS based application and the embedded query tools can be used to generate a range of tables, maps and charts to represent the quantitative flood risk indicators and other relevant data in a highly visual manner. These visual aids have been used extensively by Rivers Agency to present and explain many key elements of the assessment to a broad range of stakeholders. The following are examples of the type of data visualisations that are possible.

5.1 Source apportionment of flood risk

The contributions to flood risk from each of the different flood sources (fluvial, coastal or pluvial) have been examined for each Sub-plan Area in terms of the more important flood risk indictors including AAAD and AAKSF. Figure 5-1 shows the percentage contribution from fluvial, coastal or pluvial flooding to the total measure of flood risk using some key indicators (Table 4-1). For the majority of grid squares, fluvial and pluvial flooding are the dominant sources across each of flood risk indicators. An exception to this would be a grid square that is predominantly ASSI and likely to flood from the sea. However in this case the flooding may not cause any adverse affects and therefore may not be a true risk.

The bar chart inset in the Figure 5-1 shows how the ratios change when the contribution from each source is assessed for the Core SFRAs that have been identified within the Belfast Sub-plan Area. Here it can be seen that the fluvial contribution generally increases, or the pluvial contribution generally decreases, suggesting fluvial flood risk is more significant in the core SFRAs. Appendix B contains similar bar charts for the other Sub-plan Areas.

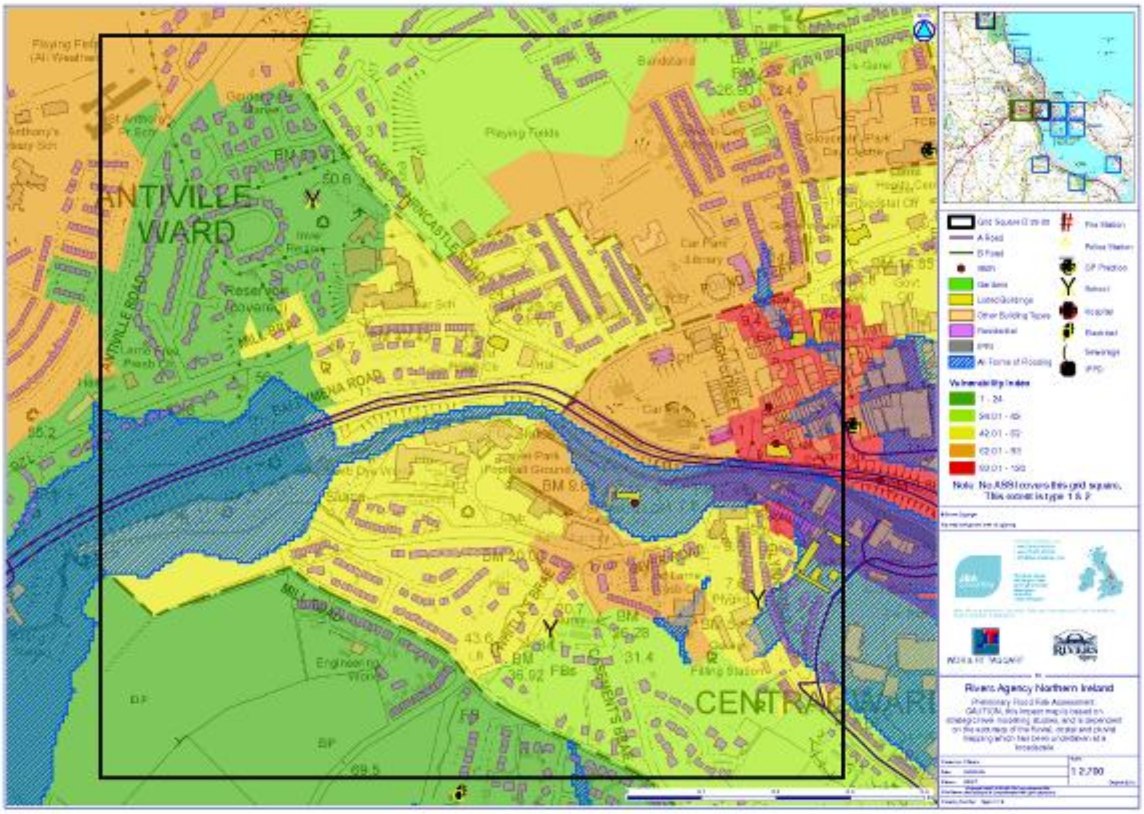
Figure 5-1: Source apportionment of flood risk within the Belfast Sub-plan Area



5.2 Visualisation of receptor data

Figure 5-2 is an example of the detailed flood risk information that can be generated through the GIS based application. This particular map highlights the extents of the potential flooding from all sources and the nature of the receptors that this may affect.

Figure 5-2: Visualisation of flood receptors within SFRA



6. PFRA Conclusions

This Preliminary Flood Risk Assessment for Northern Ireland has taken account of a broad range of available or readily derivable information to assess the spatial distribution of potential flood risk to meet the requirements of Articles 4 of the EU Floods Directive. It uses a variety flood risk indicators to measure the adverse consequences of future floods on Economic Activity, Human Health, the Environment and Cultural Heritage. It also describes the methodology by which Rivers Agency has made use of the most important flood risk indicators to identify those areas for which potential significant flood risks exists to satisfy Article 5 of the Directive.

The assessment considers the national risk from fluvial, coastal and pluvial flooding and from the failure of impounded water bodies. However, the assessment of flood risk from impounded water bodies is not conclusively addressed within this report as there is currently insufficient 'available or readily available' information to conduct a robust assessment of the risk from this source. The reason for this lack of information is that, unlike the rest of the UK, Northern Ireland does not have legislation for the management of reservoir safety and as a consequence the owners of impoundments have not been required to collate such information as would be necessary to assess the potential risk of their failure. To bridge this information gap, Rivers Agency produced a separate strategic assessment, *Flooding from Impoundments – Northern Ireland (June 2010)* to scope the potential adverse consequences from flooding by impounded water bodies. This report has revealed that there are at least 156 large impoundments and that the risk to human health from their potential failure is 'significant'. Rivers Agency proposes to address the assessment and management of this risk through the introduction of new reservoir safety legislation and work to progress this legislation has commenced. Therefore, as the potential flood risk from impoundments has already been determined to be 'significant' and shall be effectively managed through a legislative mechanism the assessment of the flood risk from this source is not specifically covered within this report.

Within the transposing Regulations, Northern Ireland has exercised the permitted flexibility to exclude floods from sewerage systems that are caused solely by a system failure or blockage and therefore this flooding mechanism is not considered within the assessment. Flooding due to the hydraulic under-capacity of sewerage systems is included in the Regulations. There is currently no available or readily derivable information to specifically identify areas that are prone to flooding from sewerage systems. However, pluvial (surface water) flooding and flooding from sewerage systems are inextricably linked and consequently, a strategic pluvial model has been used to highlight areas in which flooding from sewerage systems may be a factor.

The assessment was based on three different probability events (low, medium and high) for each of the flood sources. By using three flood outlines with markedly different return periods it was possible to produce damage – probability curve for each of the quantitative flood risk indicators. The total area under the curve represents the annualised value of the flood risk indicator or to put it another away the long-term average annual value of the flood risk indicator. This is a vitally important concept as it provides a common basis for a rational comparison of the risk to areas in which, for example, a small number of properties are flooded on a frequent basis with those in which a large number of properties are flooded on an infrequent basis. Qualitative flood risk indicators, such as the adverse consequences to the environment were assessed through direct consultation with the appropriate responsible authority (i.e. NIEA).

Tables, visualisation maps and charts have been used to illustrate the spatial distribution of the various flood risk indicators at the national, Sub-plan Area and 1km grid square scales. The following are key elements of the PFRA and some important findings:

- It is estimated that 46,000 or 5% of the 830,000 properties in Northern Ireland are located within the un-defended 1 in 100yr (1% AEP) fluvial floodplain or 1 in 200yr (0.5% AEP) coastal floodplain. Approximately 15,500 of these properties are protected to some extent by flood defence systems and the culvert network. In addition, the surface water flood map indicates that around 20,000 or 2.5% of the properties in Northern Ireland are sited in an area that is shown to be at risk of flooding from a 1 in 200yr (0.5% AEP) pluvial event greater than 300mm deep, however, many of these properties would already be at risk of flooding from fluvial and/or coastal flooding.

- The key geography of Northern Ireland relating to flood risk has been described and mapped as required in Article 4 of the Directive. The maps incorporate details of the international borders, the boundaries of the River Basin Districts, International RBDs and Sub-plan Areas and the land use characteristics and topography.

- Key institutions were contacted in order to obtain all available and readily derivable information on flood risk for Northern Ireland. A wide range of data was obtained from different institutions and pre-processed ready to use with a spatial query tool that checks if the assets are located within or outside of the (high, medium or low likelihood) strategic floodplain outlines for each of the flood sources

- A set of flood risk indicators were derived from the broad range of receptor base-data. The flood risk indicator values were computed using an automated ArcGIS query tool and stored in a systematic way in a results geo-database. The indicators were calculated on a 1km grid to enable the spatial variation in the potential adverse consequences to be visualised at a practical scale. These flood risk indicators included the:

-
    - Number of different building types located within any flood outline;
    - Number of flooded key services split into different categories and totalled;
    - Number of people at risk;
    - Number of IPPC sites flooded and the area of IPRI site polygons flooded;
    - Length of key infrastructure flooded (roads);
    - Area of flooded buildings;
    - Area of flooded ASSI;
    - Vulnerability based on census data
    - Economic Deprivation
    - Property damages of flooded buildings
    - Agricultural damages

- The long-term annual average values of all these indicators was computed for fluvial, coastal and pluvial flooding by integrating the indicator (i.e. damage) versus probability curves. The long term average annual damages were scaled to give agreement with the Multi-Coloured-Manual 2010 with the assumption of first flooding at the 1 in 5 years (20% AEP).

- The spatial distribution of the key flood risk indicators was summarised in tables, maps and charts to effectively communicate the spatial variation in risk across the country and how overall risk within areas is apportioned to the various flood sources.

- Due to uncertainties in the modelling techniques and data used to generate the surface water flood maps it would not have been appropriate to produce a surface water map for the 2030yr climate change epoc. As a consequence it is not possible to make a direct comparison of the flood risk sensitivity to climate change from this source with rivers and the sea as the climate change maps for these sources have been produced in line with PPS15 for the year 2030. Notwithstanding this difference, it is clear that the flood risk sensitivity to climate change is very pronounced for pluvial flooding (estimated at 30% for some indicators including the number of people at risk and property damages). Coastal flooding was more sensitive to climate change than fluvial for most indicators, including the number of people at risk.

- The spatial distribution of flood risk from historical flooding was also examined, and compared against historical accounts pertaining to the recorded severity of the impacts. Unfortunately, there is very little information available on the actual level of damages arising from historical flooding in Northern Ireland. However, there is some evidence that the automated GIS based approach taken in this study is robust as it produces outputs in terms of the number of flooded properties for the widespread 2007 event, and the economic damages for the 1987 Omagh event that correlate well contemporaneous records.

7. Determination of Significant Flood Risk Areas

7.1 Background to SFRA

Article 5 of the Directive requires member states to use the PFRA as the basis to *'identify those areas for which they conclude that potential significant flood risk exists or might be likely to occur.'* The methodology used to determine the location and extent of these areas, which the Agency refers to as Significant Flood Risk Areas (SFRA), must be formally reported to the EC, although the Directive does not specify when this should be done. The only guidance issued by the EC is that the identification of SFRA *'must be completed soon after 22 December 2011, and in sufficient time to allow Member States to prepare flood maps by 2013.'* It is anticipated that Rivers Agency will identify the SFRA for NI in early 2012.

The identification of the SFRA is a critical milestone as these are the only areas for which the later requirements of the Directive apply. For each of the SFRA identified, Member States are required to produce detailed flood hazard maps and flood risk maps followed by flood risk management plans. Areas which are determined to be below the threshold of significant flood risk require no further action under the Directive. However, the flood risk in areas outside of the SFRA will continue to be managed by the appropriate public body with responsibility for the flooding through their existing statutory arrangements.

7.2 Methodology for the determination of SFRA

The methodology used for the determination of SFRA had two distinct strands that together take into consideration the adverse consequences of flooding on economic activity, human health, cultural heritage and the environment. Strand 1 considers the significance of the potential risk to economic activity and human health. Strand 2 identifies those areas in which the risk to the environment and cultural heritage is potentially significant.

7.3 Draft SFRA – Strand 1 (Economic Activity & Human Health)

The objective of this strand is to identify the geographic areas in which the flood risk to economic activity and human health is significant and uses, as far as possible, a common quantitative measurement so that the risk to each category can be readily combined.

This approach expresses the risk to economic activity in monetary terms using the techniques described in the Benefits of Flood and Coastal Risk Management Manual published by the Flood Hazard Research Centre 2010. Using the GIS application and a bespoke computer programme known as Flood Risk Lab, the Annual Average Damages for each source of flooding with a 1km grid scale was calculated for each source and then combined to obtain the Amalgamated Annual Average Damages/km2 (AAAD/km2).

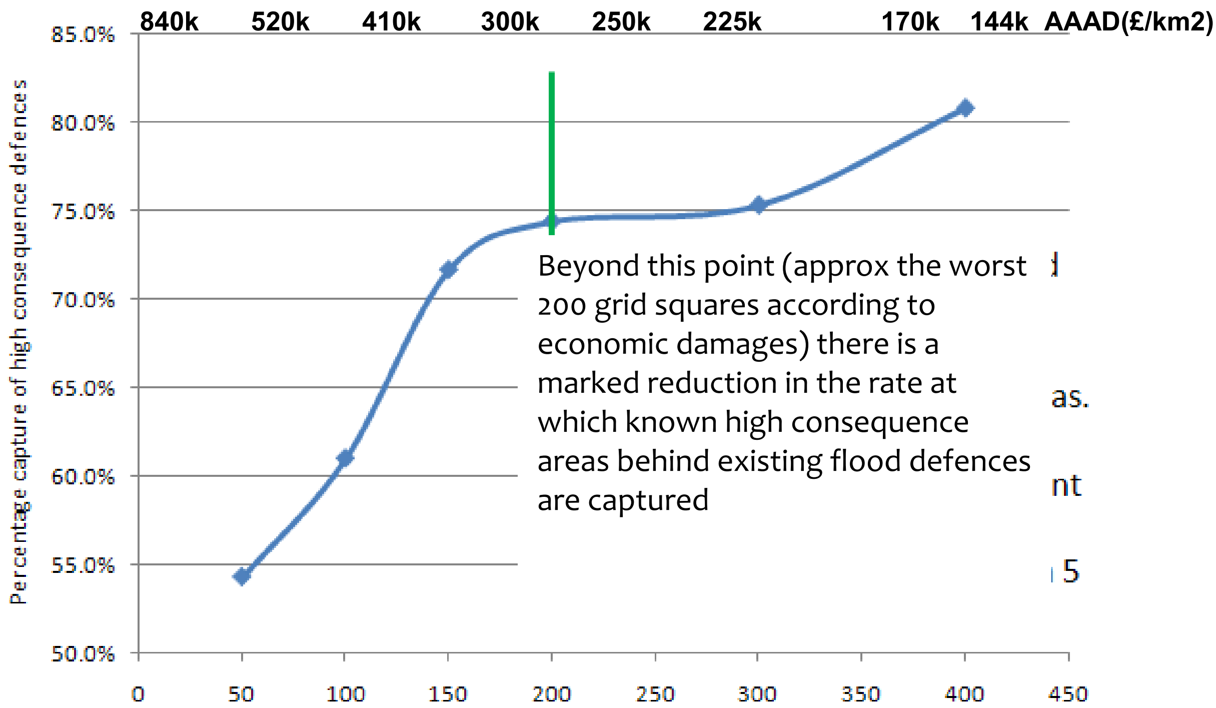
The main adverse affects of flooding to human health (people) is the distress and cost associated with flooding to their homes and the potential loss or disruption to the essential services upon which they depend. However the costs associated with the flood damage to residential property is already included within the automated calculation of AAAD/km2. To account for the intangible health impacts arising from the distress to people at risk from flooding the Benefits of Flood and Coastal Risk Management Manual recommends that this can be monetised and valued at £200/property/yr. This figure has been established through recent research funded by DEFRA and Environment Agency.

Whilst monetary damage (AAAD/km2) is a key indicator of the risk to economic activity and human health it does not fully reflect the adverse human consequences arising from the loss or disruption to essential services. To ensure that the significance of the potential adverse affects of flooding on essential services was fully considered, Rivers Agency undertook a major consultation exercise with relevant organisations from the key infrastructure sector. The responses to this consultation were taken into account in the determination of the Strand 1 – SFRAs.

7.4 Process for identifying locations of Draft SFRA (Strand 1)

The identification of the Draft SFRA (Strand 1) centres round the selection of Core SFRA which are those 1km grid squares that have AAAD which exceed £300k under present day climate conditions. This threshold was chosen because it captures the majority of the grid squares that are located behind the existing ‘high consequence’ flood defence systems throughout the province. The ‘high consequence’ defences have been classified by Rivers Agency in accordance with best practice and as outlined in its Fluvial Flood Defence Asset Management Plan (April 2010). The logic for this threshold is that past floods which caused AAAD/km2 in excess of £300k were, in most cases, considered to be sufficiently ‘significant’ to justify public expenditure on major flood defence systems. Therefore, floods that are predicted to occur in the future and which are estimated to cause economic damages of a similar magnitude should also be considered ‘significant’

Figure 7-1: Measure of capture of high consequence areas by grid squares ranked by annual average (Property and Agriculture) damages.



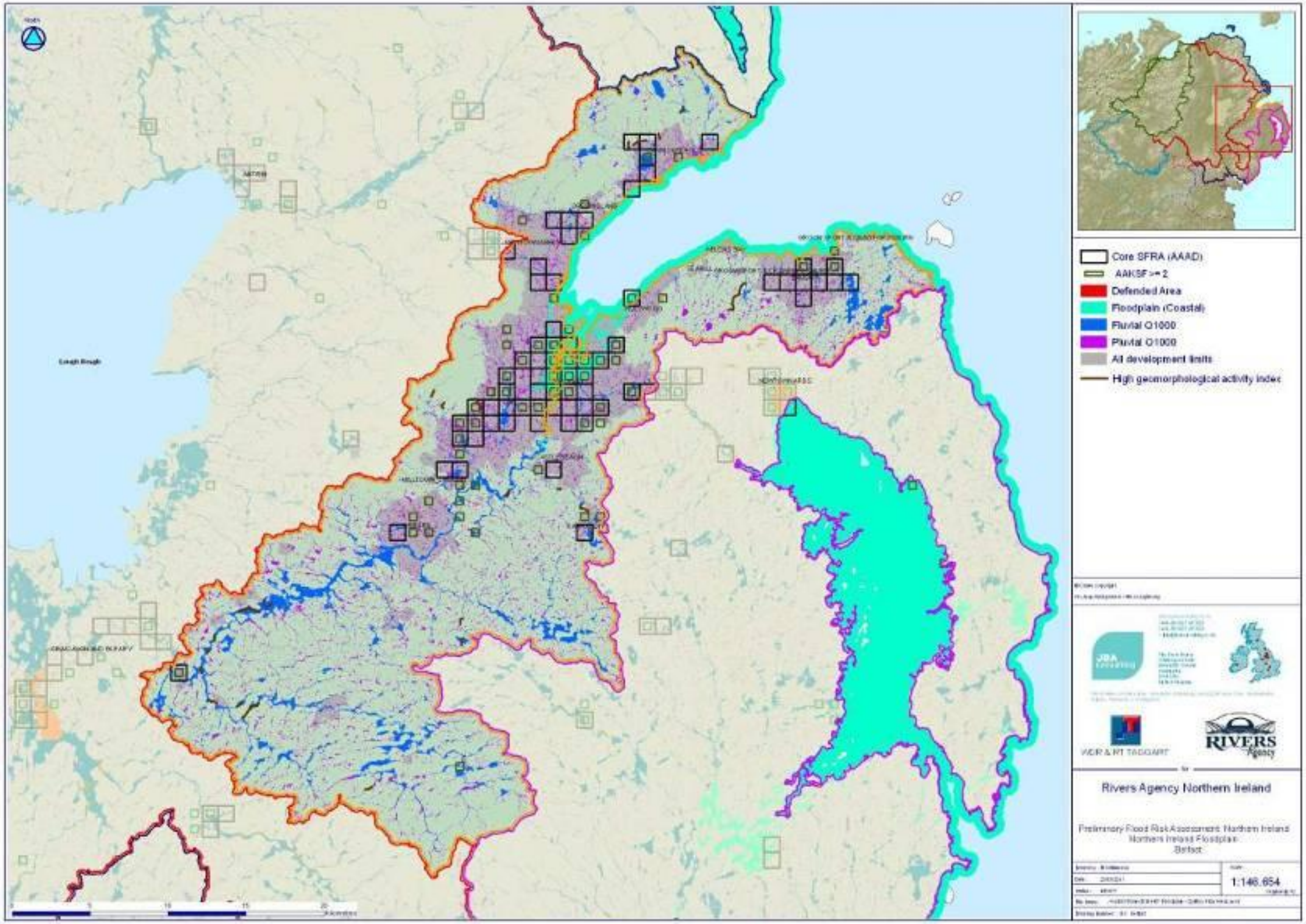
From Figure 7-1 it can be seen that, based on economic damages (AAAD/km2), there are approx 200 grid squares with AAAD/km2 greater than or equal to £300k. Of these 200 grid squares 75% are within 1km of the existing high consequence flood defence systems. The graph illustrates that it would require a disproportionately large increase in the total number of grid squares to capture a relatively modest number of additional high consequence areas. For example it would require the inclusion of another 200 grid squares to capture an additional 5% of the grid squares in the high consequence (defended) areas. The graph clearly illustrates that the optimum AAAD/km2 threshold which results in a practicable number of Core SFRA and which captures most of the known high consequence areas is £300k. In effect this threshold corresponds to approximately 100 residential properties within a 1km grid that are potentially at risk from flooding assuming that first flooding can occur at a 1 in 5yr event.

Figure 7-2 illustrates the location of Core SFRAs within the proposed Belfast Sub-plan Area and are highlighted with the black outlined grid squares. Not surprisingly, Belfast has a relatively high number of Core SFRAs (34% of the national total) because it is an extensive highly populated urban area and there is a moderate risk of coastal, fluvial and pluvial flooding.

In addition to the Core SFRA, other flood risk information is represented in Figure 7.2. This includes the identification of watercourse sections which are estimated to have a potential for high geomorphological activity and grid squares in which estimated Annual Average (number of) Key Service Flooded (AAKSF) is greater than or equal to 2.

The Core SFRA for each of the other proposed Sub-plan Areas are illustrated in the maps within Appendix E.

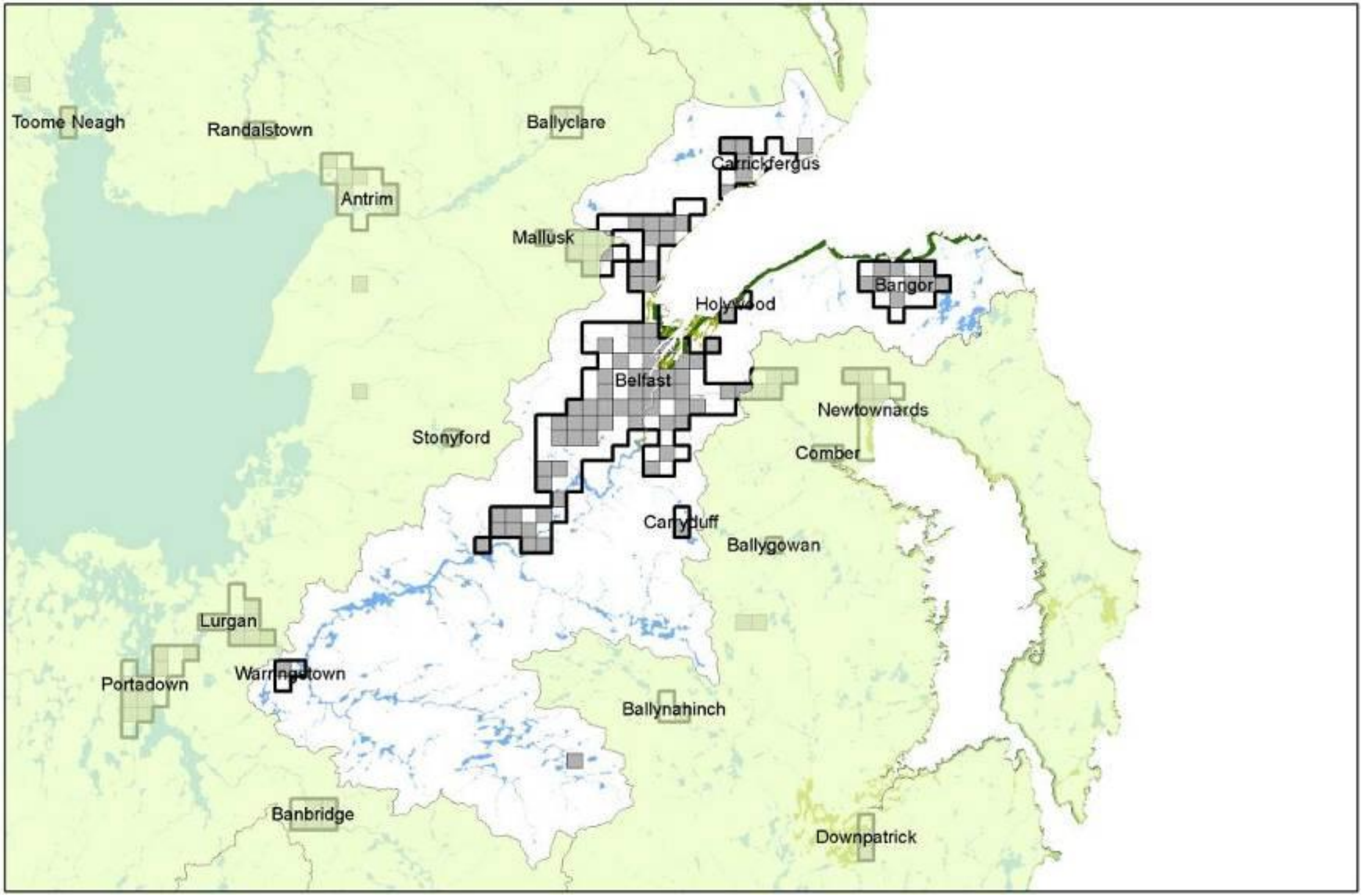
Figure 7-2: Core Significant Flood Risk Areas (Strand 1)



7.5 Process for identifying the extents of Draft SFRA (Strand 1) from Core SFRA (Strand 1)

The Core SFRA are used a seed cells from which to grow the Draft SFRA (Strand 1) by amalgamating these with adjacent grid squares which have AAAD/km2 in excess of £200k (under present day or predicted 2030yr conditions) and all grid squares which benefit from the presence of the major flood defence systems (regardless of the level of damages). Samples of the maps used in the process to grow the Draft SFRA (Strand 1) are available in Appendix F. The reason for the automatic inclusion of grid squares which benefit from existing major flood defence systems is that there will always be a residual risk to the flood prone areas located behind the defences. There is a distinct possibility that some of the existing flood defences, many of which were constructed 20 or 30yr ago, may not be providing the level of protection for which they were originally designed (typically 1:100yr). By adopting this precautionary approach an opportunity is created within the first FRMP cycle to undertake a detailed assessment of the residual risk to the defended communities and to mitigate this risk as necessary. As the detailed flood risk assessments for the existing flood defence systems will be taken into consideration within the next PFRA in six years time it is anticipated that there may be a reduction in the total number of SFRAs declared at that time. It is important to note that whilst there may be as many as 71 Core SFRA within the Belfast Sub-plan area there is a much smaller number of Draft SFRA (Strand 1). This reduction occurs because many of the Cores are adjacent to each other or amalgamated together by the inclusion of other relatively high consequence squares. An initial application of the process for growing the Draft SFRA from cores within the Belfast Sub-plan Area is shown in Figure 7-3. This should be treated as an *'indicative'* map as the location and extents of the SFRA have yet to be finalised. A map series illustrating the core and Draft SFRAs for the other Sub-plan Areas can be found in Appendix E.

Figure 7-3: Draft Significant Flood Risk Areas for Belfast Sub-plan Area



7.6 Confirmation of SFRA - Strand 1 through consultation with Key Services Sector

To ensure that the significance of the potential adverse human affects which relate to the flooding of, and loss or disruption to, essential services was fully considered in the process to identify SFRA, Rivers Agency undertook a major consultation exercise with relevant organisations from the key services sector.

Maps illustrating the location and extents of the Draft SFRA (Strand 1) were provided to all of the key service asset holders. The availability of this early information enabled the organisations to focus their responses on those flood prone key assets located outside of the Draft SFRA (Strand 1). This was important as there was no tangible benefit in stakeholders providing information for assets that are known to be located in areas that had already been identified as ‘Significant’ on the basis of economic damages alone.

The objectives of the consultation were twofold. The first was to encourage stakeholders to complete ‘Site Survey Questionnaires’ for their major flood prone assets. Completion of these questionnaires made it possible to undertake a more accurate estimate of the potential economic damages to some high value assets and subsequently to revalorise the AAAD for the grid squares in which they are located. The second objective was to require stakeholders to identify any of their assets which are deserving of a Cat 2 rating under the Cabinet Office’s Criticality Scale for National Infrastructure. Cat 2 is defined as *infrastructure whose loss would have a significant impact on the delivery of essential services leading to loss, or disruption, of services to tens of thousands of people or affecting whole counties or equivalents*.

Taking consideration of the responses from the key services stakeholders, the Draft SFRA (Strand 1) were revised as appropriate to confirm the SFRA (Strand 1).

7.7 Identification of SFRA - Strand 2 (Environment & Cultural Heritage)

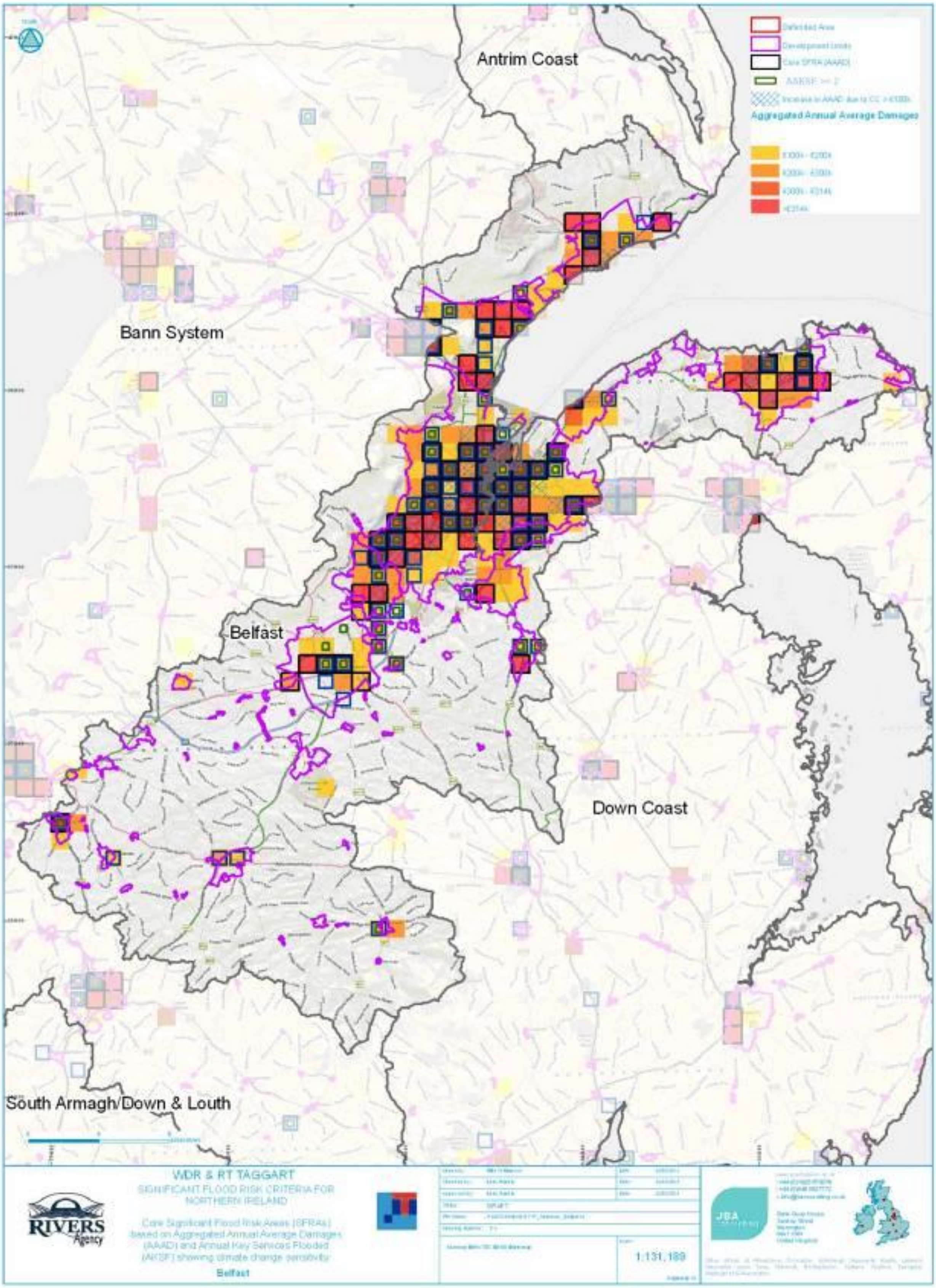
The objective of this strand is to identify those geographical areas in which the flood risk to the environment or cultural heritage is significant. This element of the assessment was effectively undertaken by NI Environment Agency which has a responsibility to protect and conserve our natural environment and built heritage.

Rivers Agency provided NIEA with such information as was necessary to determine the likelihood of flooding to ASSIs and in particular highlighted those designated areas in which the proximity of potentially polluting IPPC sites could give rise to the release of waterborne pollution. Also highlighted as prone to flooding were sites of archaeological interest and historic gardens, sites and monuments

7.8 Climate change and SFRA

The AAAD threshold that was defined for present day of £300k was applied to the economic damages estimates calculated for climate change flood outlines. This resulted in 60 additional Core SFRA. Of the 60 additional Cores, 49 of these are already included within boundaries of SFRA that have been established on the basis of the present day risk. However, this forward looking scenario is a relatively long time in the future and within this timeframe there will have been numerous iterations to PFRAs and FRMPs which, in compliance with the Floods Directive, must be undertaken on a six year cycle. As a consequence of this planning cycle there will be continuing opportunities to take new information on climate change into consideration in later PFRA. Therefore, in practical terms, it is possible that areas which are presently not considered to be SFRA may be identified as SFRA through PFRA that are undertaken in the future. Rather than highlight the specific areas where the currently available climate change mapping triggers additional Core SFRA, an absolute increase in damages of £100k was chosen to highlight the areas that may be particularly sensitive to an increased flood risk from climate change. In Figure 7-4 the grid squares highlighted with a blue cross indicate areas within the Belfast Sub-plan Area where annual average economic damages could increase by more than £100k as a consequence of climate change. The map also illustrates other information such as defended areas, development boundaries and the variation in economic damages by the colour banding of grid squares to represent AAAD. Similar maps for other Sub-plan Areas contained in Appendix F.

Figure 7-4: Addressing the additional requirements of Article 4(2)(d)



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Appendices

A Methodology and data used for the derivation of property and agricultural damages

B Summary tables and charts illustrating the distribution of flood risk by Sub-plan Area

C Maps illustrating records of historical flood outlines

D Examples of combined flood risk indicators

E Maps illustrating Core SFRA by Sub-plan Area

F Maps illustrating Core SFRA, AAAD and climate change sensitivity by Sub-plan Area

G Samples of detailed maps illustrating flood extents and receptors

H Assessment of geomorphological sensitivity

A Methodology and data used for the derivation of property and agricultural damages.

A.1 Derivation of property damage per unit area for the Building Polygon dataset

The main attributes and make-up of the Building Polygon dataset are summarised in Table A-1, where it can be seen that over 90% of the buildings are residential.

Table A-1 Summary Characteristics of Northern Ireland Building Polygon Dataset

FEAT_CODE	FC_NAME	Count	% of total count	Area	% of total area	Avge Area
				m^2		m^2
1042	LAW_ADMIN : COMMUNAL BUILDING FOR LAW AD	76	0.0%	33564	0.0%	442
1043	HEALTH_B : COMMUNAL BUILDINGS ASSOCIATED	3312	0.4%	875937	1.1%	264
1044	EDUCATE_B : COMMUNAL BUILDING FOR EDUCAT	8584	1.0%	2542182	3.2%	296
1045	RELIGION_B : COMMUNAL BUILDING ASSOCIATE	4050	0.5%	1053524	1.3%	260
1046	SERVICES_B : COMMUNAL BUILDING FOR PUBLI	5478	0.7%	569559	0.7%	104
1047	RECREAT_B : COMMUNAL BUILDING FOR RECREA	2413	0.3%	706205	0.9%	293
1048	GOV_OFFICE : COMMUNAL BUILDING FOR GOVER	1400	0.2%	413012	0.5%	295
1049	COMM_OTH : ANY OTHER TYPE OF COMMUNAL BU	5626	0.7%	1230045	1.5%	219
1051	INDUSTRY_B : GENERAL BUILDING ASSOCIATED	10007	1.2%	6995493	8.7%	699
1052	COMMERCE_B : GENERAL BUILDING ASSOCIATED	40498	4.9%	9708546	12.0%	240
1053	DWELL_HOUS : GENERAL BUILDING - ALL TYPE	744642	90.1%	56543146	70.1%	76
1054	GENERAL_OT : ANY OTHER GENERAL BUILDING	ignored for this analysis				
1058	GLASS_B : GLASS BUILDINGS	ignored for this analysis				
	Total	826086		80671213		

Each property falls into one of 13 types given by the feature code (FEAT_CODE) and its description FC_NAME. Property types 1054 and 1058 were removed from the dataset on the advice of the Rivers Agency, and were not considered in the flood risk analysis.

The derivation of property damage data per unit area as a function of depth of flooding is based on the Flood Hazard Research Centre's "Multi-Coloured Manual" (MCM), described in the following sub-sections.

Residential (Building Polygon feature code 1053)

All residential property is given the same feature code, so no further breakdown into property types is possible. The depth-damage data used for this study is taken from the MCM[2] for the residential sector average, short duration flood (<12 hours) and is given in Table A-2.

[2] Chapter 4, Appendix 4.1, Short Duration, Residential sector average

Table A-2 Depth-Damage Data for Residential Property Type 1053

Flood Depth (m)	Damage / m2 (2005)		Flood Depth (m)	Damage / m2 (2010)
-0.3	£ 11.28		-0.3	£19.75
0	£ 11.28		0	£19.75
0.05	£ 202.50		0.05	£173.55
0.1	£ 249.25		0.1	£239.44
0.2	£ 429.80		0.2	£388.51
0.3	£ 481.75		0.3	£457.37
0.6	£ 540.11		0.6	£566.37
0.9	£ 576.97		0.9	£607.84
1.2	£ 609.72		1.2	£662.34
1.5	£ 638.92		1.5	£704.02
1.8	£ 671.71		1.8	£787.38
2.1	£ 698.51		2.1	£829.41
2.4	£ 725.26		2.4	£870.97
2.7	£ 786.03		2.7	£968.91
3	£ 814.10		3	£1,012.38

The table shows the 2005 values that were originally used, along with the 2010 updated values following the update to the MCM 2010.

The next step for residential is to estimate an average depth of flooding for a particular design flood outline, since depth of flooding over the floodplain was not available for all the types of flooding considered. This is undertaken in Section A2 below using a large sample set of data from the North East of England.

Non-Residential (Building Polygon feature codes 1042, 1043, 1044, 1045, 1046, 1047, 1049, 1051, 1052)

Table A3 shows the depth-damage data for all the non-residential property types used in this analysis updated for MCM 2010. The derivation of this data, showing the assumed property type correspondences and the weights used, is given in Table A-4. As for the residential property type, the damage values extracted from the MCM are those appropriate to short-term flooding (<12 hours).

The depth-damage data used in this study for these property types have been derived by assuming a correspondence between the feature codes of the building polygon dataset and the property type codes available in the MCM. Where a feature code corresponds to more than one MCM property type, the final damage values are calculated using a weighted mean. Following the MCM methodology, the weights used are the relative abundance of the property types in the England & Wales Flood Zone 3.

Table A-3 Depth Damage Data for Non-Residential Property types

Building Polygon Feature Code	Direct Damage in £ per m2 for flood depths above upper surface of ground floor MCM 2010												
	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
1042	90.64	243.60	384.34	544.80	663.98	734.98	801.69	850.64	893.43	927.17	963.04	990.46	1,023.85
1043	0.00	259.94	363.56	437.45	505.60	617.73	683.56	721.36	758.38	793.37	820.49	854.81	888.01
1044	139.18	476.87	753.68	1,048.92	1,264.76	1,447.45	1,576.12	1,678.75	1,769.52	1,851.87	1,933.40	1,993.18	2,061.19
1045	0.00	54.39	112.97	159.93	208.00	233.05	259.67	284.36	310.87	327.71	331.32	334.93	337.34
1046	87.29	247.38	407.17	639.32	797.90	917.16	1,032.68	1,123.74	1,213.69	1,246.00	1,279.83	1,306.00	1,337.79
1047	82.56	239.28	363.92	536.07	682.67	763.76	839.62	894.08	942.62	977.33	1,012.31	1,039.71	1,070.97
1048	87.29	247.38	407.17	639.32	797.90	917.16	1,032.68	1,123.74	1,213.69	1,246.00	1,279.83	1,306.00	1,337.79
1049	29.84	114.14	186.70	250.53	312.76	349.89	387.65	420.89	455.40	476.20	484.05	490.94	497.49
1051	60.15	217.23	420.21	587.79	709.53	799.00	881.49	948.13	1,011.46	1,067.84	1,122.10	1,175.49	1,227.72
1052	99.62	263.66	428.49	599.13	728.09	814.28	891.64	949.05	999.57	1,038.10	1,077.49	1,106.69	1,140.76

Table A-4 Derivation of Non-Residential Property Damage Data updated to MCM2010

Building Polygon Feature Code	NI BP Feat Name	Equiv. MCM Code	MCM Description	Nr. in FZ3	Wgt. used	2010 Price Base													
						MCM Damage Data – direct damage in £ per m2 for flood depths above upper surface of ground floor													
						-0.25	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3
1042	LAW_ADMIN : COMMUNAL BUILDING FOR LAW AD	680	Law Court	79	100%	81	91	244	384	545	664	735	802	851	893	927	963	990	1024
1043	HEALTH_B : COMMUNAL BUILDINGS ASSOCIATED	620	Surgery / Health Centre	2350	100%	0	0	260	364	437	506	618	684	721	758	793	820	855	888
			1043 take as for Surgery/Health centre			0	0	260	364	437	506	618	684	721	758	793	820	855	888
1044	EDUCATE_B : COMMUNAL BUILDING FOR EDUCAT	610	School/College /University/ Nursery	3239	100%	124	139	477	754	1050	1265	1447	1576	1679	1770	1852	1933	1933	2061
1045	RELIGION_B : COMMUNAL BUILDING ASSOCIATE	690	Church	No data	100%			54	113	160	208	233	260	284	311	328	331	335	337
1046	SERVICES_B : COMMUNAL BUILDING FOR PUBLI	640	Library	350	32%	85	95	286	478	790	991	1147	1296	1422	1536	1572	1608	1637	1671
		650	Fire / Ambulance Station	230	21%	57	64	158	263	392	495	586	683	743	833	856	881	899	922
		651	Police Station	295	27%	81	91	244	384	545	664	735	802	851	893	927	963	990	1024
		670	Museum	214	20%	85	95	286	478	790	991	1147	1296	1422	1536	1572	1608	1637	1671
			1046 Weighted Mean	1089		78	87	247	407	639	798	917	1033	1123	1213	1246	1279	1306	1338
1047	RECREAT_B : COMMUNAL BUILDING FOR RECREA	523	Sports & Leisure Centres	1649	31%	68	113	254	401	549	671	738	804	856	904	934	963	988	1017

Table A-4 Derivation of Non-Residential Property Damage Data updated to MCM2010																			
Building Polygon Feature Code	NI BP Feat Name	Equiv. MCM Code	MCM Description	Nr. in FZ3	Wgt. used	2010 Price Base													
						MCM Damage Data – direct damage in £ per m2 for flood depths above upper surface of ground floor													
						-0.25	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3
		524	Amusement Arcade / Park	233	4%	83	98	303	530	740	904	1018	1115	1187	1253	1304	1353	1386	1422
		527	Swimming Pool	79	1%	68	113	254	401	549	671	738	804	856	904	934	963	988	1017
		511	Hotel	1185	22%	108	121	290	433	631	842	929	1015	1076	1130	1173	1218	1253	1295
		512	Boarding House	1026	19%	0	0	53	88	283	460	573	674	738	790	827	863	891	918
		515	Self-Catering Unit	922	17%	53	59	252	314	398	458	502	544	575	603	626	649	667	689
		517	Bingo Hall	78	1%	99	111	737	1360	2045	2161	2242	2321	2377	2427	2466	2507	2539	2577
		518	Theatre / Cinema	212	4%	88	99	424	674	948	1150	1291	1393	1466	1532	1587	1640	1680	1723
			1047 Weighted Mean	5384		63	83	239	364	536	683	764	840	894	943	977	1012	1040	1071
1048	GOV_OFFICE : COMMUNAL BUILDING FOR GOVER	?	use damage data as for 1046			78	87	247	407	639	798	917	1033	1124	1214	1246	1280	1306	1338
1049	COMM_OTH : ANY OTHER TYPE OF COMMUNAL BU	625	Residential Home	No data	20%	53	59	252	315	398	457	502	544	575	603	626	649	667	689
		630	Community Centres / Halls	3263	80%	20	22	80	155	214	276	312	349	382	418	439	443	447	450
			1049 Weighted Mean	3263		27	30	114	187	250	313	350	388	420	455	476	484	491	497
1051	INDUSTRY_B : GENERAL BUILDING ASSOCIATED	8	Factory Bulk Class	33745	53%	42	48	207	454	617	721	783	834	866	893	918	939	961	988
		4	Distribution / Logistics (Warehouse)	29661	47%	66	75	229	382	555	697	817	935	1042	1146	1239	1331	1419	1500

Table A-4 Derivation of Non-Residential Property Damage Data updated to MCM2010																			
Building Polygon Feature Code	NI BP Feat Name	Equiv. MCM Code	MCM Description	Nr. in FZ3	Wgt. used	2010 Price Base													
						MCM Damage Data – direct damage in £ per m2 for flood depths above upper surface of ground floor													
						-0.25	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3
			1051 Weighted Mean	63406		53	60	217	420	588	709	799	881	948	1011	1068	1122	1175	1227
1052	COMMERCE_ B : GENERAL BUILDING ASSOCIATED	21	Shop/Store	23077	29%	83	98	303	530	740	904	1018	1145	1187	1253	1304	1353	1386	1422
		22	Vehicle Services	6773	8%	41	46	133	246	339	403	448	492	521	546	567	588	605	626
		23	Retail Services	14201	18%	135	151	311	459	626	755	852	940	1009	1065	1104	1145	1176	1215
		3	Office	36751	45%	81	91	245	387	548	667	739	806	856	899	933	969	997	1030
			1052 Weighted Mean	80802		88	100	264	428	599	728	814	892	949	1000	1038	1077	1107	1141

A.2 Average depths associated with fluvial flooding

Depth grids from fluvial modelling were not available for this study, as the fluvial outlines are generated from 1D steady state modelling with GIS interpolation of peak levels over the floodplain. It was therefore necessary to make a judgement on the depths of flooding experienced by properties from events of various magnitudes based on a large donor data set for which depths were available. Average depths have been derived using the results of a recent strategic study carried out by JBA Consulting for the Environment Agency of England and Wales' North East Region[3]. This strategic study generated depth grids from fluvial flooding over a region of North East England comprising some 10,000 km of main river and watercourses. As part of that study, the depths at each property were calculated for 19 different combinations (or scenarios) of flood event magnitude and flood defence standard of protection, representing a very large dataset from which to derive average depths for different return periods.

The individual property flood depths were further analysed here for three different scenarios, namely the undefended (Standard of protection of 1 in 2 years or 50% AEP) flood events with return periods of 20 years (5% AEP), 100 years (1% AEP) and 1000 years (0.1% AEP). Table A-5 summarises the average depths experienced by properties in these three floodzones.

Table A-5 Average Depths of Flooding Experienced by Properties from Fluvial Events in North East England

Property Type	Q20			Q100			Q1000		
	Count	Mean (m)	Std Dev	Count	Mean (m)	Std Dev	Count	Mean (m)	Std Dev
All	102985	0.457	0.63	148150	0.565	0.79	204790	0.733	0.95
Res	83877	0.411	0.58	122597	0.508	0.74	171637	0.672	0.9
Non-Res	19108	0.657	0.8	25553	0.841	0.97	33153	1.051	1.11

A.3 Annual average damages by property type

The calculation of annual average damages combines the average damage per flooded property for a number of events of differing probability to produce a single value of damage which is the annual average expected for any property which floods. This process was described in Section 2.3.2. The following methodology is similar to that used in the MCM. Three events are considered, Q20 (5% AEP), Q100 (1% AEP) and Q1000 (0.1% AEP). It is further assumed that damages are zero for the Q5 (AEP 20%) event.

The average damage per flooded property for each event is calculated by determining the damage per unit area (Table A-2 and Table A-3) corresponding to the average depth experienced by a property of the appropriate type for that event taken from Table A-. Thus, as an example, for a residential property, the mean depth of flooding for a 5% AEP event is, from Table A-, 0.411m. The damages per unit area corresponding to this depth are calculated by interpolation from Table A-2 as £503.34. The average area of a residential property in floodzone 3 is 65.85 m2 (from Table A-1). Hence the average damage per flooded property for the 5% AEP (or Q20) event is £503.34 x 65.85 = £33,144.93. Average damages for other property types and other events are calculated in an analogous way.

The average damages for each event are then combined into an annual average by integrating the damages over the full range of probabilities of flood events that can cause damage (ie from 0 to 50%). An example of this is given in Table A- for residential property. For flood events with a return period between 5 and 20 years (between 20% and 5% AEP), the mean damage is the average of the values at 5 and 20 years. The probability of a flood occurring in this interval is 20% -5% = 15% or 0.15. Hence the contribution to the total annual average damages from this probability interval is the product of the probability of a flood occurring in this interval and the mean damage experienced. This process is repeated for all the probability intervals and the damages summed to get the total annual average damage.

[3] Environment Agency - North East Region - Broad Scale Risk Modelling for CFMP's in NE Region. JBA Report 2007s2465 (Feb 2008).

Table A-6 Annual Average Fluvial Damage Calculation for Residential Property

Return period (years)	Exceedance Probablility	Damage (£)	Probability of flood in interval	Mean Damage (£)	Annual Interval Damage (£)
5	0.2	0			
			0.1	£ 16,387.19	£ 1,638.72
10	0.1	£ 32,774.38			
			0.09	£ 33,934.80	£ 3,054.13
100	0.01	£ 35,095.21			
			0.009	£ 36,523.52	£ 328.71
1000	0.001	£ 37,951.82			
			0.001	£ 37,951.82	£ 37.95
>1000	0	£ 37,951.82			
	Weighted annual average damage				£ 5060

The final figure for residential property of £5,060 compares with £3,116 assuming Standard of Protection of 5 years (P 24 MCM2010 - the estimate for no protection is now quoted as £5,393). The mean damage functions for properties in the different flood outlines were therefore re-scaled by the ratio of these estimates - reduced by a factor of 0.616 for fluvial damages. The correction factor is different for pluvial (0.79) and coastal flooding (0.617) owing to the different probabilities of the flood outlines used for these (Fluvial 0.1%, 1% and 10%, coastal 0.1%, 0.5% and 10%, pluvial 0.1%, 0.5% and 3.33% AEP).

The same approach was taken for non-residential properties, although most of these had to be classed as 'Office / other Bulk Class and by using Table 5.1b of the MCM2010, assuming 'no basement' is more typical in Northern Ireland. The correction factors for non-residential properties were all considerably lower (sometimes 0.2 for particular non-residential property types), suggesting that the estimation of damages was overly conservative if not re-scaled in this way.
The effect of re-scaling means that the only influence of the NE regional dataset is the *distribution* of damages per design event. The annualised damages will always sum to the values quoted in the MCM2010 report.

Table A-7 Damage functions (damages in £ per square m) for each type of flooding for each probability event for each type of property

Property code and description		FLUVIAL F_10	F_100	F_1000	COASTAL C_10	C_200	C_1000	PLUVIAL P_30	P_200	P_1000
1042	LAW_ADMIN : COMMUNAL BUILDING FOR LAW AD	114.31	138.60	159.88	115.02	139.46	160.86	151.31	183.46	211.62
1043	HEALTH_B : COMMUNAL BUILDINGS ASSOCIATED	117.79	132.82	151.84	118.33	133.43	152.54	153.43	173.00	197.78
1044	EDUCATE_B : COMMUNAL BUILDING FOR EDUCAT	114.78	137.80	159.13	115.46	138.63	160.09	151.59	182.00	210.18
1045	RELIGION_B : COMMUNAL BUILDING ASSOCIATE	112.81	140.50	168.75	113.67	141.56	170.03	150.30	187.19	224.83
1046	SERVICES_B : COMMUNAL BUILDING FOR PUBLI	112.33	141.61	167.04	113.17	142.65	168.27	150.04	189.13	223.10
1047	RECREAT_B : COMMUNAL BUILDING FOR RECREA	112.76	140.80	167.02	113.58	141.83	168.25	150.29	187.67	222.62
1048	GOV_OFFICE : COMMUNAL BUILDING FOR GOVER	112.33	141.61	167.04	113.17	142.65	168.27	150.04	189.13	223.10
1049	COMM_OTH : ANY OTHER TYPE OF COMMUNAL BU	114.53	137.97	161.78	115.27	138.85	162.82	151.41	182.39	213.88
1051	INDUSTRY_B : GENERAL BUILDING ASSOCIATED	118.40	142.43	163.99	119.10	143.28	164.97	156.44	188.19	216.68
1052	COMMERCE_B : GENERAL BUILDING ASSOCIATED	142.28	171.61	198.06	143.14	172.65	199.26	188.10	226.88	261.86
1053	DWELL_HOUS : GENERAL BUILDING - ALL TYPE	306.52	328.22	354.94	307.30	329.07	355.85	394.59	422.53	456.93

B. Summary tables and charts illustrating the distribution of flood risk b Sub-plan Area

This Appendix contains summary tables of the annualised flood risk indicators for each of the Sub-plan Areas and a series of pie-charts that illustrate how each Sub-plan Area contributes to the overall national flood risk for each of the flood sources (with and without climate change).

B.1 Tables of Flood Risk Indicators by Sub-plan Area

Table B-8: Summary of the annualised flood risk indicators for Belfast Sub-plan Area

Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change (2100yr)	All sources combined without climate change
AAAD with intangibles	£36.5m	£37.7m	£15.4m	£17m	£43.3m	£59.3m	£95.2m
		3.4%		10.7%		37.1%	
All Property and Agriculture (AAAD)	£36.2m	£37.5m	£15.3m	£16.9m	£43.1m	£59.1m	£94.7m
		3.4%		10.7%		37.1%	
Property Damage	£36.2m	£37.4m	£15.3m	£16.9m	£43.1m	£59m	£94.6m
		3.4%		10.7%		37.1%	
Agricultural Damage	£33.5k	£34.8k	£1.4k	£1.5k	£19.8k	£24.4k	£54.8k
		3.9%		5.7%		23.3%	
Key Services	3.31	3.41	1.39	1.58	2.78	3.51	7.47
		3.2%		14.2%		26.2%	
Key Infrastructure	4.2k	4.4k	3.1k	3.3k	4.1k	5.5k	11.6k
		3.5%		6.8%		31.7%	
ASSI Area	18ha	18ha	87ha	88ha	9ha	10ha	115ha
		0.0%		0.9%		10.1%	
Number of IPPC Sites	0.37	0.38	0.21	0.26	0.15	0.36	0.73
		1.5%		23.7%		135.5%	
Number of People at Risk	3000	3100	1000	1100	2300	3400	6400
		2.9%		9.8%		46.1%	
Vulnerability	0.6k	0.7k	0.1k	0.1k	1.2k	1.3k	2k
		6.3%		4.7%		5.9%	
Economic Deprivation	0.3k	0.3k	0k	0k	0.6k	0.6k	1k
		5.4%		3.2%		7.4%	

Table B-9: Summary of the annualised flood risk indicators for Antrim Coast Sub-plan Area

Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change (2100yr)	All sources combined without climate change
AAAD with intangibles	£2.3m	£2.4m	£0.6m	£0.6m	£7.8m	£9.3m	£10.8m
		5.1%		9.6%		19.2%	
All Property and Agriculture (AAAD)	£2.3m	£2.4m	£0.6m	£0.6m	£7.8m	£9.3m	£10.7m
		5.1%		9.6%		19.2%	
Property Damage	£2.2m	£2.4m	£0.6m	£0.6m	£7.8m	£9.3m	£10.7m
		5.2%		9.6%		19.2%	
Agricultural Damage	£29.1k	£30.3k	£1.9k	£2k	£18.7k	£22.8k	£49.8k
		4.1%		3.9%		21.3%	
Key Services	0.31	0.31	0.26	0.26	1.32	1.52	1.88
		0.0%		1.2%		15.3%	
Key Infrastructure	0.6k	0.6k	0.6k	0.7k	1.3k	1.6k	2.5k
		1.7%		10.4%		26.1%	
ASSI Area	13ha	14ha	79ha	80ha	11ha	14ha	105ha
		5.8%		0.3%		23.0%	
Number of IPPC Sites	0.00	0.00	0.00	0.00	0.23	0.23	0.23
						0.0%	
Number of People at Risk	100	100	0k	0k	400	500	600
		5.5%		4.8%		24.5%	
Vulnerability	0.2k	0.3k	0k	0k	0.5k	0.6k	0.9k
		7.3%		0.0%		14.3%	
Economic Deprivation	0.2k	0.2k	0k	0k	0.4k	0.5k	0.6k
		6.4%		4.4%		16.6%	

Table B-10: Summary of the annualised flood risk indicators for South Armagh and Down & Louth Sub-plan Area							
Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change (2100yr)	All sources combined without climate change
AAAD with intangibles	£10.8m	£11.1m	£8.1m	£8.5m	£6m	£7.5m	£25m
		3.1%		5.2%		25.3%	
All Property and Agriculture (AAAD)	£10.8m	£11.1m	£8.1m	£8.5m	£6m	£7.5m	£24.9m
		3.1%		5.2%		25.3%	
Property Damage	£10.7m	£11.1m	£8.1m	£8.5m	£6m	£7.5m	£24.9m
		3.1%		5.2%		25.3%	
Agricultural Damage	£16.8k	£17.4k	£1.8k	£2.3k	£14.9k	£17.6k	£33.6k
		3.2%		30.6%		18.1%	
Key Services	2.96	2.96	1.95	1.95	0.99	1.42	5.90
		0.0%		0.0%		43.4%	
Key Infrastructure	2.2k	2.3k	1.6k	1.8k	1.7k	2.2k	5.7k
		5.2%		6.5%		25.9%	
ASSI Area	22ha	22ha	88ha	89ha	10ha	13ha	121ha
		0.1%		1.1%		23.1%	
Number of IPPC Sites	0.16	0.16	0.15	0.15	0.06	0.06	0.36
		0.0%		0.0%		0.0%	
Number of People at Risk	300	300	200	200	300	300	800
		4.2%		9.8%		25.5%	
Vulnerability	0.2k	0.2k	0k	0k	0.4k	0.5k	0.8k
		2.4%		8.5%		16.4%	
Economic Deprivation	0.1k	0.1k	0k	0k	0.4k	0.5k	0.6k
		2.9%		10.8%		19.7%	

Table B-11: Summary of the annualised flood risk indicators for Erne and Melvin Sub-plan Area							
Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change (2100yr)	All sources combined without climate change
AAAD with intangibles	£4m	£4.2m			£4.4m	£5.2m	£8.5m
		4.5%				17.7%	
All Property and Agriculture (AAAD)	£4m	£4.2m			£4.4m	£5.2m	£8.5m
		4.5%				17.7%	
Property Damage	£3.9m	£4.1m			£4.4m	£5.2m	£8.4m
		4.5%				17.7%	
Agricultural Damage	£40.9k	£42k			£18k	£21.2k	£58.9k
		2.8%				17.8%	
Key Services	0.51	0.51			0.50	0.50	1.00
		0.0%				-0.4%	
Key Infrastructure	1.1k	1.2k			1.1k	1.3k	2.3k
		4.8%				18.7%	
ASSI Area	71ha	73ha	799ha	801ha	31ha	40ha	902ha
		3.3%		0.3%		27.6%	
Number of IPPC Sites	0.00	0.00			0.00	0.01	0.00
Number of People at Risk	1200	1300	500	600	600	800	2400
		6.1%		11.1%		38.2%	
Vulnerability	0.4k	0.4k	0.2k	0.2k	0.8k	0.9k	1.5k
		4.4%		8.4%		12.0%	
Economic Deprivation	0.2k	0.2k	0.1k	0.1k	0.5k	0.6k	0.9k
		5.2%		8.8%		14.5%	

Table B-12: Summary of the annualised flood risk indicators for Down Coast Sub-plan Area

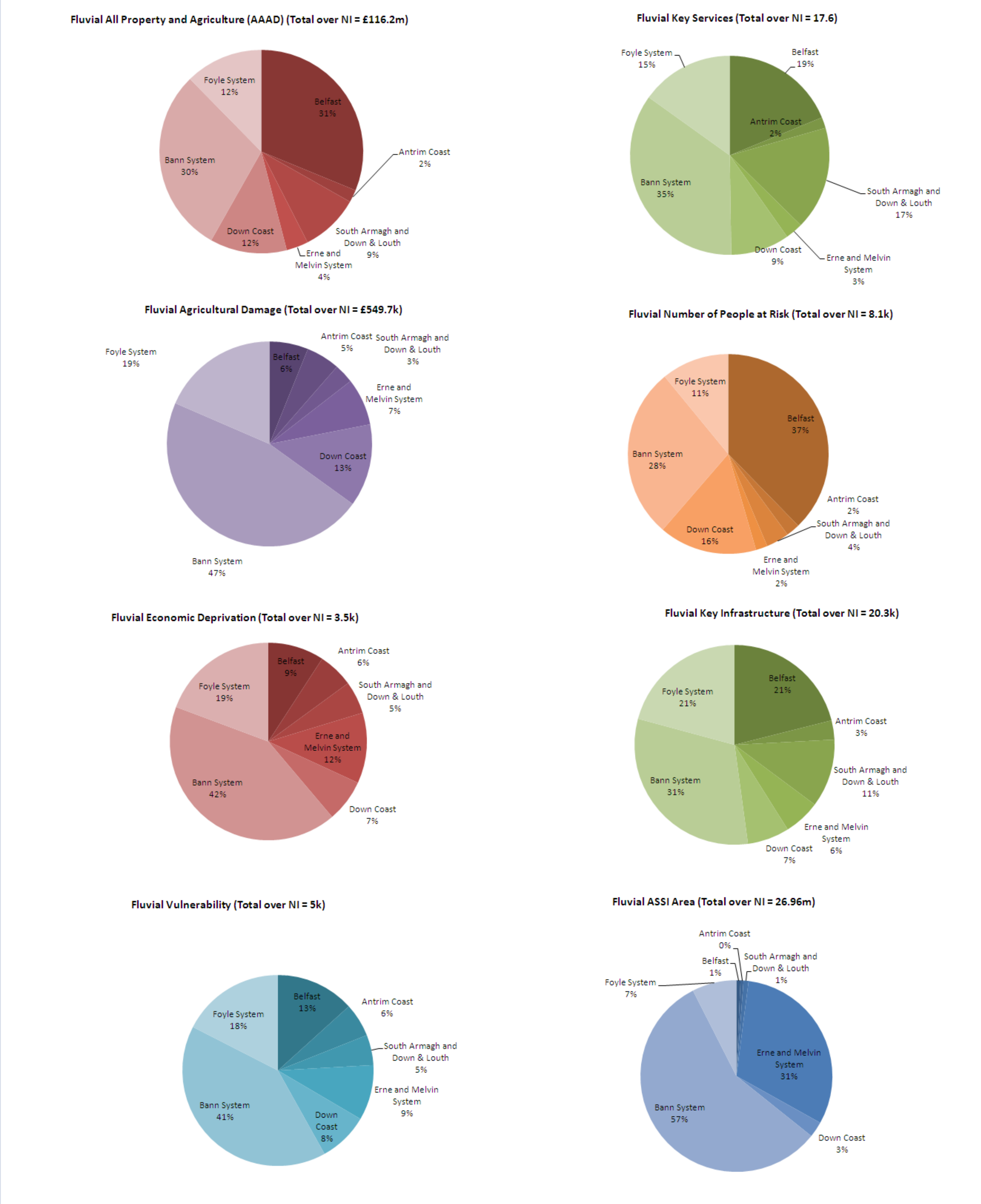
Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change (2100yr)	All sources combined without climate change
AAAD with intangibles	£14.2m	£15.1m	£7.9m	£8.6m	£10.7m	£14.3m	£32.9m
		5.8%		8.3%		33.8%	
All Property and Agriculture (AAAD)	£14.1m	£15m	£7.8m	£8.5m	£10.7m	£14.3m	£32.7m
		5.8%		8.3%		33.8%	
Property Damage	£14.1m	£14.9m	£7.8m	£8.4m	£10.6m	£14.2m	£32.6m
		5.8%		8.4%		33.8%	
Agricultural Damage	£71.6k	£73.3k	£50.6k	£52.4k	£38.3k	£46.9k	£160.7k
		2.4%		3.6%		22.2%	
Key Services	1.68	1.68	1.11	1.16	0.61	0.97	3.39
		0.0%		4.5%		59.5%	
Key Infrastructure	1.3k	1.4k	1.8k	2k	1k	1.4k	4.3k
		4.2%		11.8%		35.2%	
ASSI Area	71ha	73ha	799ha	801ha	31ha	40ha	902ha
		3.3%		0.3%		27.6%	
Number of IPPC Sites	0.30	0.30	0.30	0.30	0.06	0.26	0.66
		0.0%		0.0%		322.3%	
Number of People at Risk	1200	1300	500	600	600	800	2400
		6.1%		11.1%		38.2%	
Vulnerability	0.4k	0.4k	0.2k	0.2k	0.8k	0.9k	1.5k
		4.4%		8.4%		12.0%	
Economic Deprivation	0.2k	0.2k	0.1k	0.1k	0.5k	0.6k	0.9k
		5.2%		8.8%		14.5%	

Table B-13: Summary of the annualised flood risk indicators for Bann System Sub-plan Area							
Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change (2100yr)	All sources combined without climate change
AAAD with intangibles	£34.4m	£36.7m	£0.2m	£0.2m	£44m	£54.4m	£78.6m
		6.7%		1.4%		23.8%	
All Property and Agriculture (AAAD)	£34.2m	£36.5m	£0.2m	£0.2m	£43.8m	£54.3m	£78.3m
		6.7%		1.4%		23.8%	
Property Damage	£34m	£36.2m	£0.2m	£0.2m	£43.7m	£54.1m	£77.9m
		6.7%		1.4%		23.8%	
Agricultural Damage	£256k	£265k	£0.6k	£0.6k	£103k	£1256k	360k
		3.6%		2.0%		21.6%	
Key Services	6.19	6.63	0.00	0.00	4.38	5.71	10.57
		7.2%				30.3%	
Key Infrastructure	6.3k	7k	0.2k	0.2k	6.7k	8.7k	13.3k
		10.7%		7.2%		29.2%	
ASSI Area	1531ha	1534ha	27ha	27ha	45ha	55ha	1603ha
		0.2%		0.7%		21.8%	
Number of IPPC Sites	0.00	0.00	0.00	0.00	0.41	0.51	0.41
		-		-		24.5%	
Number of People at Risk	2.200	2400	0k	0k	1600	2200	3900
		7.2%		0.6%		30.9%	
Vulnerability	2k	2.1k	0k	0k	2.6k	2.9k	4.6k
		3.7%		0.4%		12.9%	
Economic Deprivation	1.5k	1.5k	0k	0k	1.9k	2.1k	3.4k
		3.8%		0.5%		14.7%	

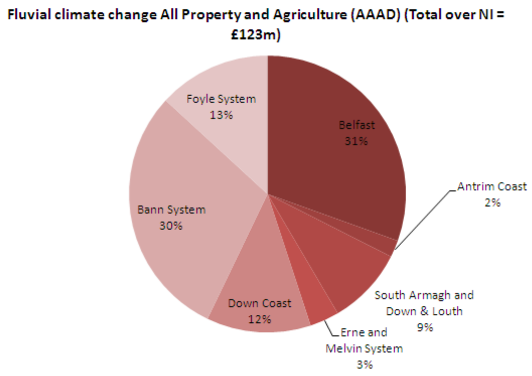
Table B-14: Summary of the annualised flood risk indicators for Foyle System Sub-plan Area							
Flood Risk Indicator	Fluvial	Fluvial with climate change (2030yr)	Coastal	Coastal with climate change (2030yr)	Pluvial	Pluvial with climate change	All sources combined without climate change
AAAD with intangibles	£14.4m	£16.2m	£1.1m	£1.3m	£24m	£30.5m	£39.6m
		12.9%		14.2%		26.9%	
All Property and Agriculture (AAAD)	£14.3m	£16.1m	£1.1m	£1.3m	£23.9m	£30.3m	£39.4m
		12.8%		14.2%		26.9%	
Property Damage	£14.2m	£16m	£1m	£1.2m	£23.8m	£30.3m	£39.2m
		12.9%		14.7%		26.9%	
Agricultural Damage	£101.6k	£104.9k	£51k	£53.2k	£40.1k	£48.6k	£192.8k
		3.2%		4.3%		21.3%	
Key Services	2.66	2.86	0.00	0.00	2.23	2.79	4.89
		7.5%				25.3%	
Key Infrastructure	4.2k	4.5k	2k	2.1k	2.4k	3k	8.7k
		6.4%		3.3%		26.5%	
ASSI Area	201ha	204ha	269ha	271ha	86ha	96ha	557ha
		1.4%		0.8%		11.3%	
Number of IPPC Sites	0.16	0.16	0.15	0.15	0.16	0.26	0.46
		-		-		61.7%	
Number of People at Risk	800	1000	0k	0k	1200	1600	2200
		17.0%		21.7%		28.9%	
Vulnerability	0.8k	0.9k	0k	0k	1.4k	1.6k	2.3k
		6.1%		20.4%		15.1%	
Economic Deprivation	0.6k	0.7k	0k	0k	1.2k	1.4k	1.9k
		6.9%		16.1%		18.1%	

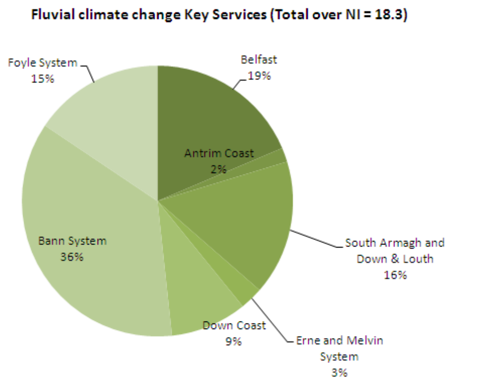
B.2 Sub-plan Area - flood risk contribution for each flood sources

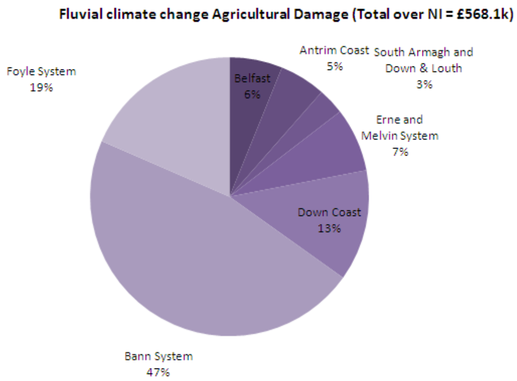
B-15: Sub-plan Area – Contribution to Overall National Risk – Fluvial Flooding

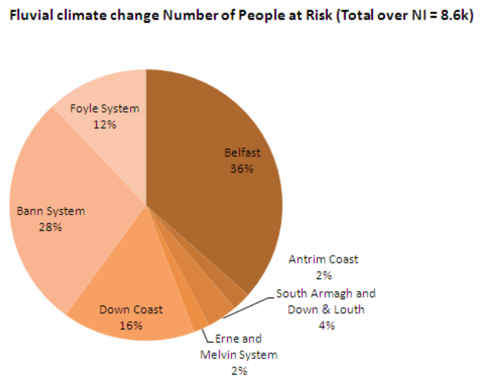


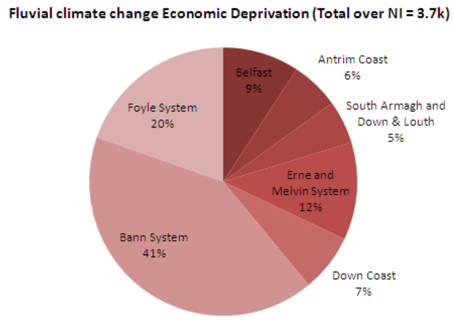
B-16: Sub-plan Area – Contribution to Overall National Risk - Fluvial Flooding with Climate Change

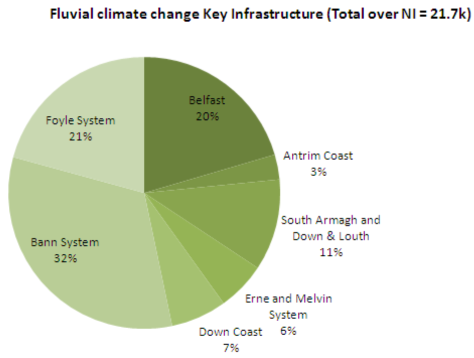


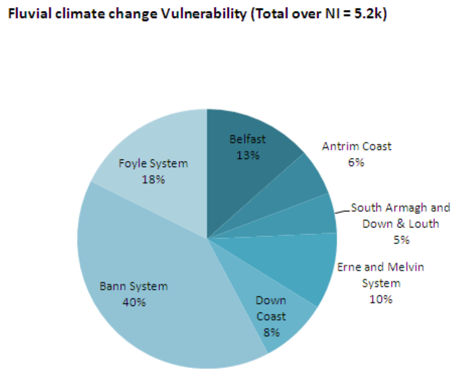


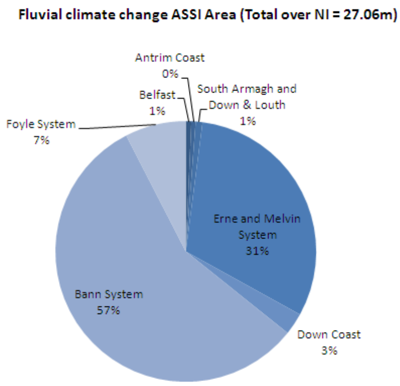






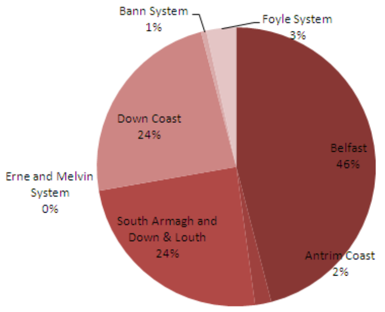




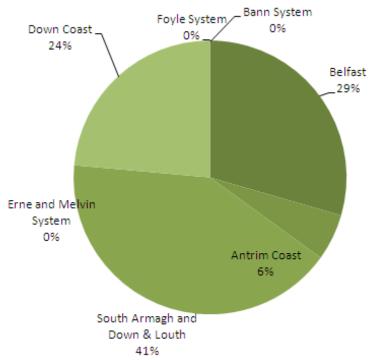


B-17: Sub-plan Area – Contribution to Overall National Risk – Coastal Flooding

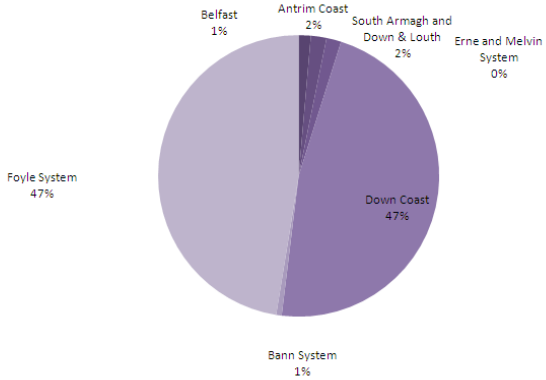
Coastal All Property and Agriculture (AAAD) (Total over NI = £33.3m)



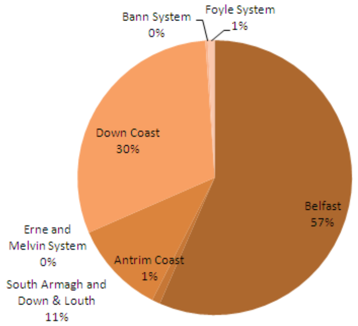
Coastal Key Services (Total over NI = 4.7)



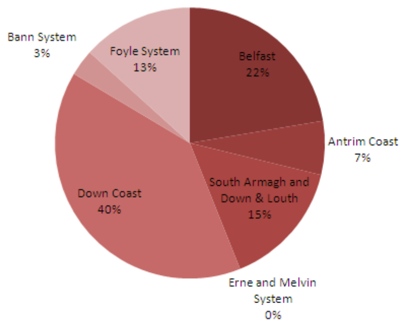
Coastal Agricultural Damage (Total over NI = £107.6k)



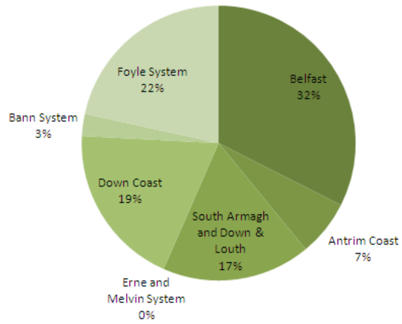
Coastal Number of People at Risk (Total over NI = 1.8k)



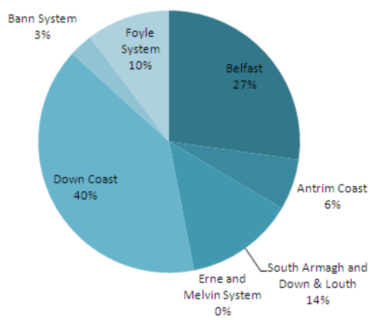
Coastal Economic Deprivation (Total over NI = 0.3k)



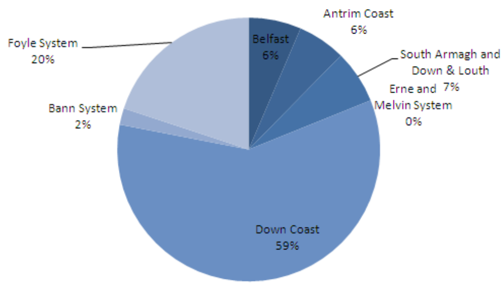
Coastal Key Infrastructure (Total over NI = 9.6k)



Coastal Vulnerability (Total over NI = 0.6k)

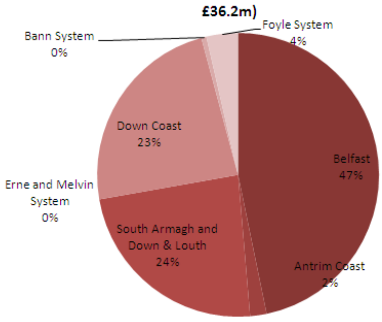


Coastal ASSI Area (Total over NI = 13.52m)

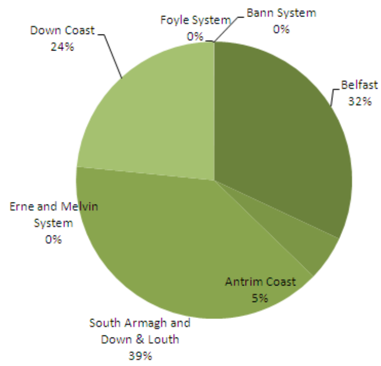


B-18: Sub-plan Area – Contribution to Overall National Risk – Coastal Flooding with Climate Change

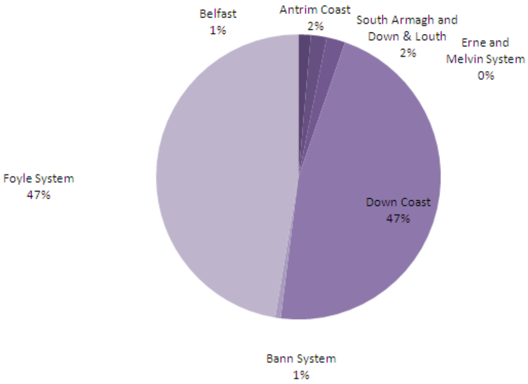
Coastal climate change All Property and Agriculture (AAAD) (Total over NI = £36.2m)



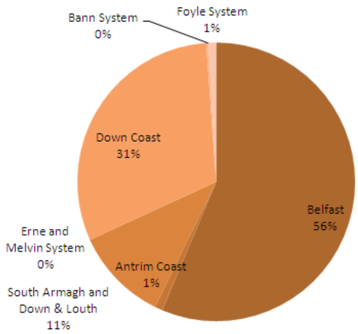
Coastal climate change Key Services (Total over NI = 4.9)



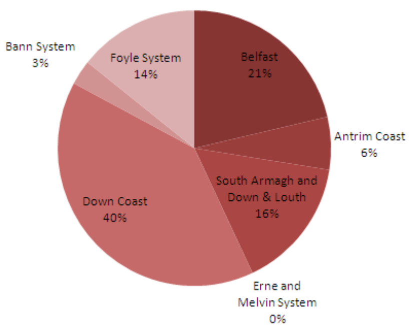
Coastal climate change Agricultural Damage (Total over NI = £112.3k)



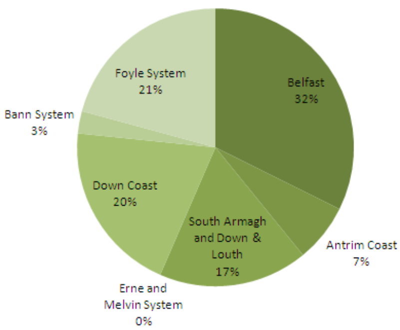
Coastal climate change Number of People at Risk (Total over NI = 2k)



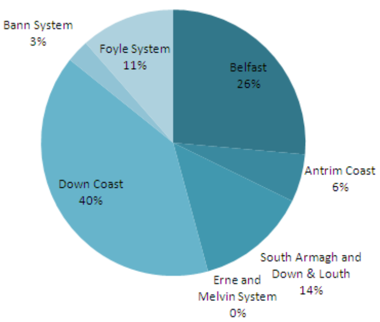
Coastal climate change Economic Deprivation (Total over NI = 0.4k)



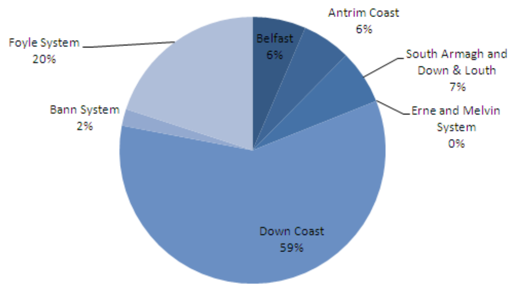
Coastal climate change Key Infrastructure (Total over NI = 10.3k)



Coastal climate change Vulnerability (Total over NI = 0.7k)

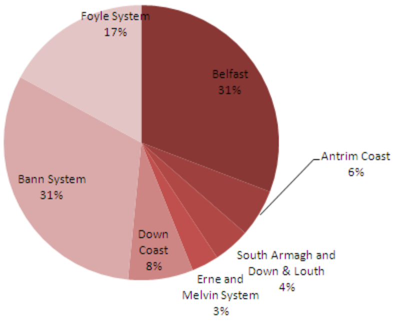


Coastal climate change ASSI Area (Total over NI = 13.58m)

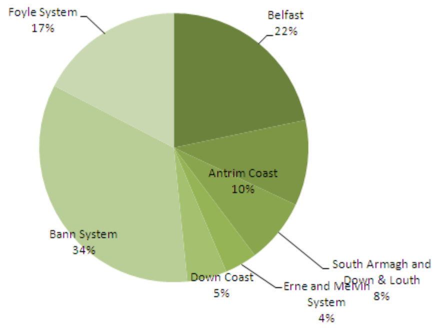


B-19: Sub-plan Area – Contribution to Overall National Risk – Pluvial Flooding

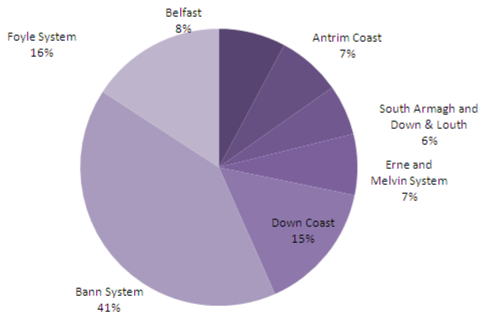
Pluvial All Property and Agriculture (AAAD) (Total over NI = £140m)



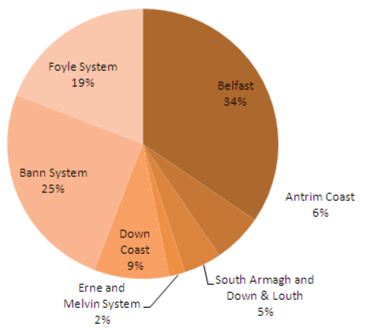
Pluvial Key Services (Total over NI = 12.8)



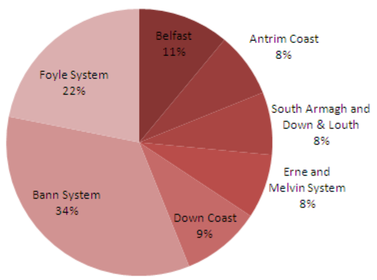
Pluvial Agricultural Damage (Total over NI = £253.5k)



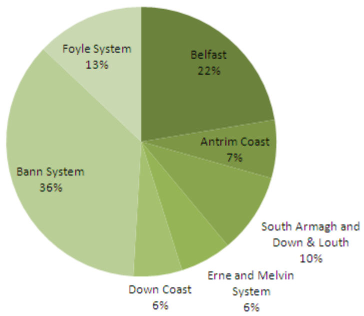
Pluvial Number of People at Risk (Total over NI = 6.7k)



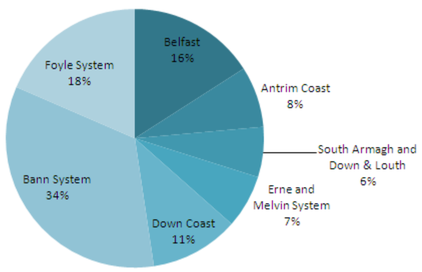
Pluvial Economic Deprivation (Total over NI = 5.5k)



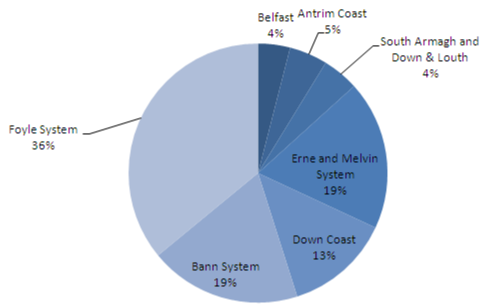
Pluvial Key Infrastructure (Total over NI = 18.7k)



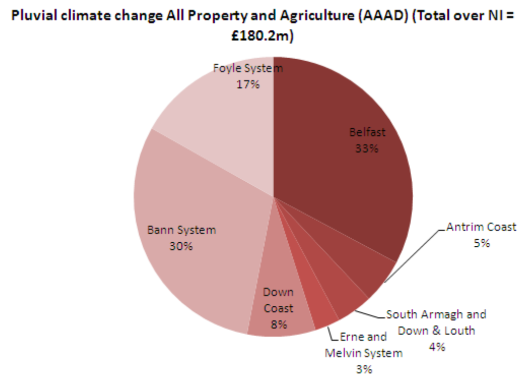
Pluvial Vulnerability (Total over NI = 7.7k)

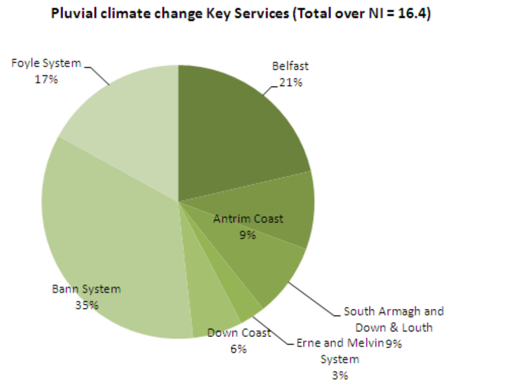


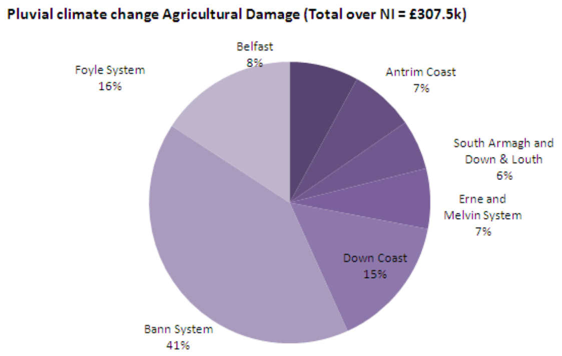
Pluvial ASSI Area (Total over NI = 2.4m)

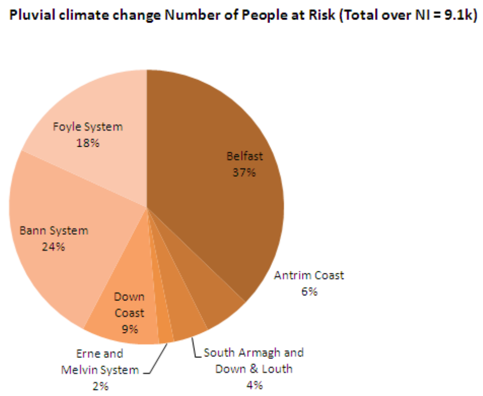


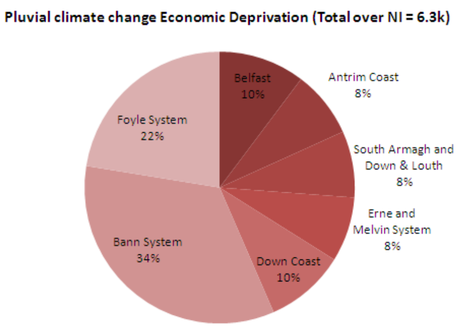
B-20: Sub-plan Area – Contribution to Overall National Risk – Pluvial Flooding with Climate Change

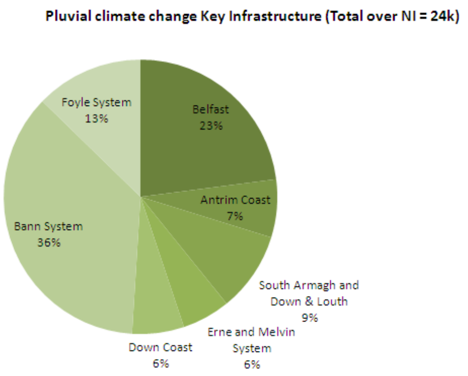


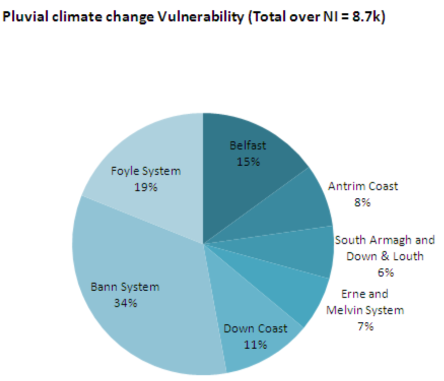


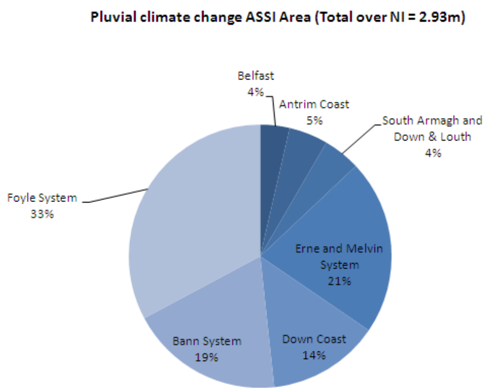




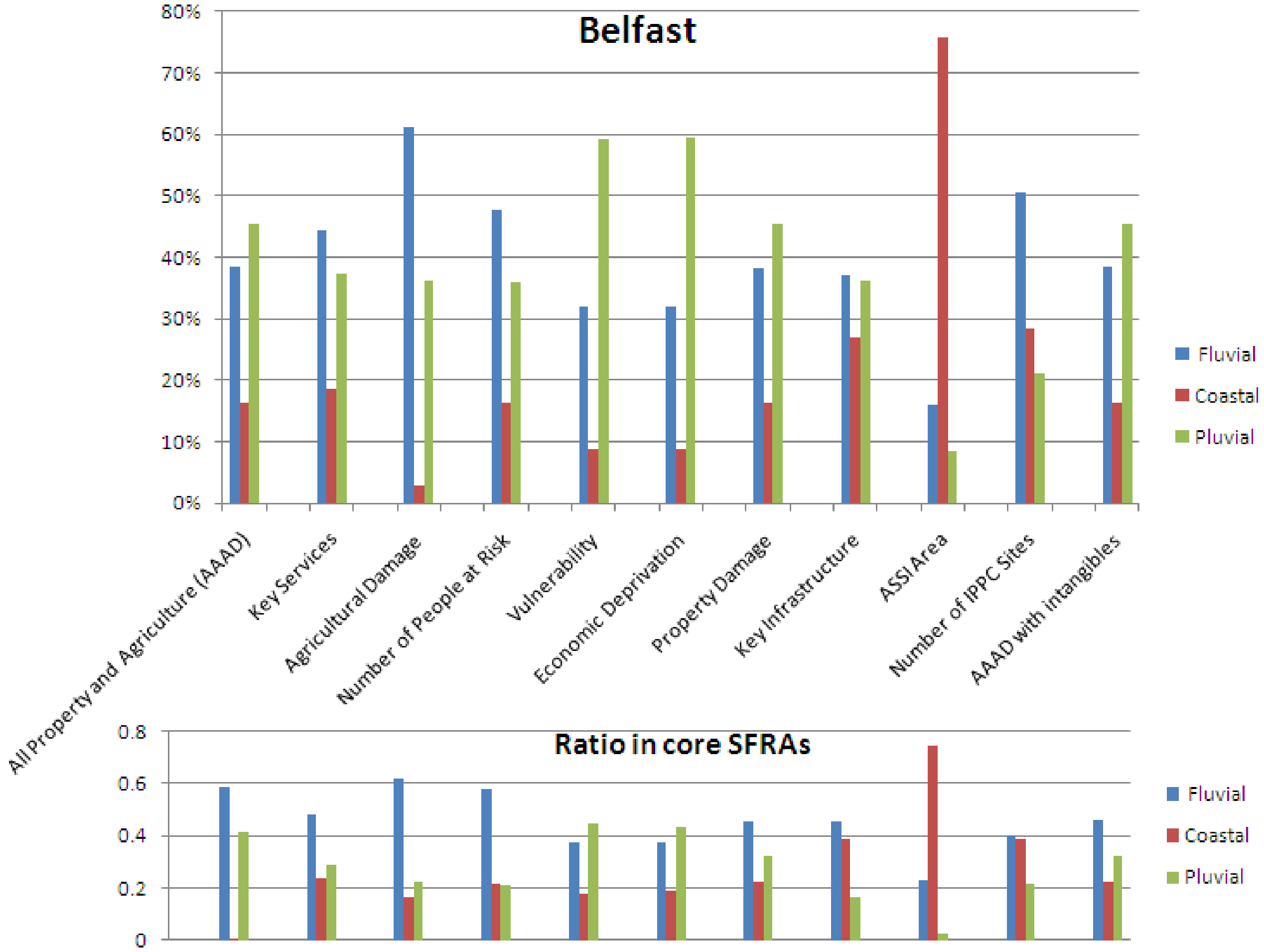




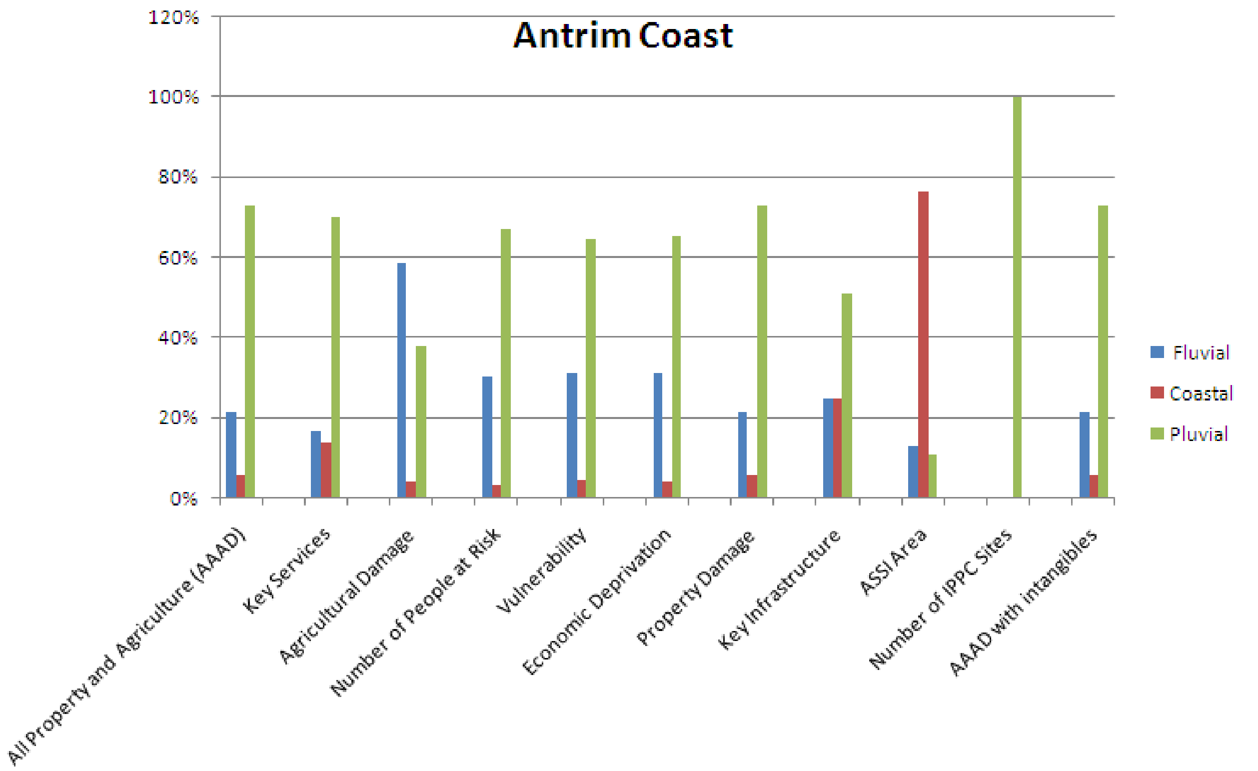




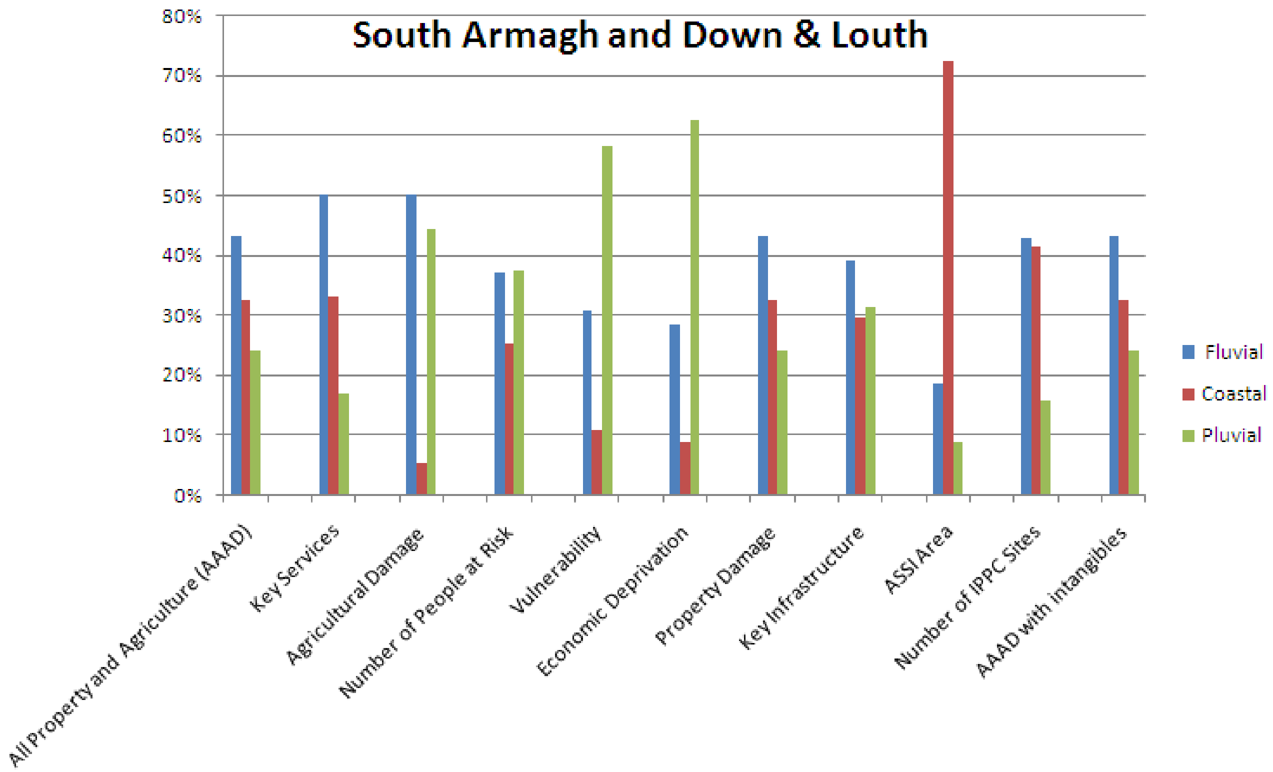
B-21: Flood source apportionment for the Belfast Sub-plan Area



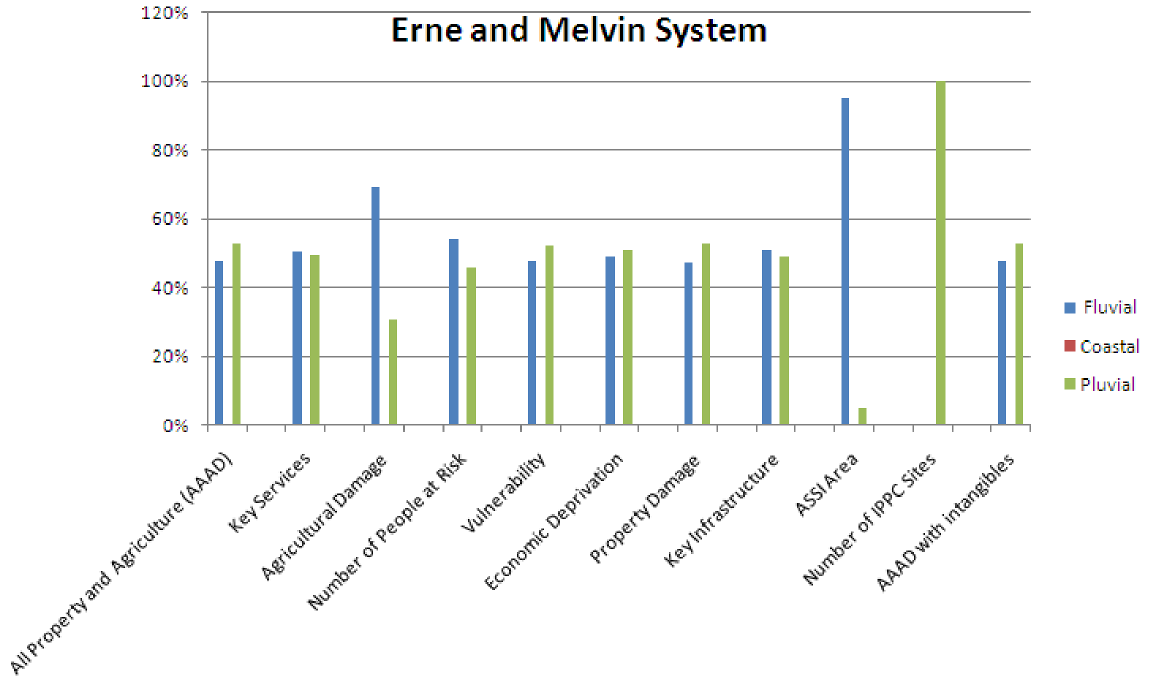
B-22: Flood source apportionment for the Antrim Coast Sub-plan Area



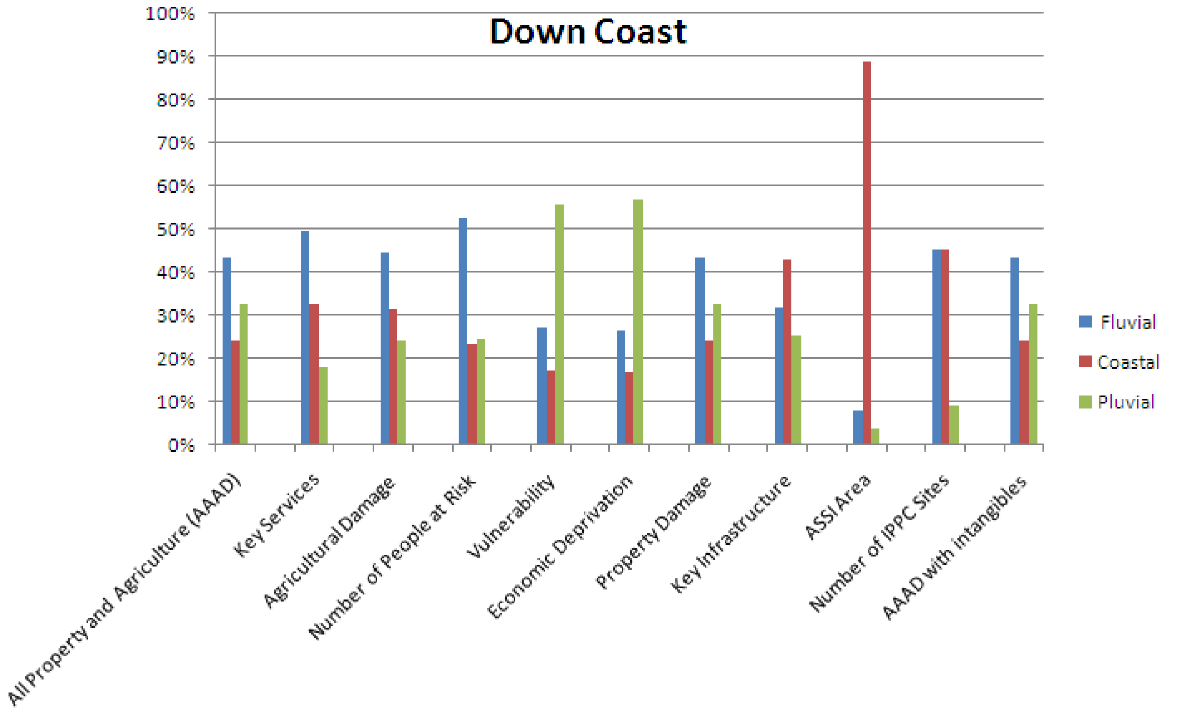
B-23: Flood source apportionment for the South Armagh, Louth and Down Sub-plan Area



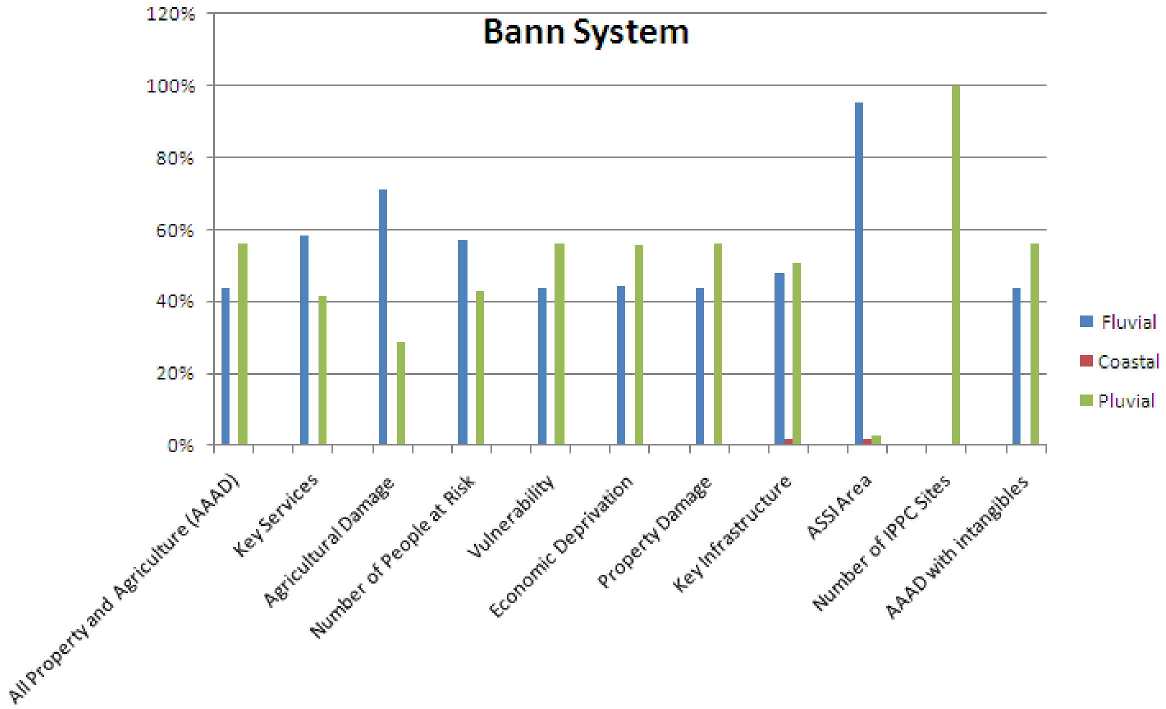
B-24: **Flood source apportionment for the Erne and Melvin Sub-plan Area**



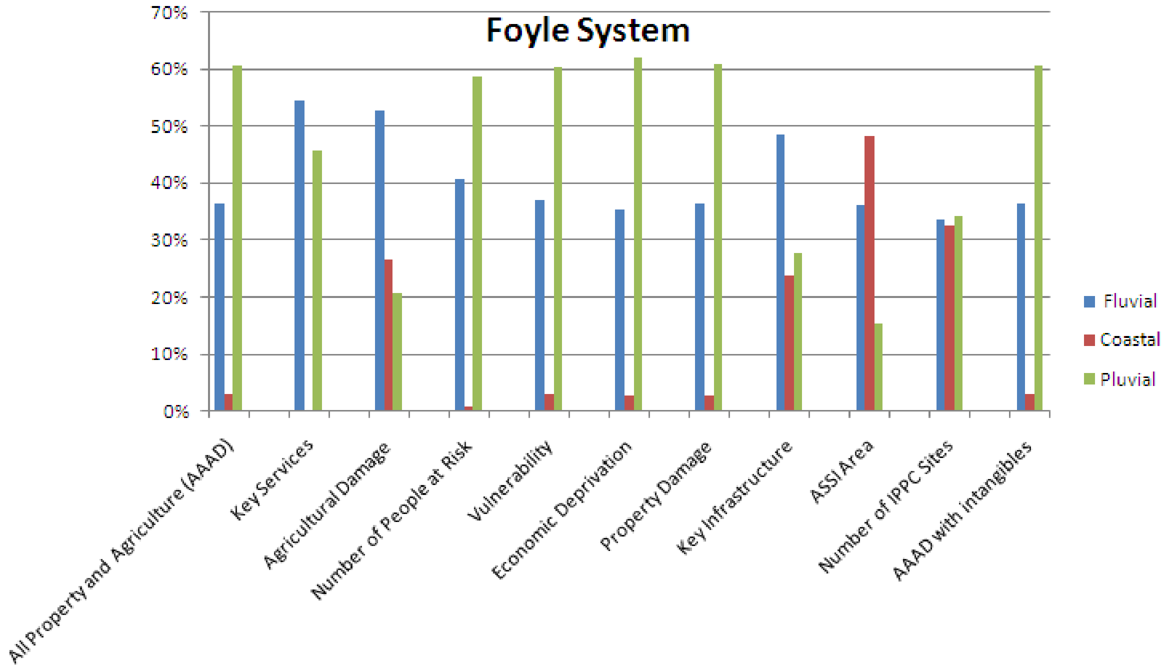
B-25: Flood source apportionment for the Down Coast Sub-plan Area



B-26: Flood source apportionment for the Bann System Sub-plan Area



B-27: Flood source apportionment for the Foyle Sub-plan Area



C. Maps illustrating records of Historical flood outlines - Article 4 (2) (b)

All key maps are included in this appendix for completeness, although the high quality 'pdf' maps, which are available as separate documents, should be used for enlargements.

Figure C-1: Historical - Belfast Sub-plan Area

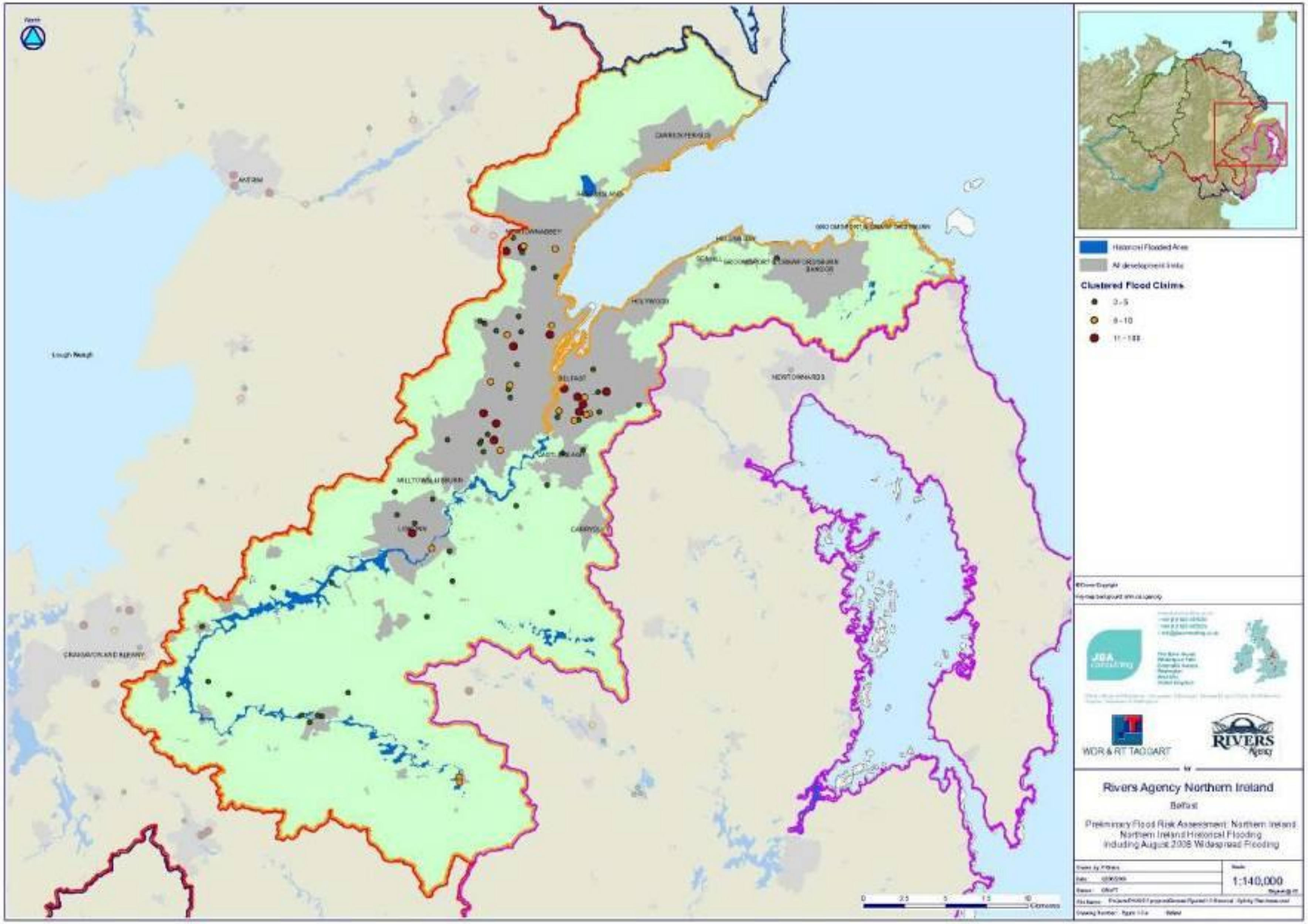


Figure C-2: Historical - Antrim Coast Sub-plan Area

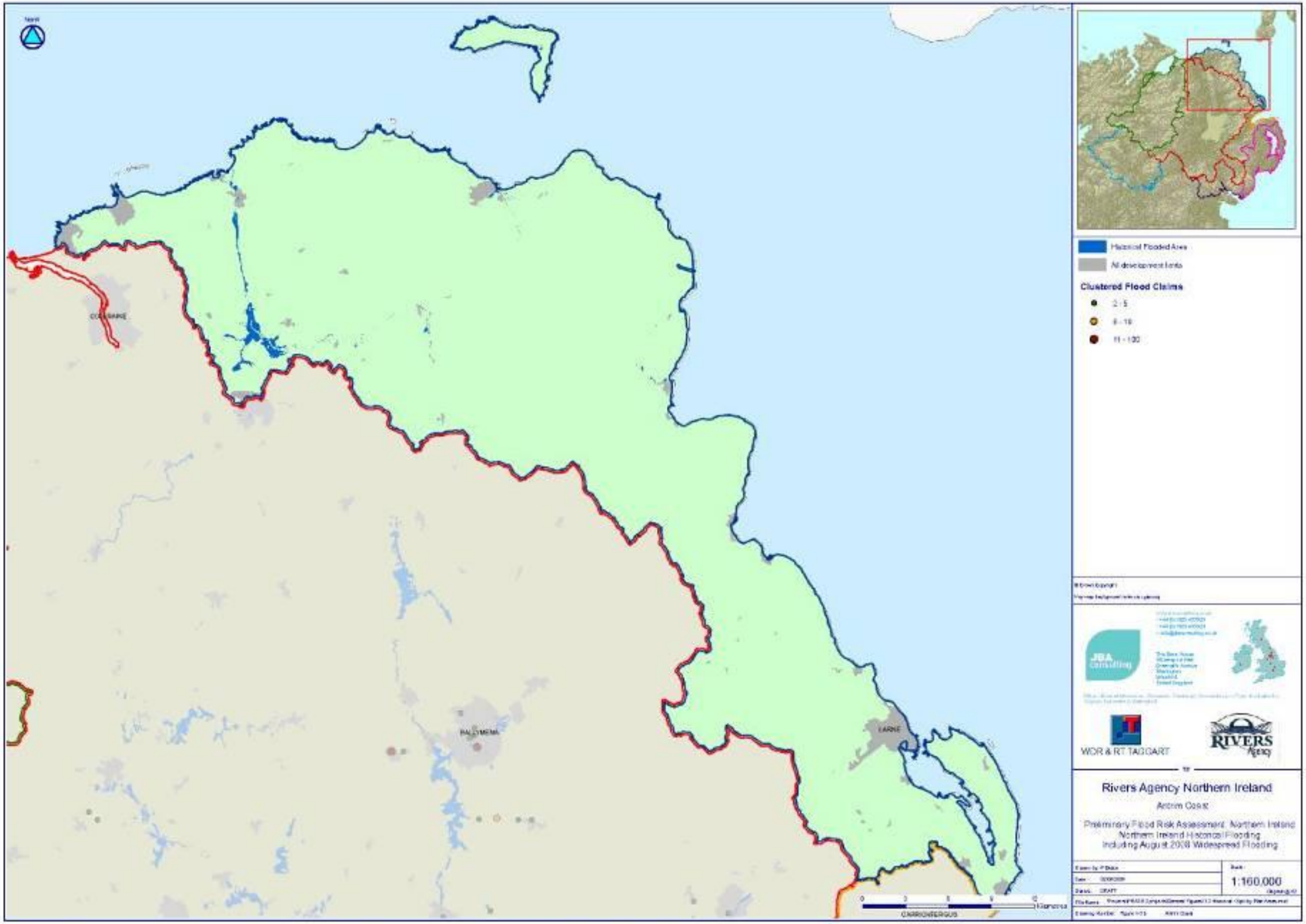


Figure C-3: Historical South Armagh and Down and Louth Sub-plan Area

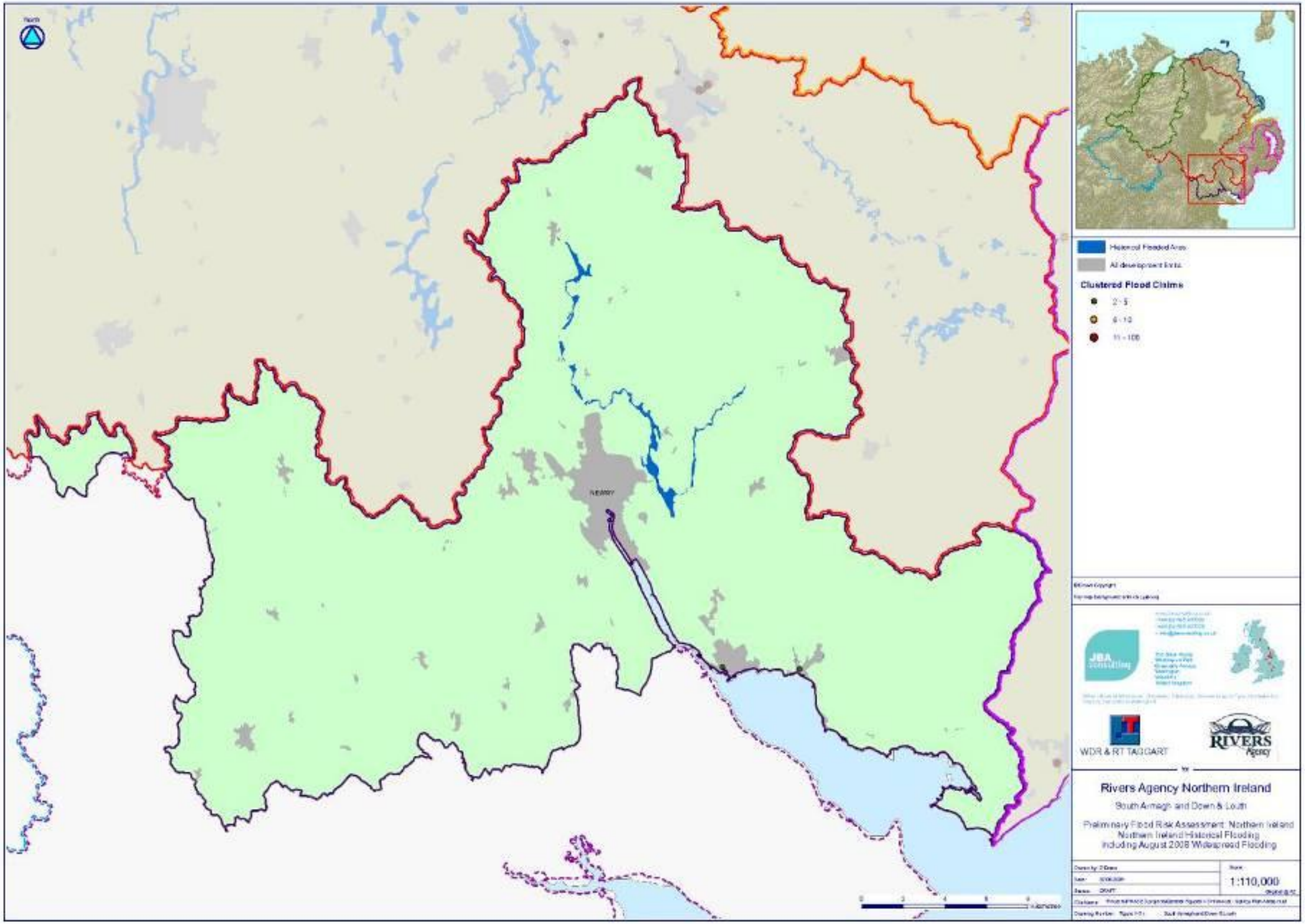


Figure C-4: Historical Erne And Melvin System Sub-plan Area

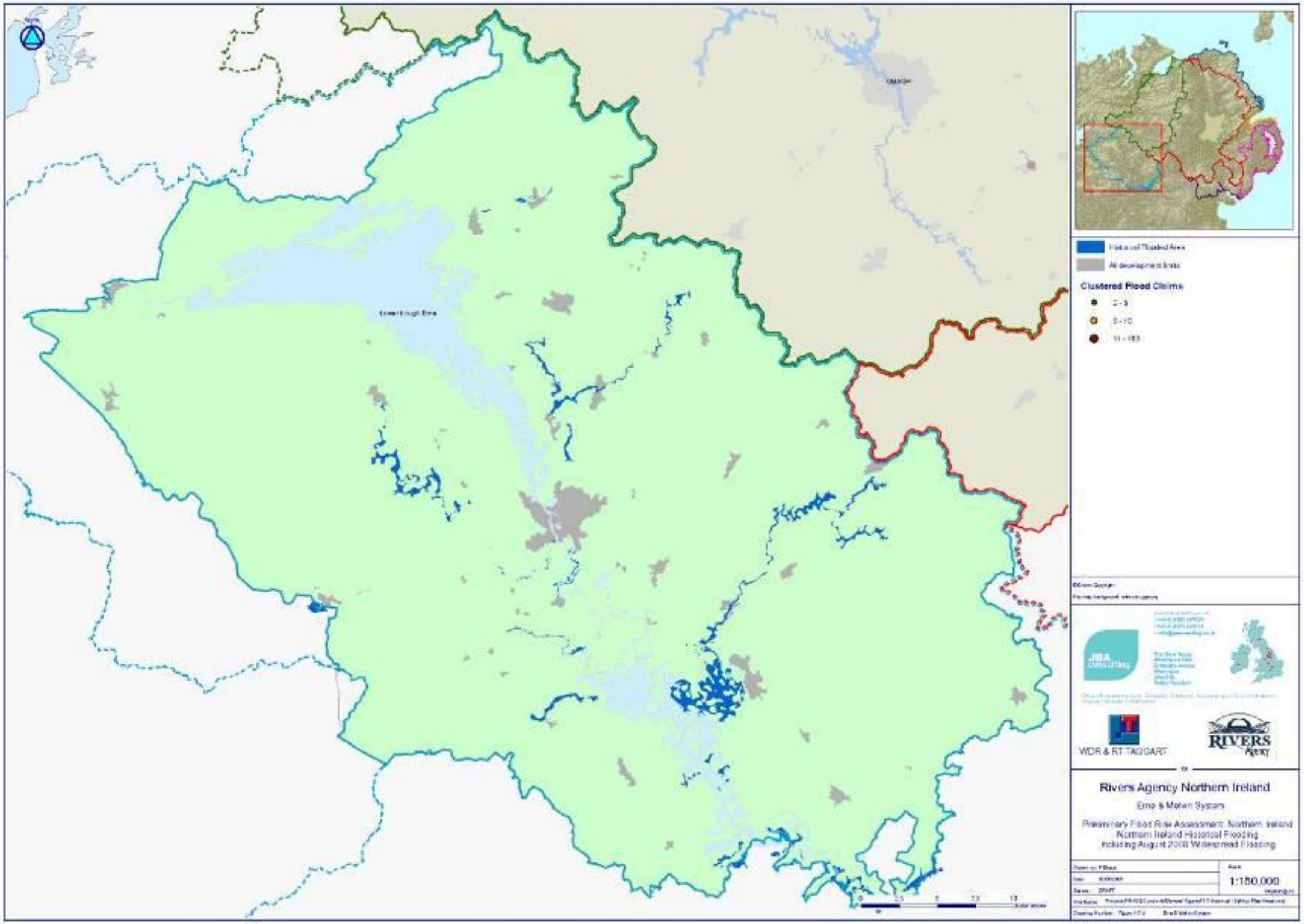


Figure C-5: Historical: Down Coast Sub-plan Area

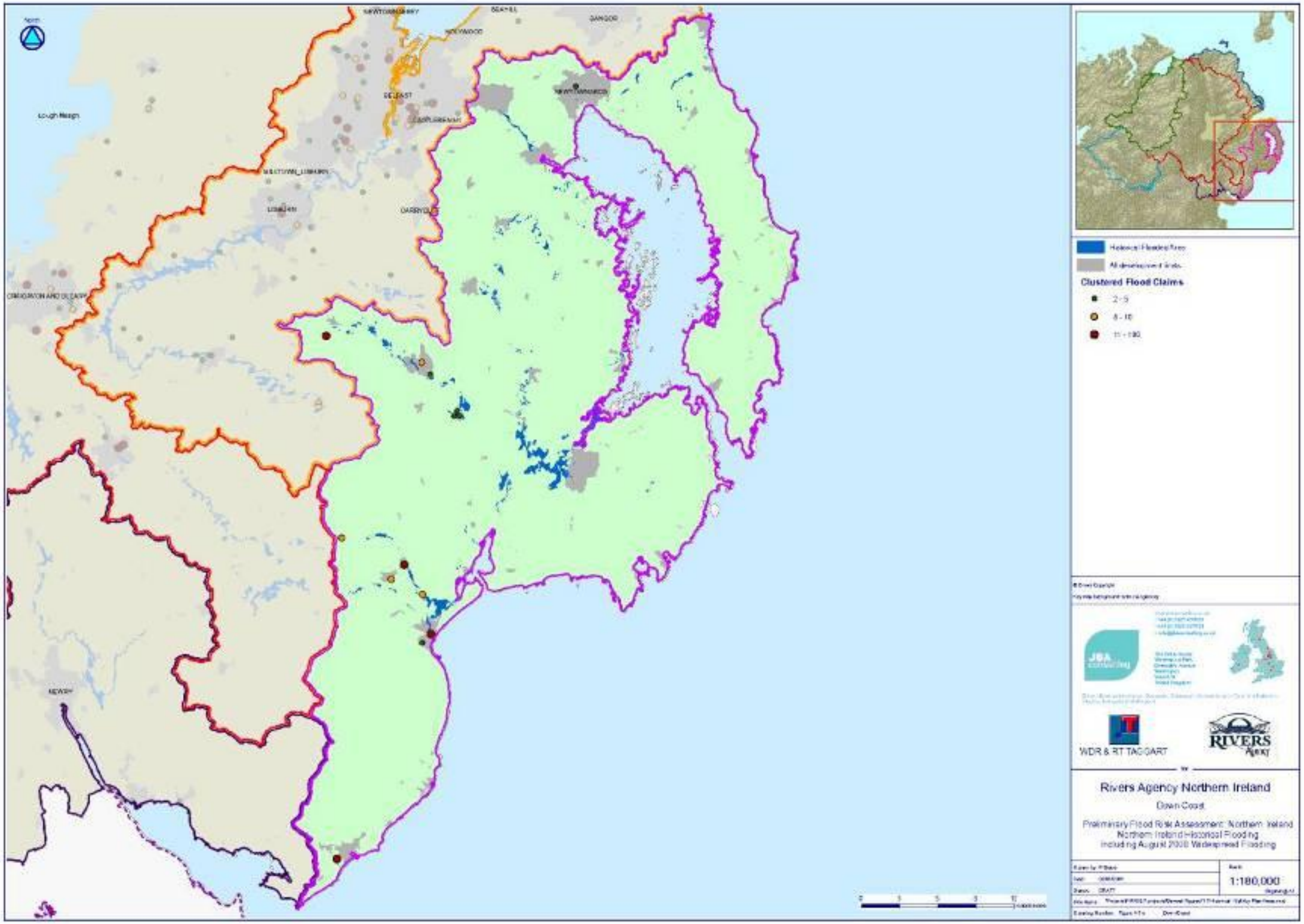


Figure C-6: Historical: Bann System Sub-plan Area

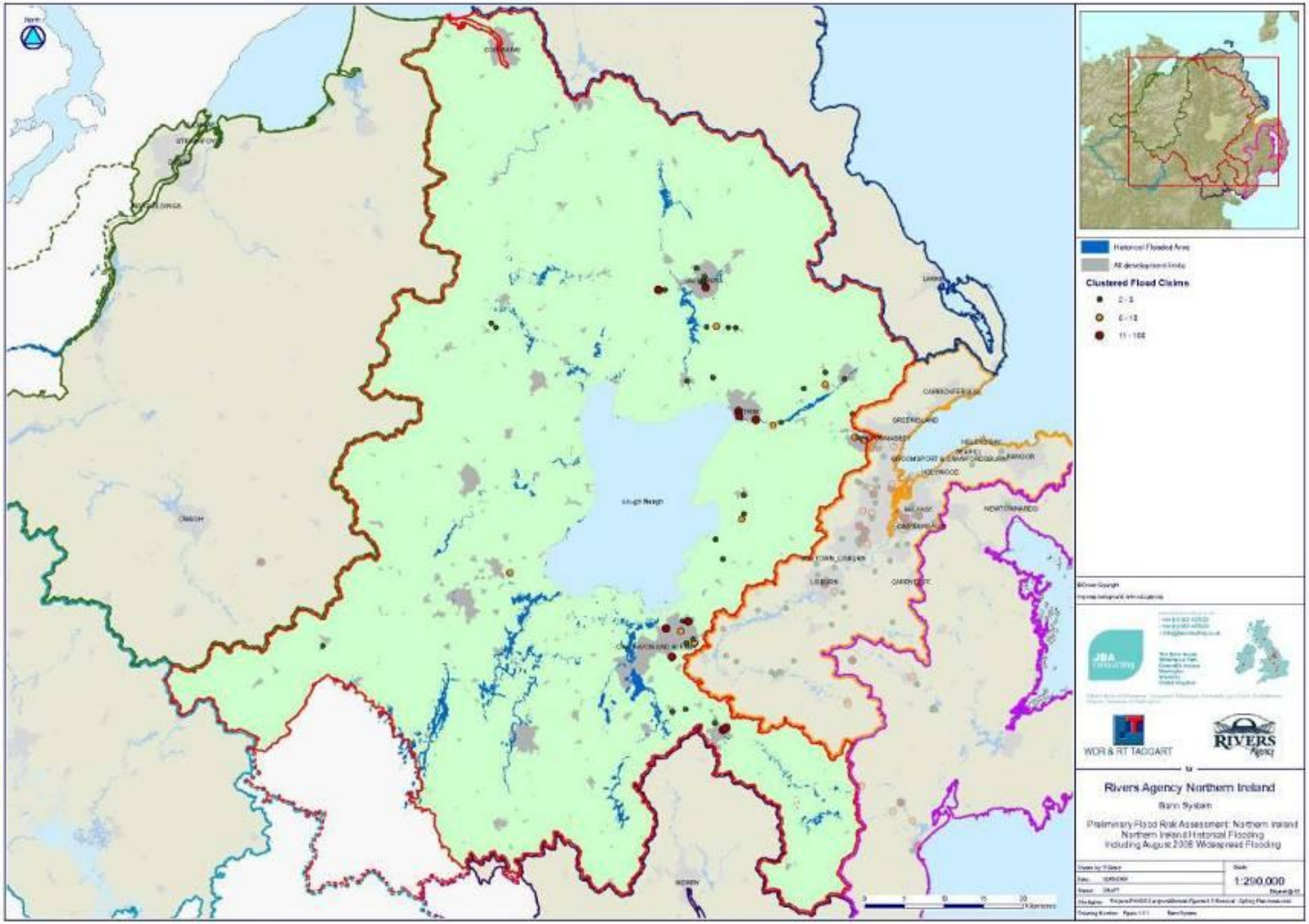
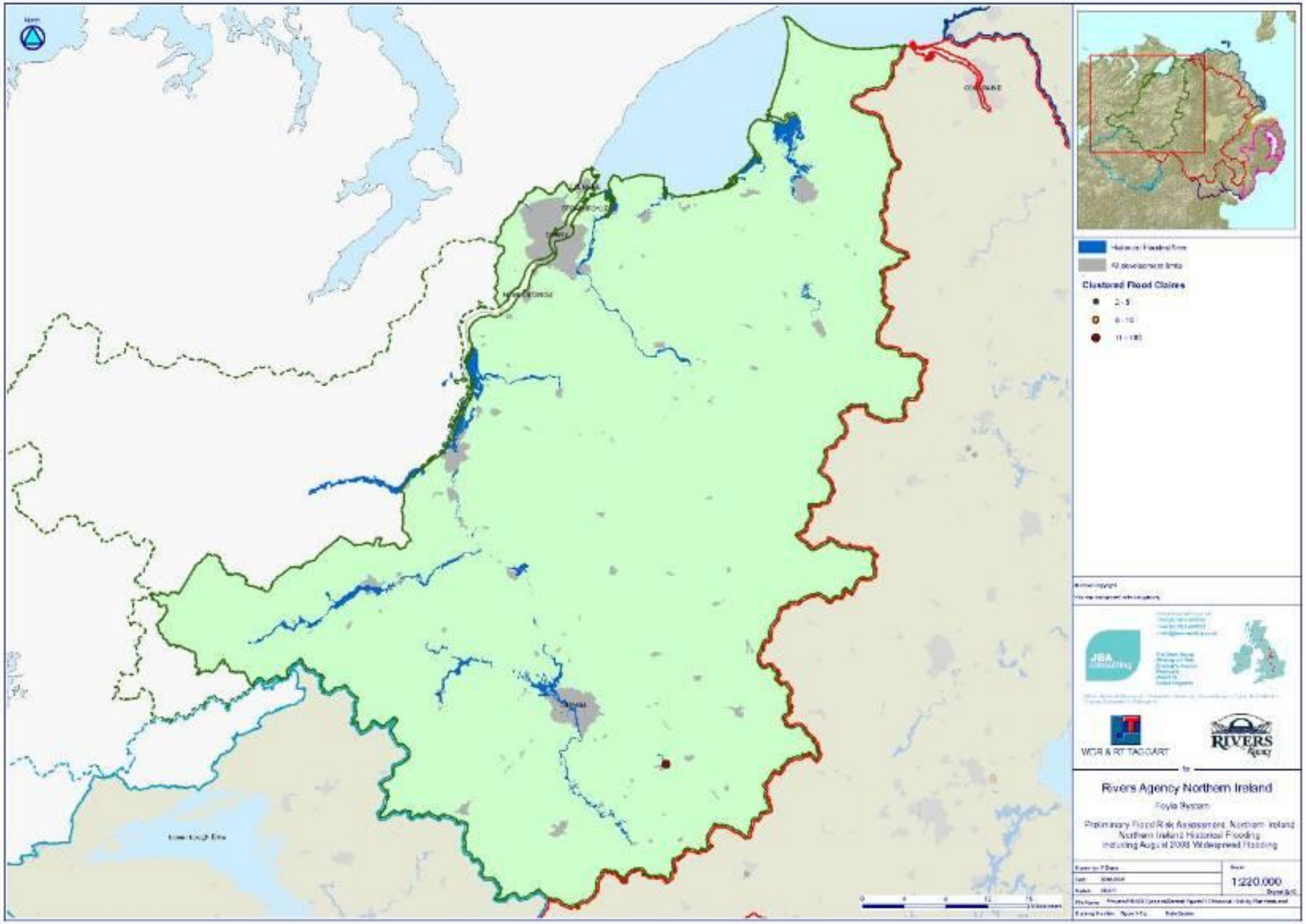


Figure C-7: Historical: Foyle System Sub-plan Area



D. Examples of combined flood risk indicators

This Appendix gives some example outputs of flood risk indicators that were combined to reflect overall measures of potential adverse consequence to human health, economic activity, the environment and cultural heritage to help meet the aims of Article 4 of the Directive. This involved grouping different indicators, for instance a count of residential properties into each of the four risk categories and combining them. Different combination methods were investigating, broadly as parametric and non-parametric.

D.1 Parametric and non-parametric techniques

The parametric combination method first re-scales the different metrics to allow for inter-comparison. This is because the metrics are all on different scales, for example, some are areas of flooded buildings, and others are a count of flooded assets. This was undertaken for all the individual flood risk metrics using the location/scale normalisation given by equation (D-1):

$$Z=(x-\mu)/\sigma \qquad \text{(D-1)}$$

Where Z is the re-scaled metric, x is the original flood risk metric, μ is the mean of the individual flood risk metric and σ is its standard deviation (over all Phase 1, 1km grids). The normalised metrics (Z) were then combined into the four Floods Directive risk categories. For heavily skewed data it may be necessary to derive a non-parametric method based around ranking the worst chosen percentile of each metric. However, it was found that this system of combining metrics identified very similar extremes.

D.2 Union, intersection and maximum spatial combinations

Three general combination methods were considered for combining the re-scaled metrics (Z), that of union (summation) and intersection (multiplication) and maximum (max operator). The ‘union’ is equivalent to an 'OR' statement, and results in a combined flood risk metric that reflects information from all of its constituent parts, but as a result of this may not yield strong variation (if all areas have a flood risk ‘from something’).

The multiplication combination method is equivalent to an ‘AND’ statement, and depending upon the metrics that are combined, can be more discerning, but can also result in a lot of areas having an overall risk of zero if there is no intersection of different indicators.

The maximum combination method was also experimented with for combining flood risk from different sources although it made no difference to the areas identified with worst flood risk.
The key flood risk metrics pertaining to human health, economic activity, cultural heritage and the environment flood risk can now be defined using the following combinations of normalised flood risk metrics, starting with flood risk to Human Health.

D.3 The Human Health Flood Directive Metric

Equation D-2 gives the indicators that were combined together to generate a measure of potential adverse consequences to human health:

$$\{\, w_V Z_{\text{Vulnerability}} + w_E Z_{\text{Economic deprivation}} + w_P Z_{\text{Annualised No people}} + w_e Z_{\text{elderly}} + w_C Z_{\text{key services}} + w_R Z_{\text{road lengths}} \,\}_{\text{fluvial}}$$
$$+ \{\}_{\text{coastal}}$$
$$+ \{\}_{\text{pluvial}} \qquad \text{(D-2)}$$

Where + means 'add' to give the 'union' combination method. The parenthesis indicate repeat for each of the named sources. The weights (w_x) in the equation were all set to unity at first, allowing each term to influence the Floods Directive Metric equally. However, the covariance matrix for the first three indicators showed a very strong correlation (0.99; 0.95; 0.97), suggesting they are essentially measuring the same thing. This is not surprising as the first two are based around similar combinations of Census data variables and are used to weight the flooded residential properties in each grid square. The third variable also pertains to the number of flooded residential properties. For this reason, the three weights, w_v, w_E, and w_P were set at 0.33 to avoid counting the same information three times.

The metrics were combined over the three sources of fluvial, coastal and pluvial flooding, since these all used different design events. This can be achieved using the union operator once more, again to be inclusive, and to recognize the different nature of each type of flooding. The pluvial and fluvial strategic floodplains are likely to have a high level of dependency, and an alternative combination method is to take the maximum score from the combined indicators over each source. This was investigated and it was found that very similar grid squares were recovered as for using the straight forward addition.

Finally, the sensitivity to whether a parametric or non-parametric combination method was used for combining the individual flood risk indicators into the overall Floods Directive Metrics was investigated. Avery similar set of cells with worst flood risk were returned confirming that the parametric re-scaling technique was robust when investigating extremes.

D.4 The Economic Activity Floods Directive Metric

Equation D-3 gives the indicators that were combined together to generate a measure of potential adverse consequences to economic activity:

$$\{ w_D Z_{\text{Annual Average Property Damage}} + w_A Z_{\text{Annual Average Agric Damage}} + w_R Z_{\text{road lengths}} \}_{\text{fluvial}}$$
$$+ \{\}_{\text{coastal}}$$
$$+ \{\}_{\text{pluvial}} \qquad \text{(D-3)}$$

There is a slightly significant 0.6 correlation between the first two indicators, but this is before the urban land cover giving agricultural damages has been ruled out, so the weights were not adjusted from unity.

D.5 The Environment Floods Directive Metric

Equation D-4 gives the indicators that were combined together to generate a measure of potential adverse consequences to the environment:

$$\{wSZ_{\text{Flooded ASSI Area}} + wIZ_{\text{Area IPRI sites}} + w_W Z_{\text{WWTW+PS}}\}_{\text{fluvial}} + \{\}_{\text{coastal}} + \{\}_{\text{pluvial}} \qquad \text{(D-4)}$$

Surprisingly, there is a 0.84 correlation between the first 2 indicators, although the flooded ASSI includes large tracts of coastal land, and is measuring something completely different to a flooded refinery. Areas identified by this metric need consideration by the relevant authority, since there was no readily derivable information on environmental vulnerability.

The Integrated Pollution and Radioactivity Inspectorate (IPRI) sites were provided as polygons, and the flooded area of polygon was considered. The IPRI sub categories included a range of processes, although the relative consequences of flooding of different processes requires further advice from the inspectorate.

D.6 The Cultural Heritage Floods Directive Metric

Equation D-5 gives the indicators that were combined together to generate a measure of potential adverse consequences to cultural heritage:

$$\{w_H Z_{\text{no. flooded historic sites}}\}_{\text{fluvial}} + \{\}_{\text{coastal}} + \{\}_{\text{pluvial}} \qquad \text{(D-5)}$$

where flooded historic sites includes the datasets of Listed buildings, Gardens, Sites and Monuments Records (SMR) and Sites of Archeological Interest.

D.7 Sensitivity to scale of Floods Directive Metrics

For Belfast, the entire Sub-plan Area was analysed using a 100m grid squares using the same process as for the 1km grid squares. The results showed that when the worst 100m grid squares were grouped they identify the same general areas as the 1km squares. The scale of the worst areas impacted by flooding is clearly greater much greater than 100m, something which can be clearly seen by overlaying the strategic flood outlines over the receptor data. Coupled with the requirement for a practical scale at which to undertake a national analysis for flood risk, the 1km grid was adopted.

D.8 Visualisation of the Floods Directive Metrics

The combined Flood Risk Metrics for each Sub-plan Area are shown in Figures D1-D7 giving a strong visualisation of potential adverse consequences to human health, economic activity, the environment and cultural heritage. The maps show the complete range of values of the metrics and colour every grid square for each Sub-plan Area according to the four Floods Directive categories. The colour scales are the same over the whole of Northern Ireland so the relative potential adverse consequences for each category can be compared between Sub-plan Areas.

Figure D-1: Combined Metrics Belfast Sub-plan Area

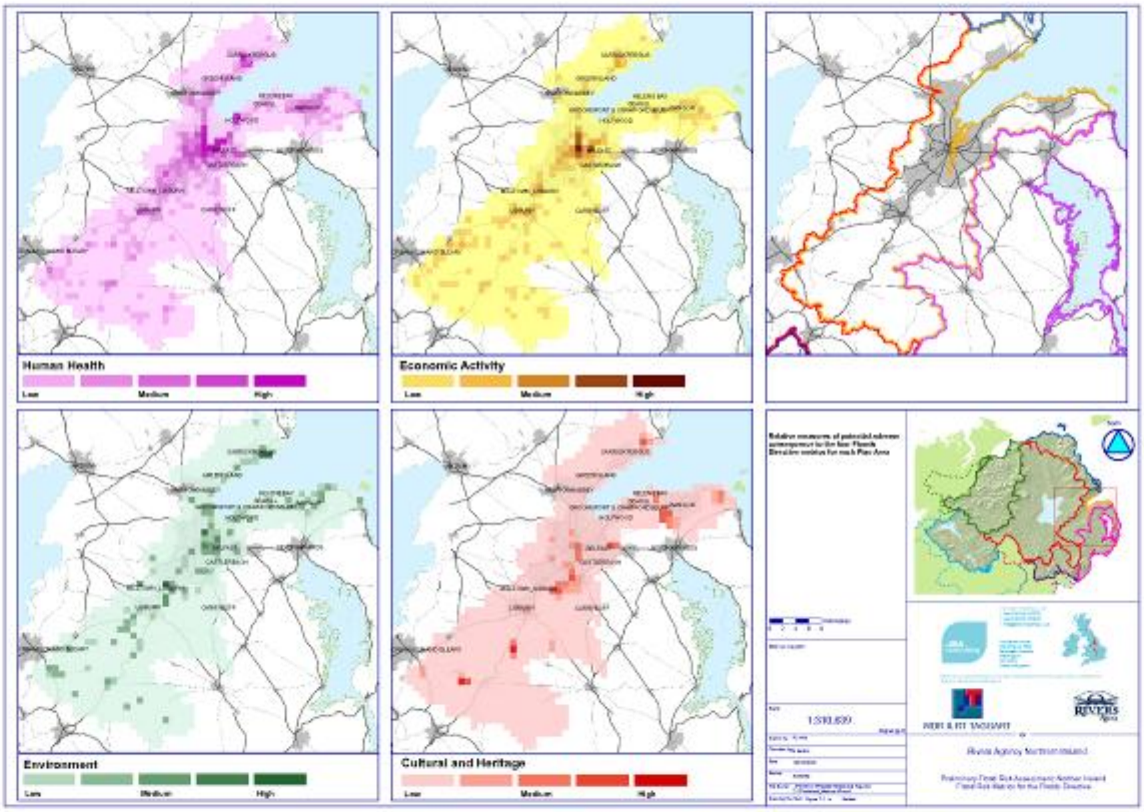


Figure D-2: Combined metrics Antrim Coast Sub-plan Area

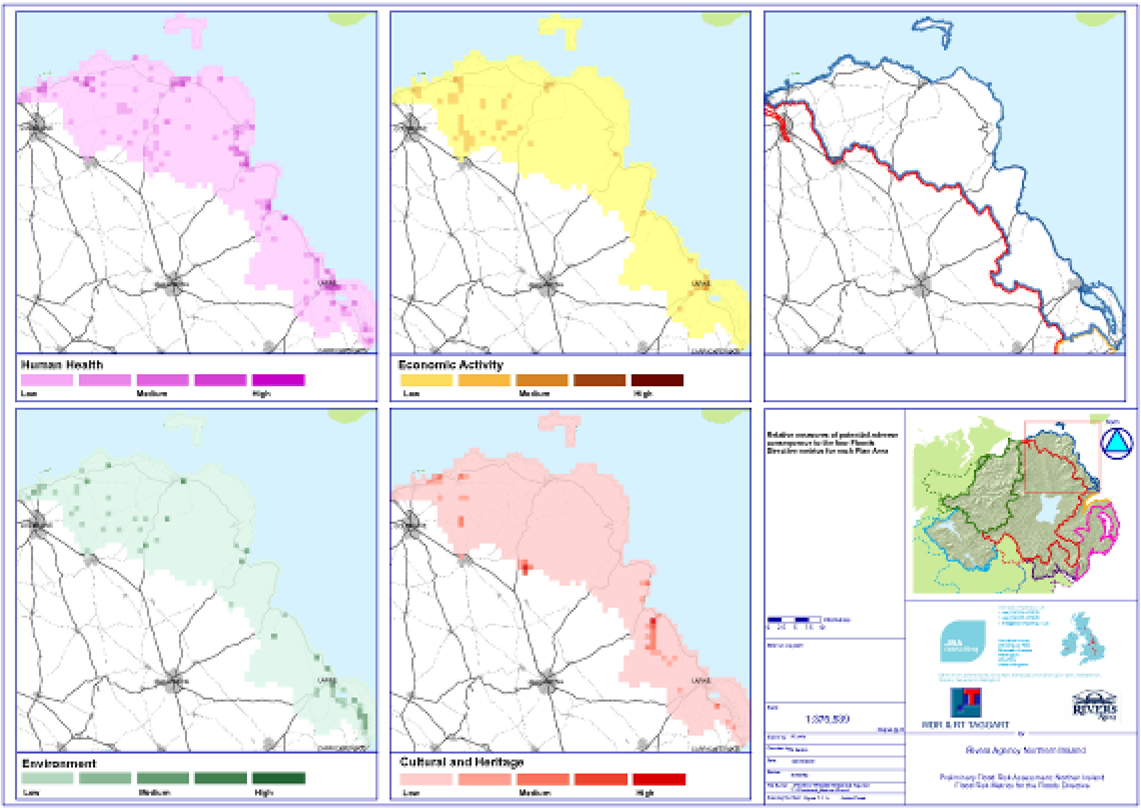


Figure D-3: Combined metrics South Armagh and Down and Louth Sub-plan Area

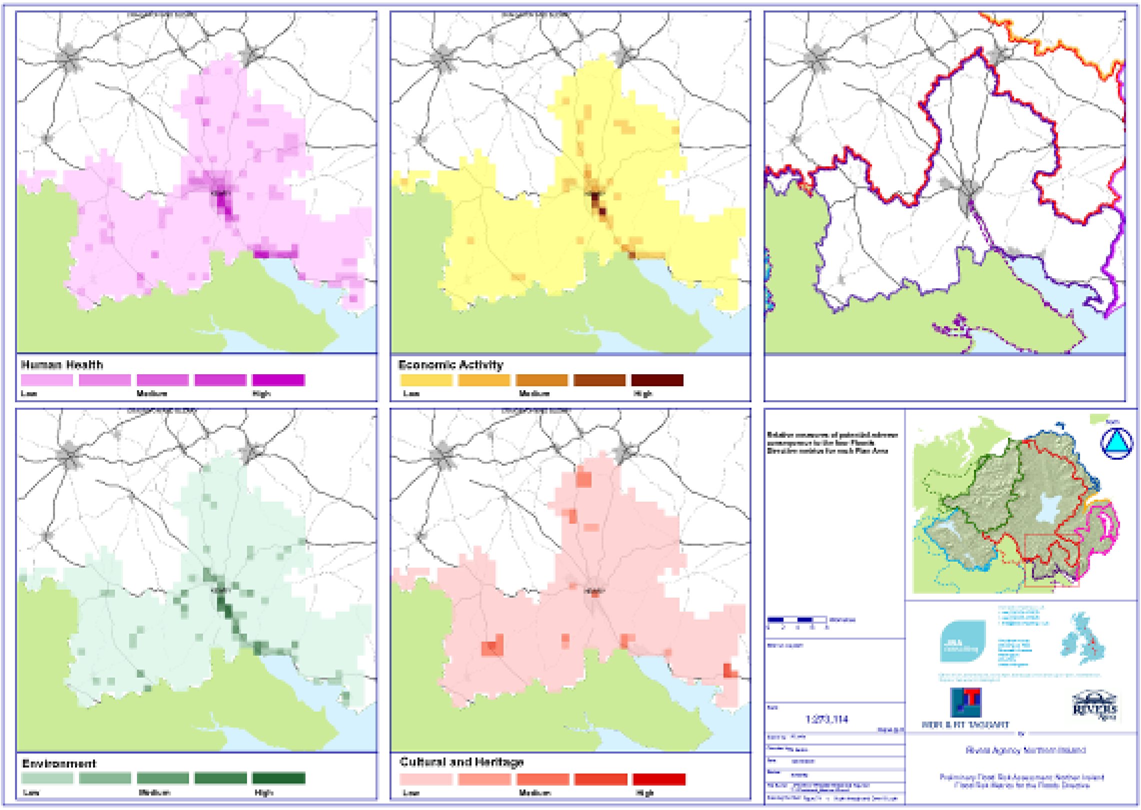


Figure D-4: Combined metrics Erne and Melvin Systems Sub-plan Area

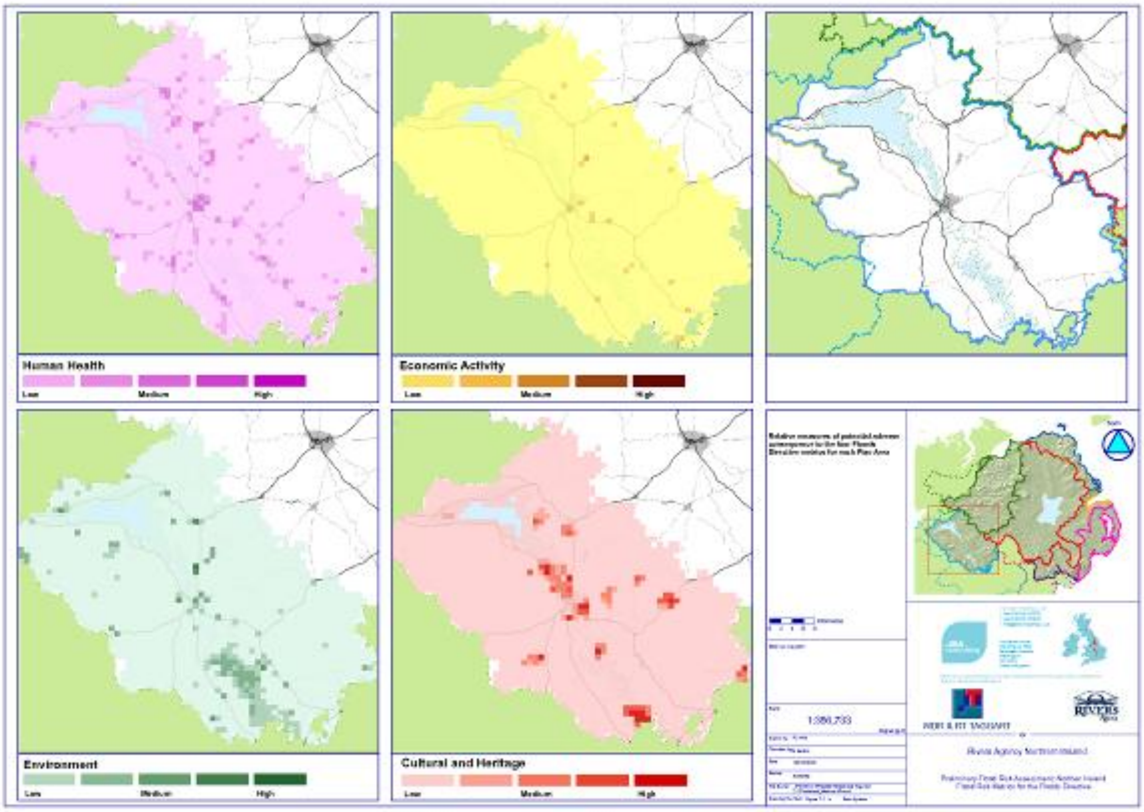


Figure D-5: Combined metrics Down Coast Sub-plan Area

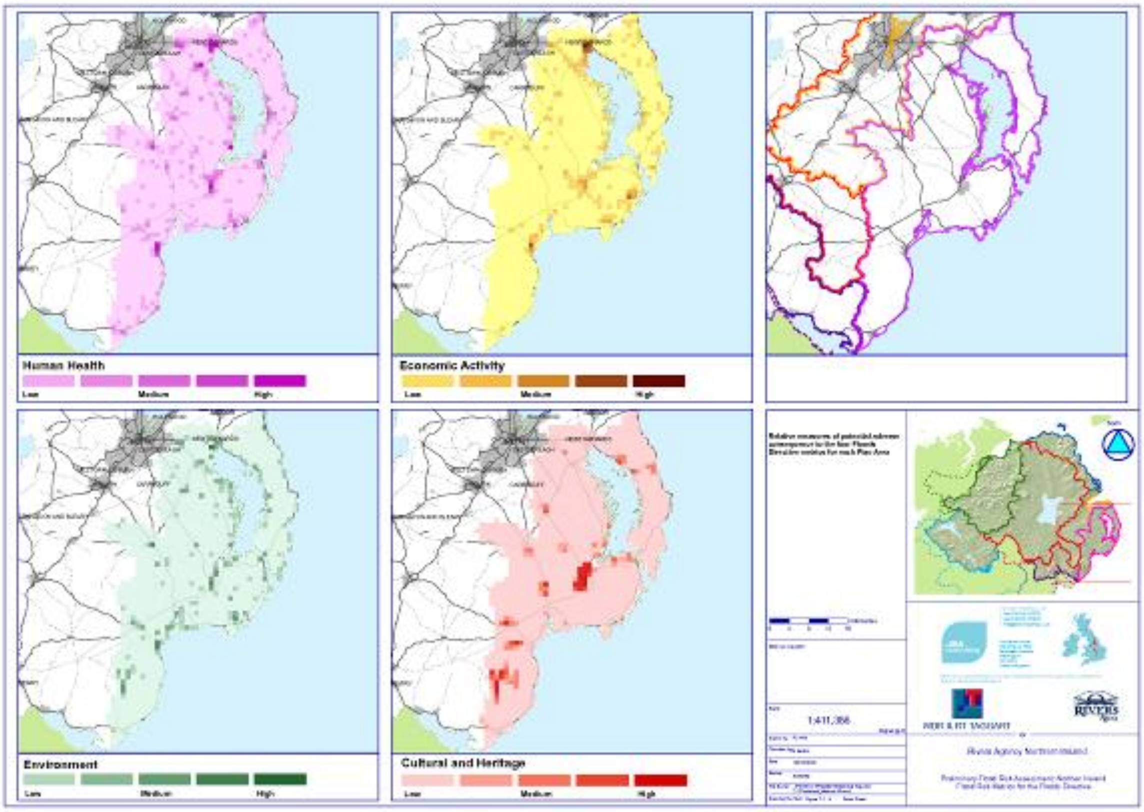


Figure D-6: Combined metrics Bann System Sub-plan Area

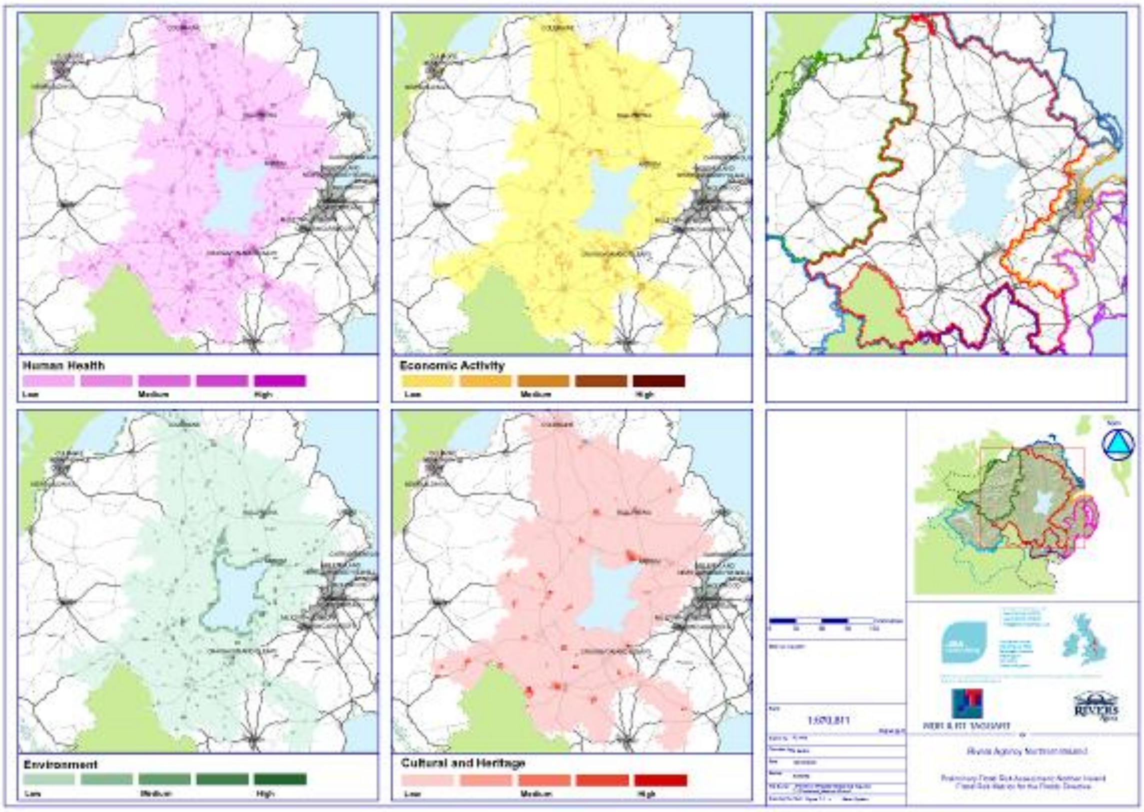
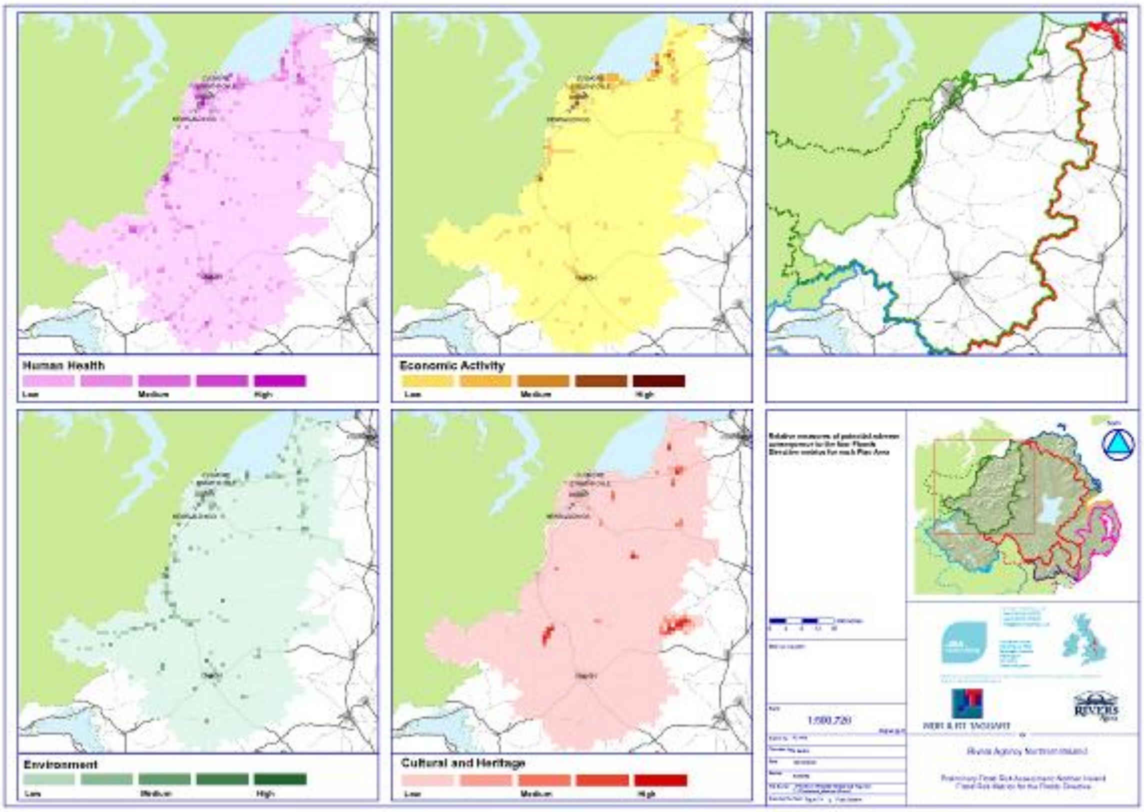


Figure D-7: Combined metrics Foyle System Sub-plan



E. Maps illustrating locations of Draft SFRA by Sub-plan Area

This map series illustrates the location of the Core SFRA, which are those 1km grid squares in which the Amalgamated Annual Average Damages exceed a £300K threshold value, together with the Draft SFRA which have been grown from these cores. These maps also identify watercourse sections that are estimated to have a potential for high geomorphological activity (Map E7 illustrated only) and grid squares in which the Amalgamated Annual Average *(number of)* Key Services Flooded (AAAKSF) value is greater than or equal to 2.

Figure E-1: Draft SFRA in the Belfast Sub-plan Area

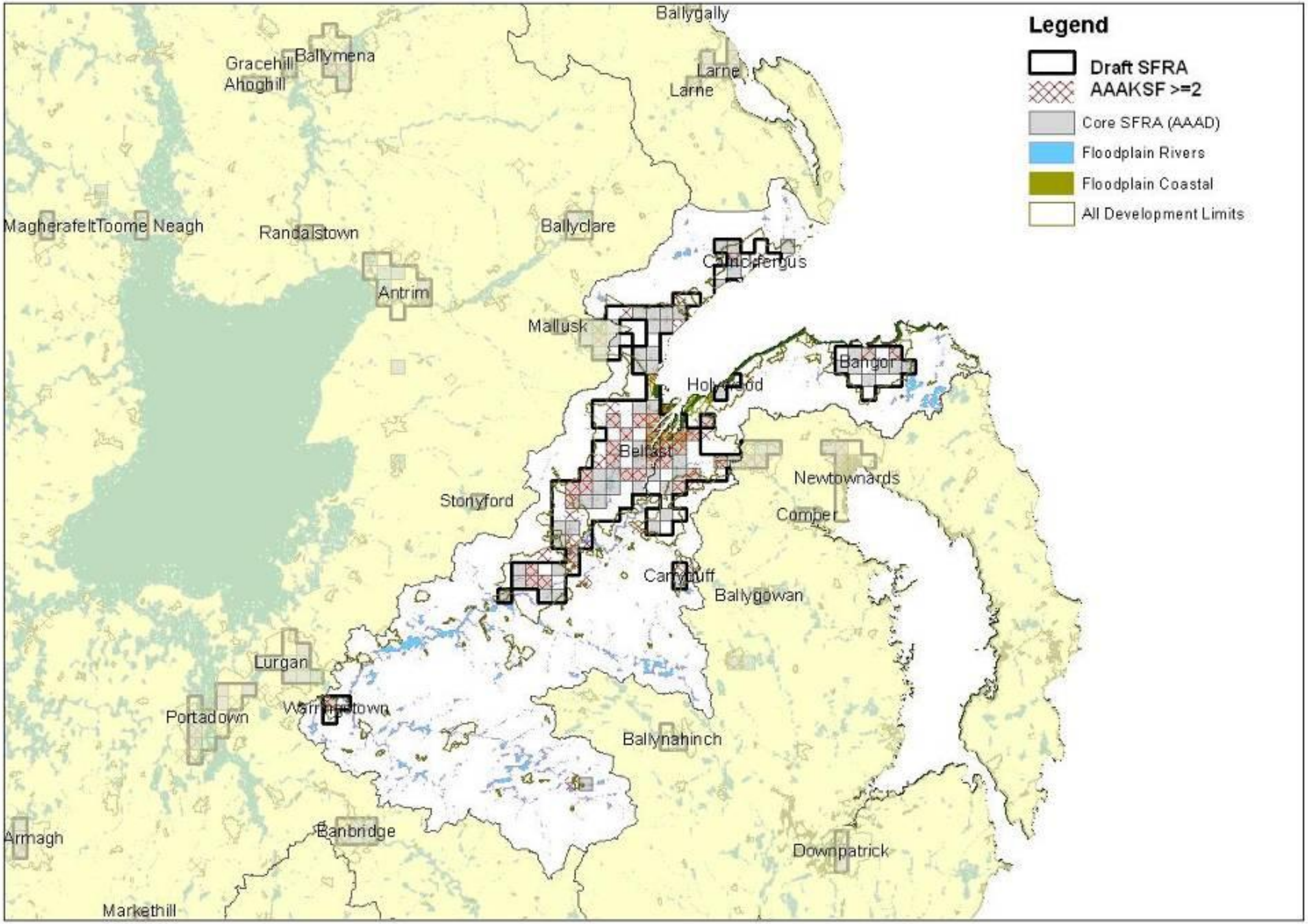


Figure E-2: Draft SFRA in the Antrim Coast Sub-plan Area

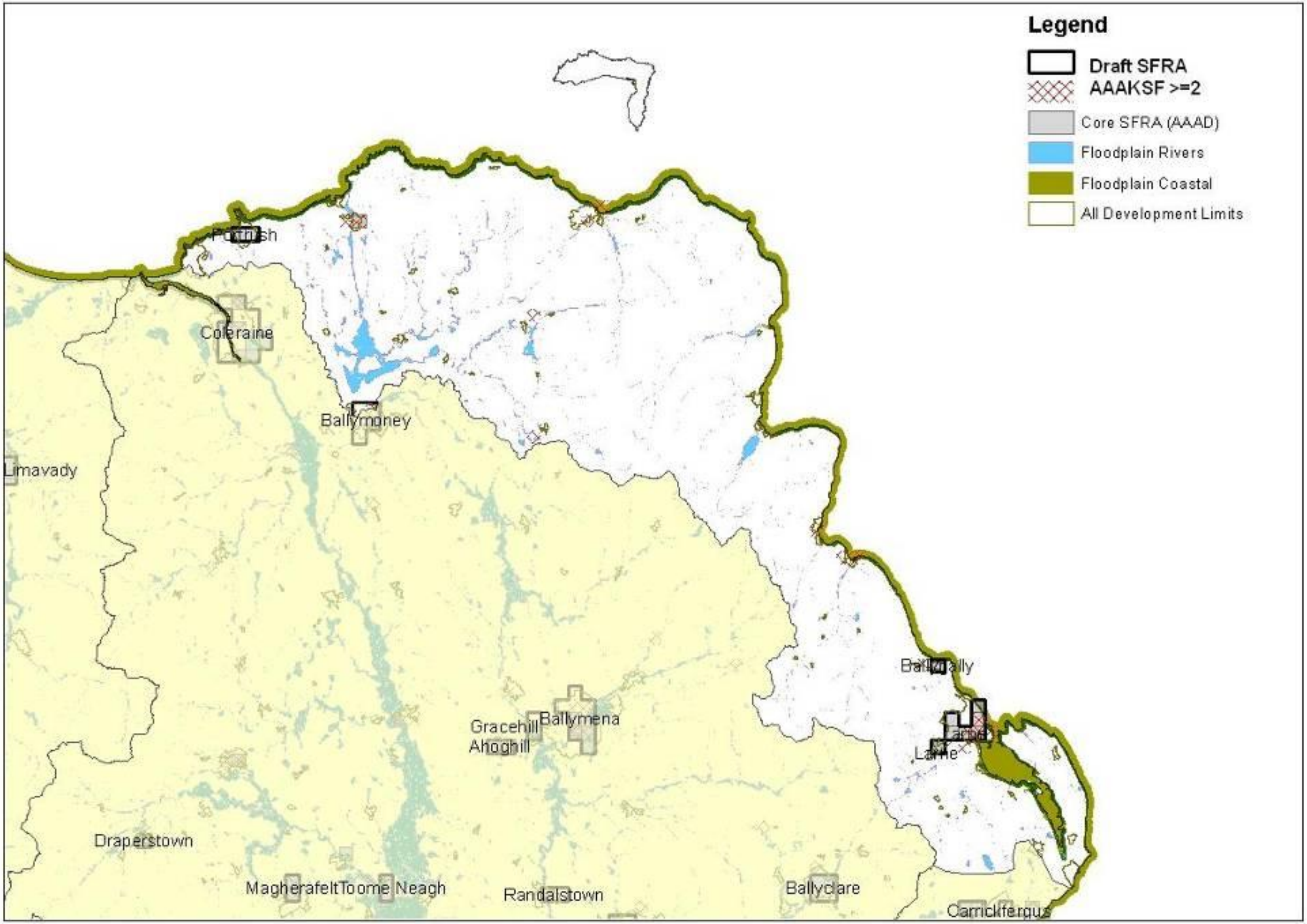


Figure E-3: Draft SFRA in the South Armagh and Down and Louth Plan Sub-plan Area

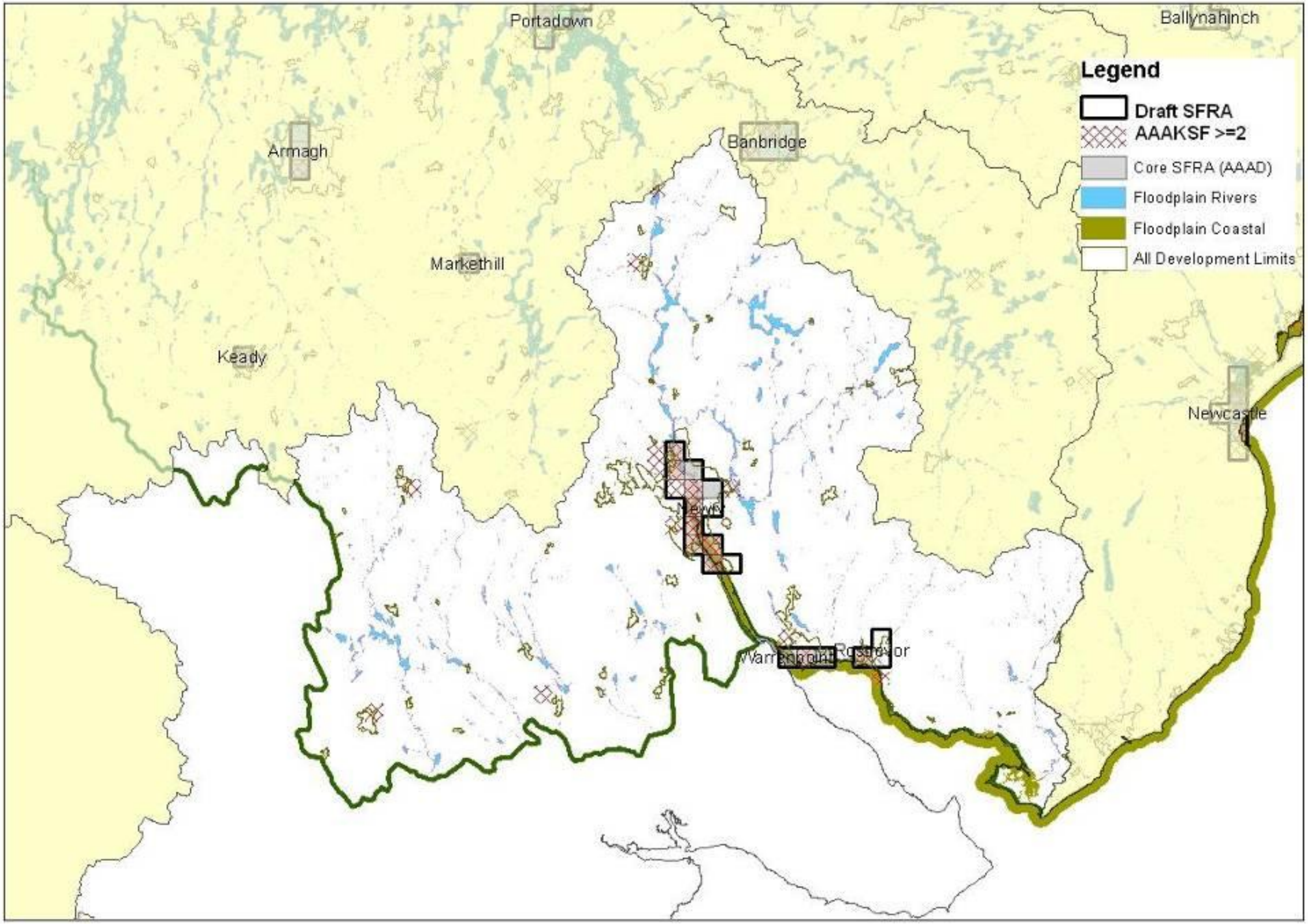


Figure E-4: Draft SFRA in the Erne and Melvin Sub-plan Area

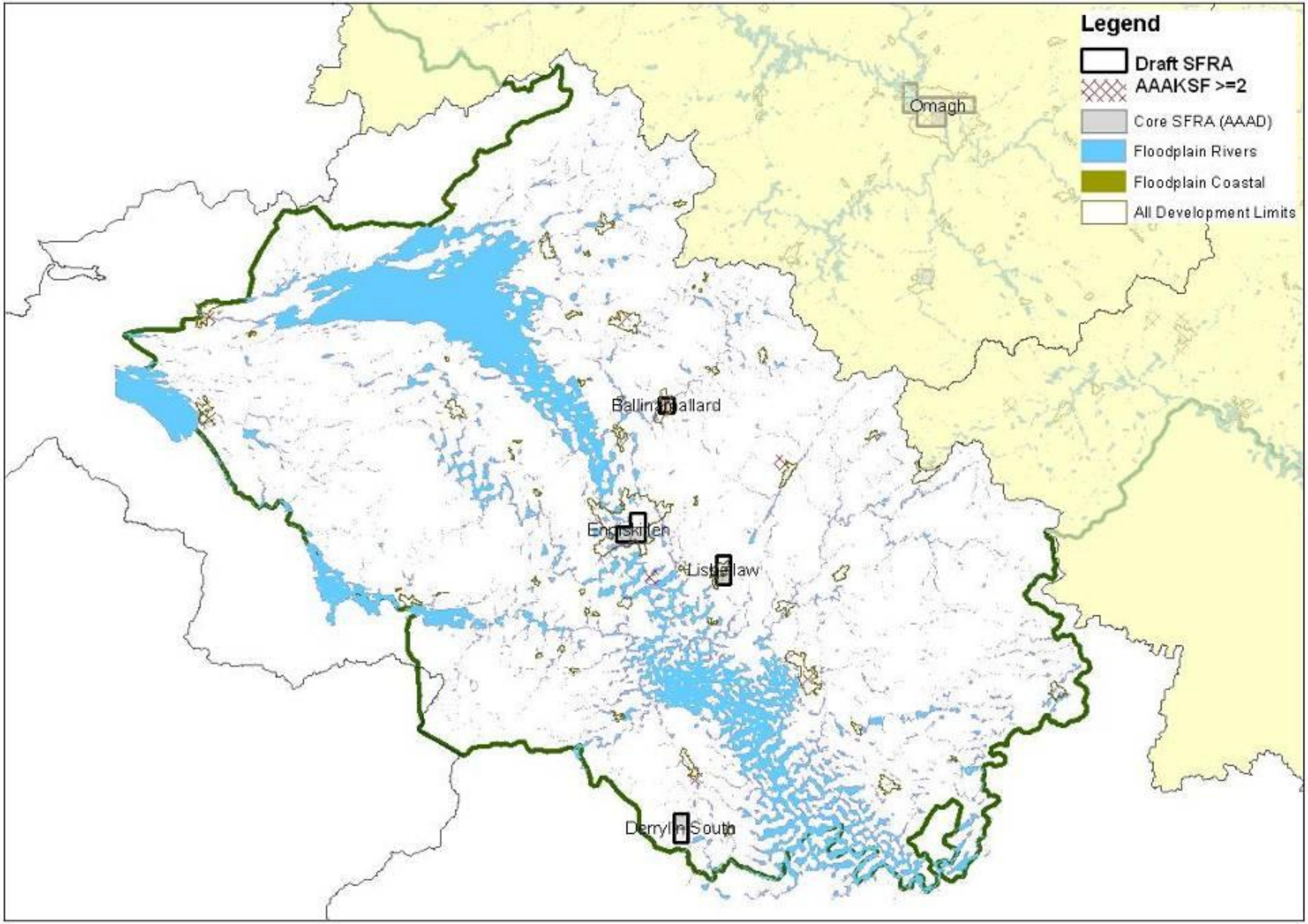


Figure E-5: Draft SFRA in the Down Coast Sub-plan Area

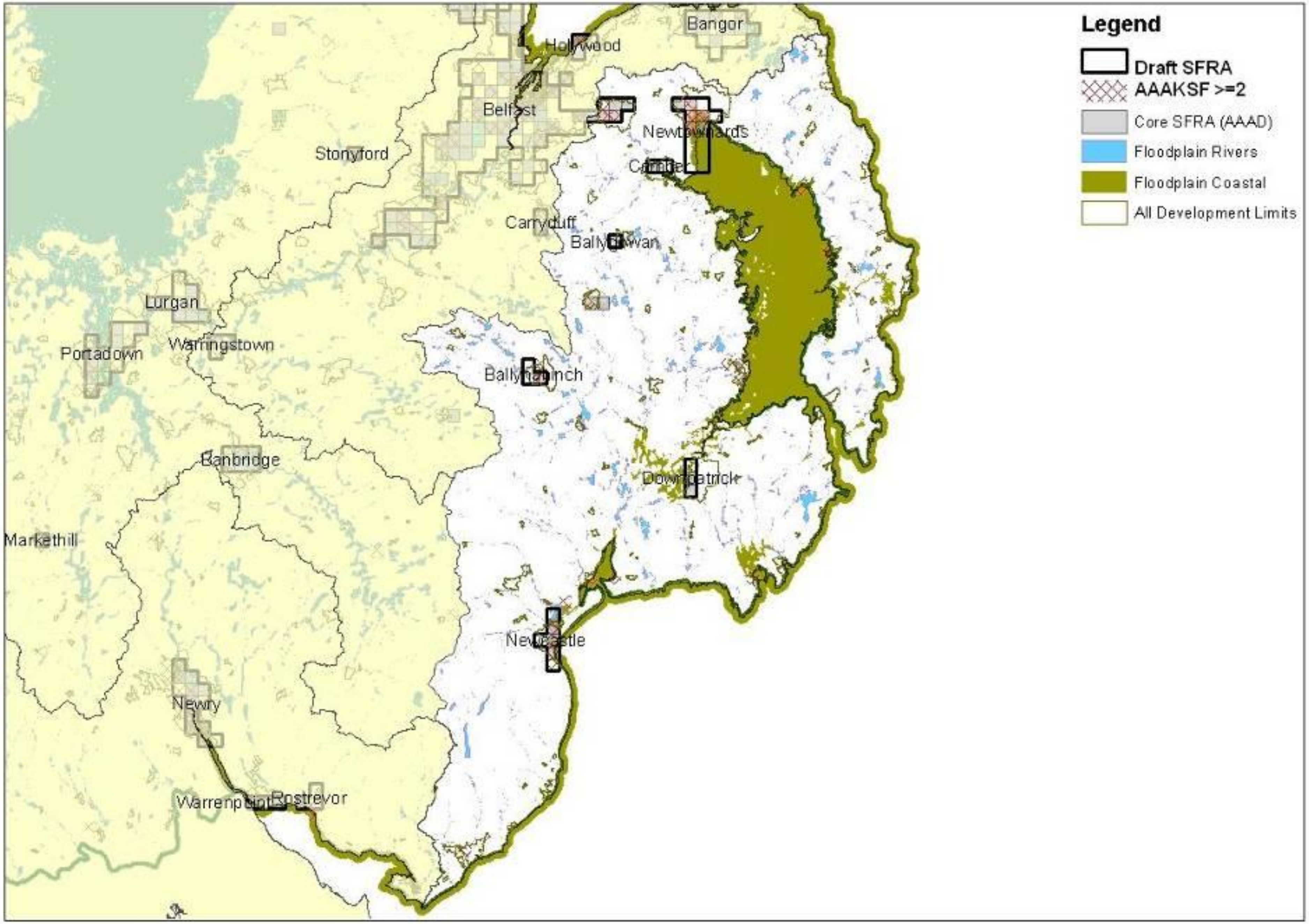


Figure E-6: Draft SFRA in the Bann system Sub-plan Area

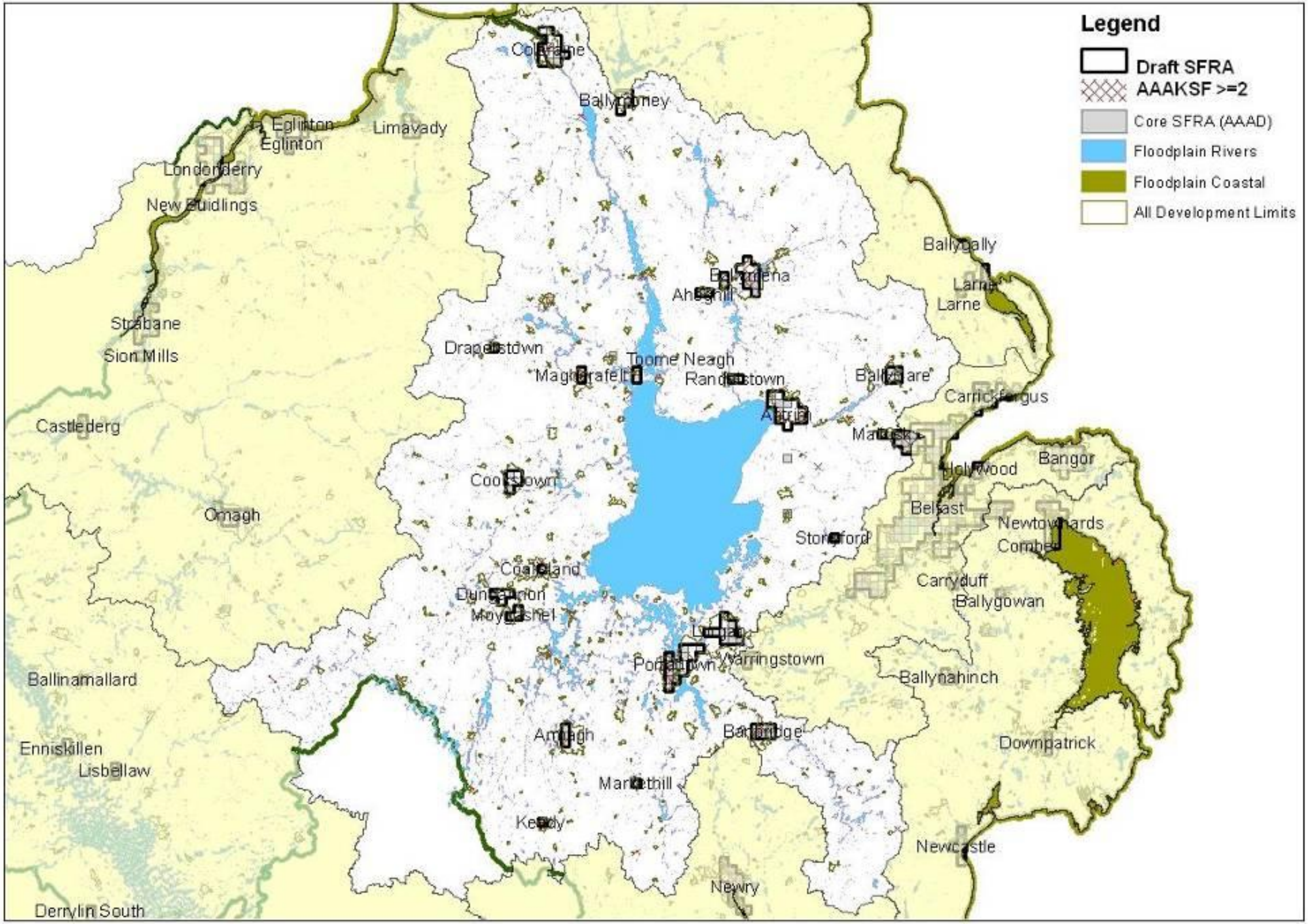
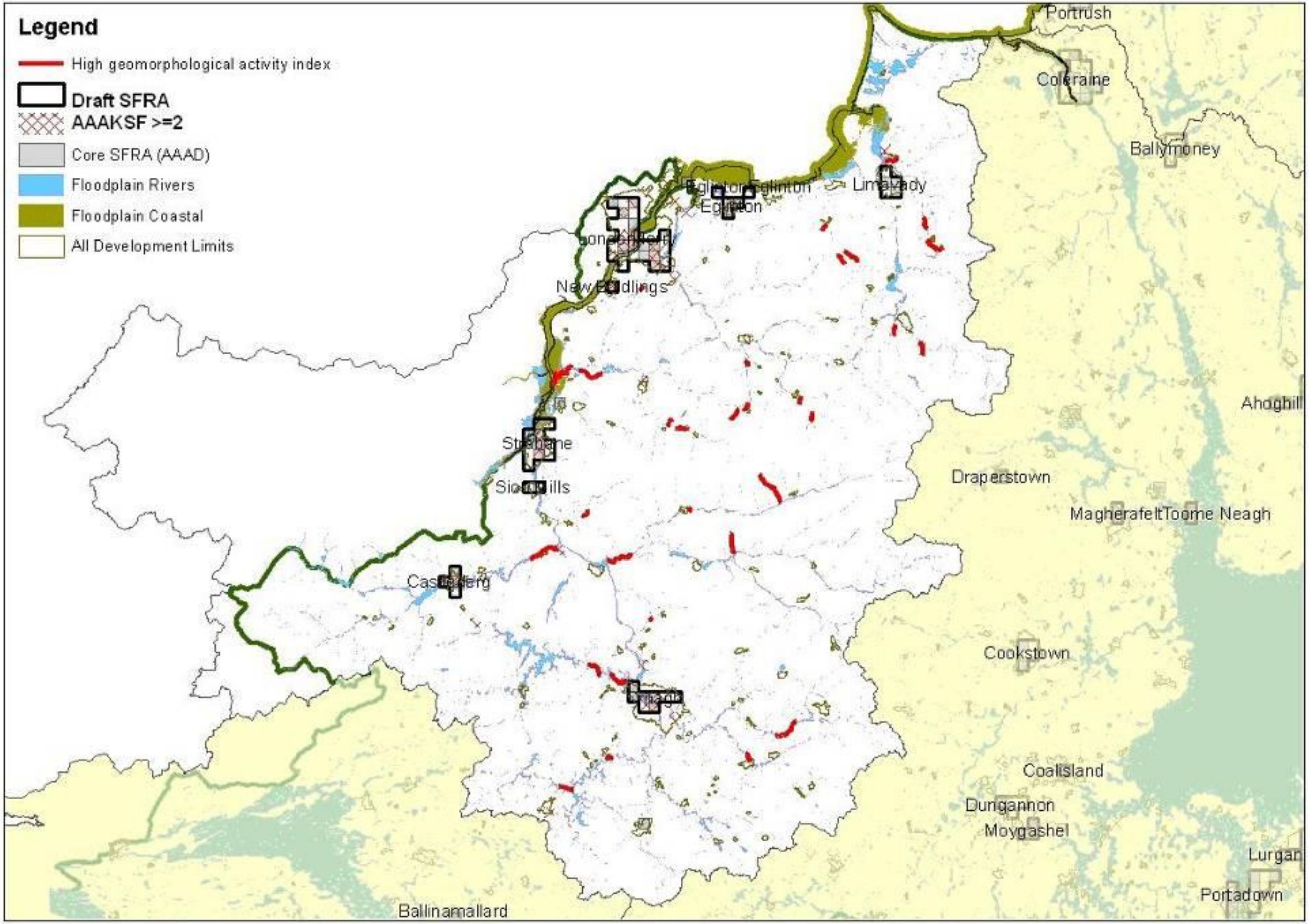


Figure E-7: Draft SFRA in the Foyle system Sub-plan Area



F. Maps illustrating Core SFRA and AAAD by Sub-plan Area

This Appendix contains a map for each of the Sub-plan areas that illustrates the Core SFRA (i.e. AAAD/km2 greater £300k) and the highlights the spatial variation in the AAAD. This range of maps was used to grow the Draft SFRA (Strand 1) from the Core SFRA.

Figure F-2: Core SFRAs and AAAD for the Antrim Coast Sub-plan Area

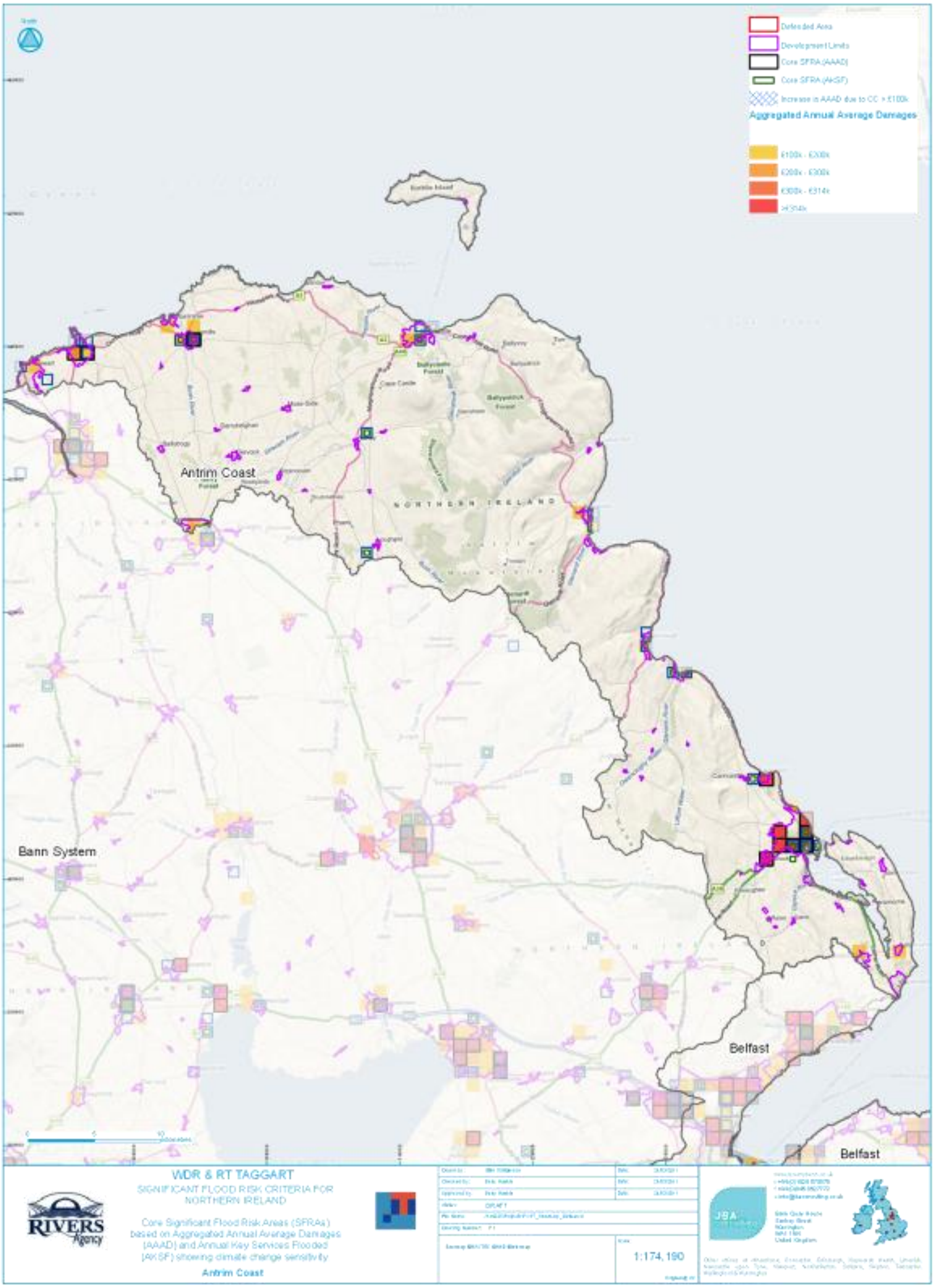


Figure F-3: Core SFRAs and AAAD for the South Armagh, Louth and Down Coast Sub-plan Area

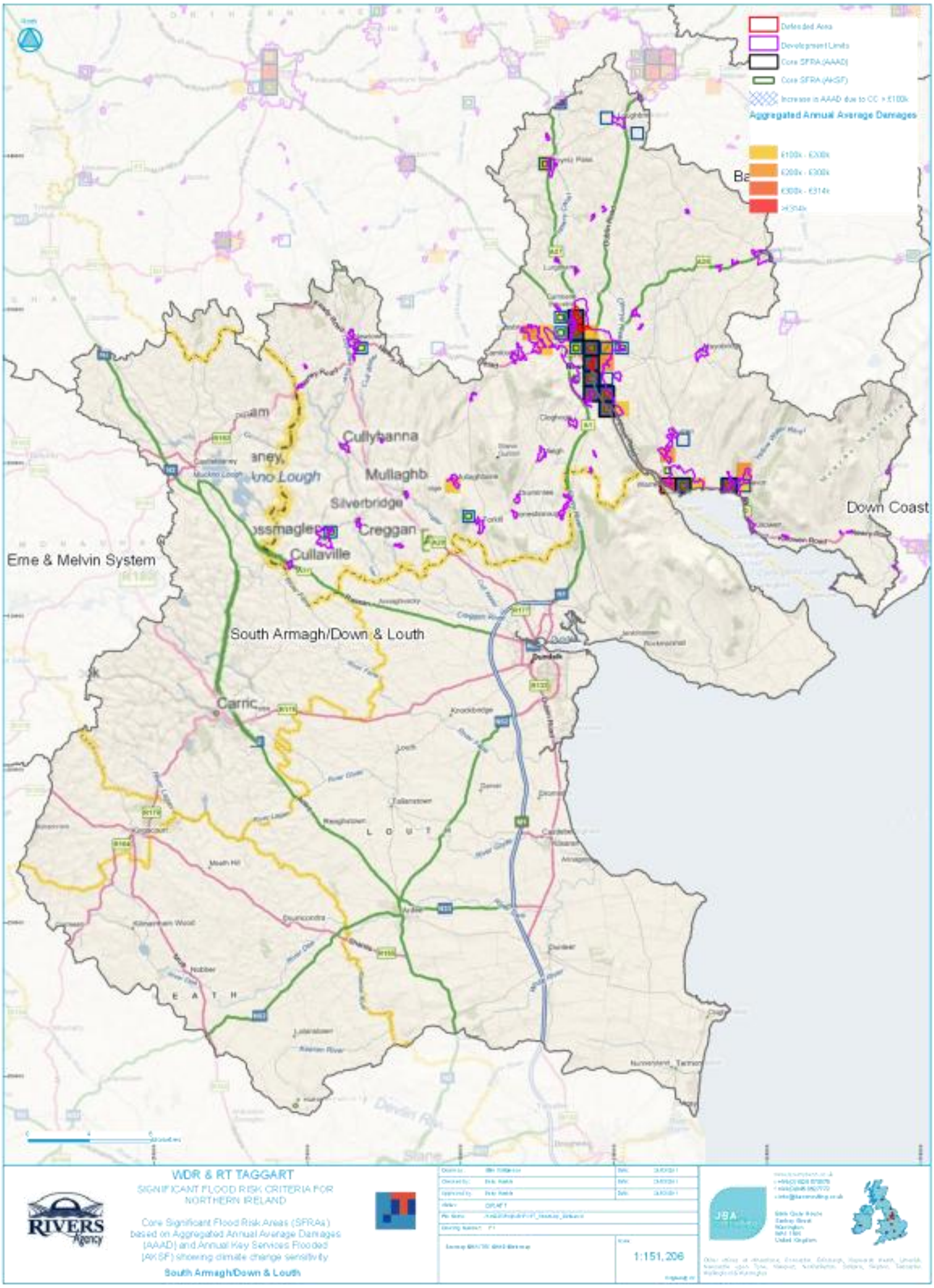


Figure F-4: Core SFRAs and AAAD for the Erne and Melvin Sub-plan Area

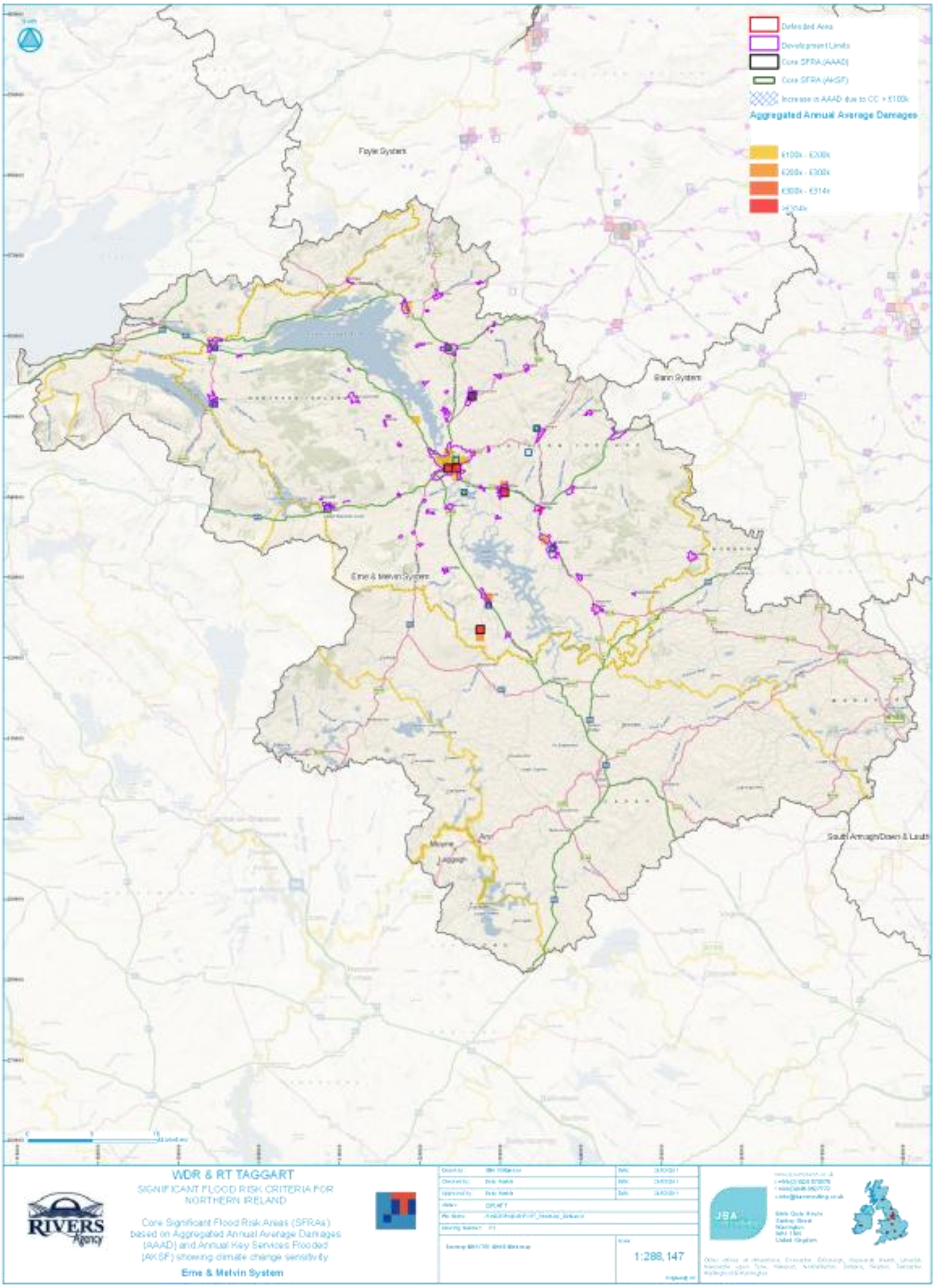


Figure F-5: Core SFRAs and AAAD for the Down Coast Sub-plan Area

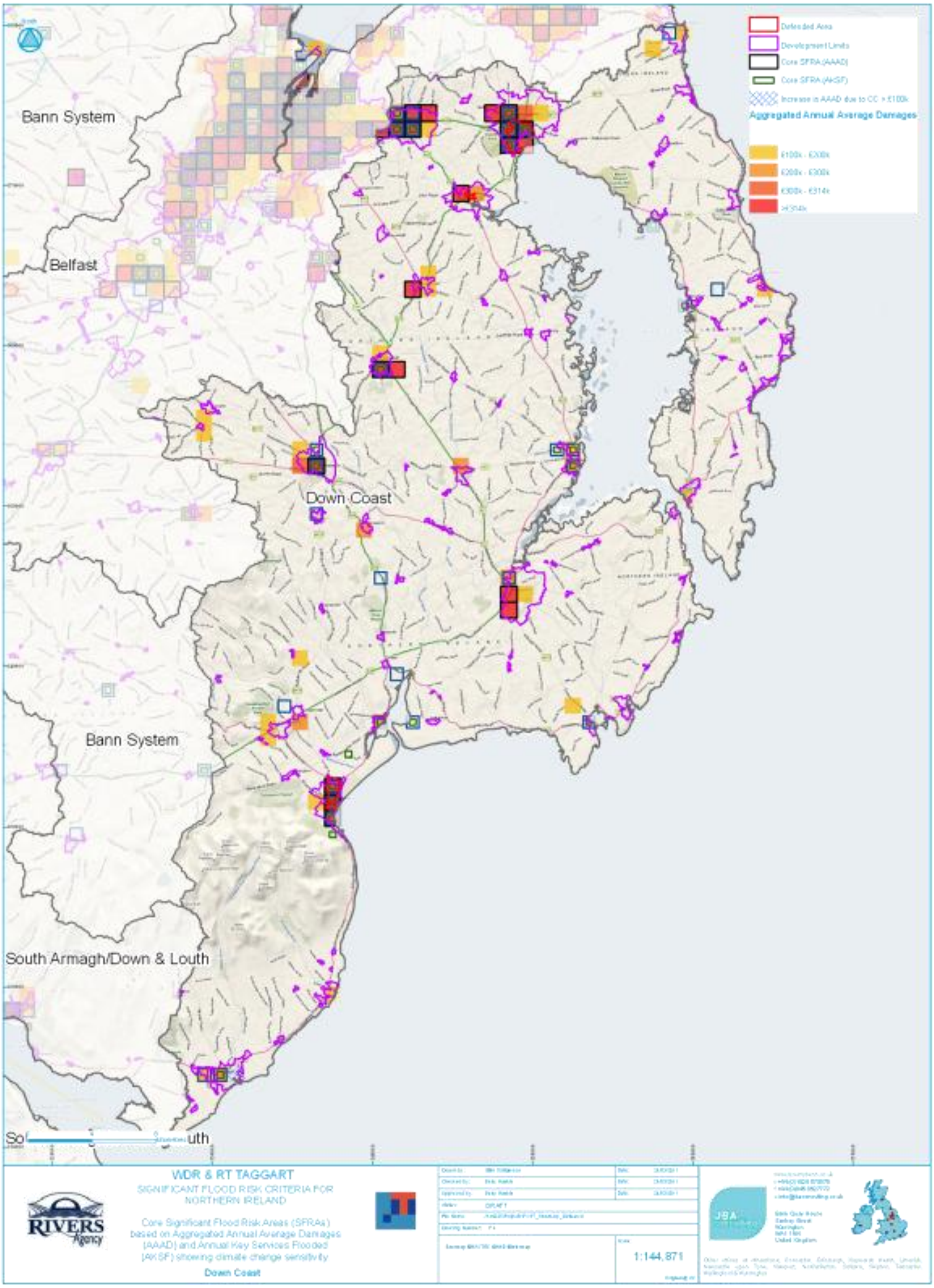


Figure F-6: Core SFRAs and AAAD for the Bann Sub-plan Area

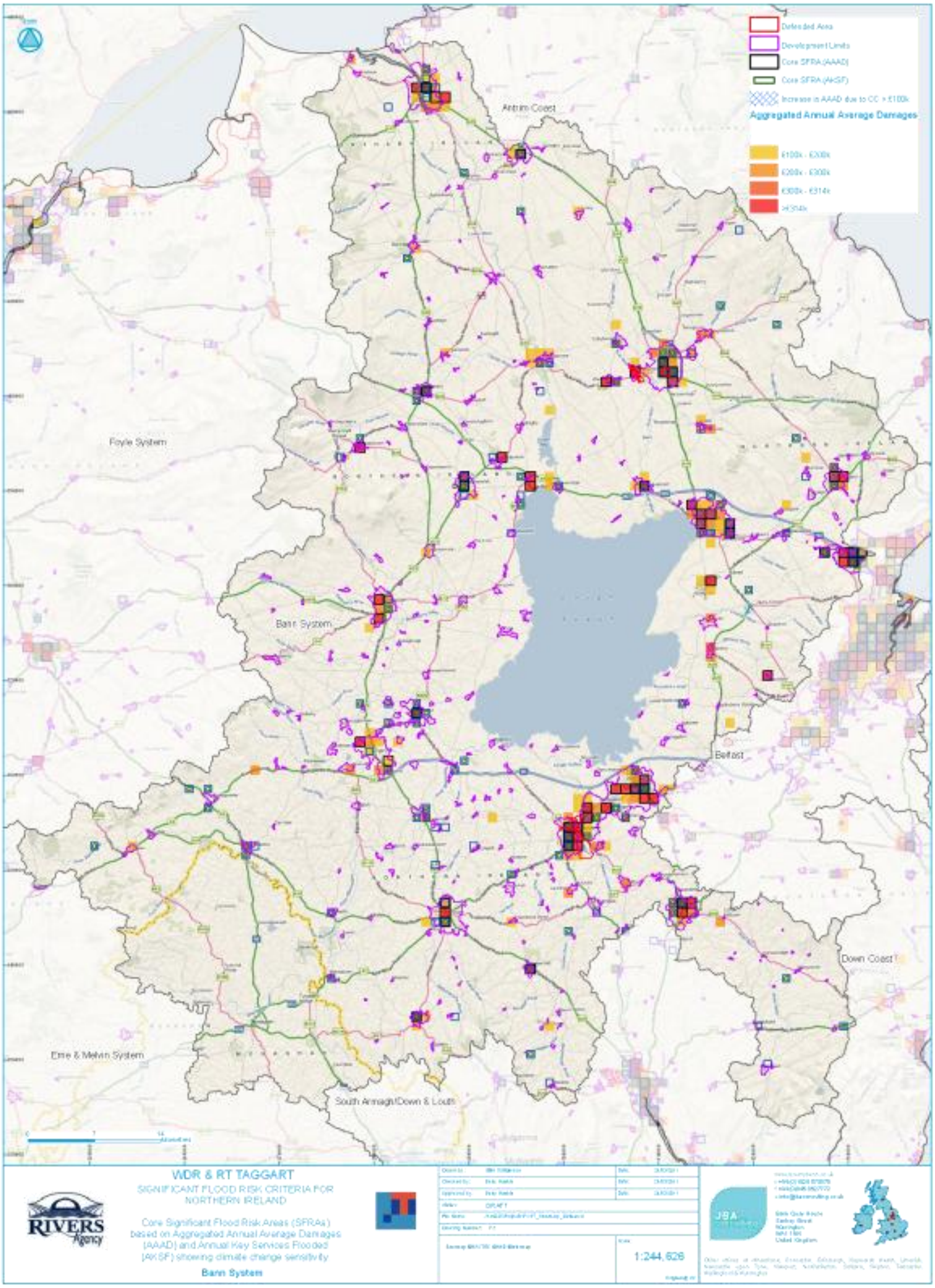
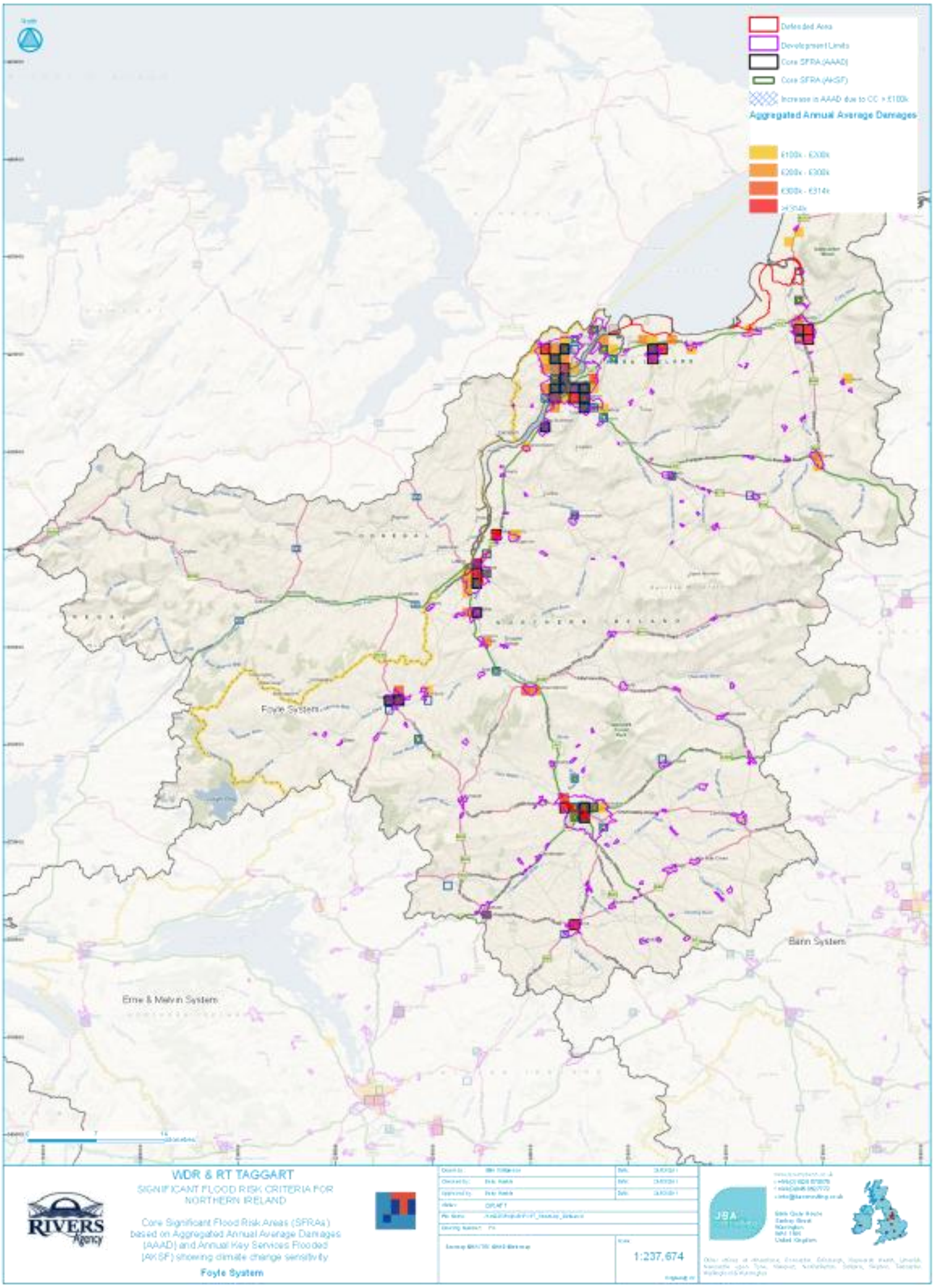


Figure F-7: Core SFRAs and AAAD for the Foyle System Sub-plan Area



G. Samples of detailed maps illustrating flood extents and receptors.

All the key maps are included in this appendix for completeness, although the high quality 'pdf' maps as separate documents should be used for enlargements.

Figure G-1: Detailed flood source and receptor comparison for example Core SFRA Belfast J3474

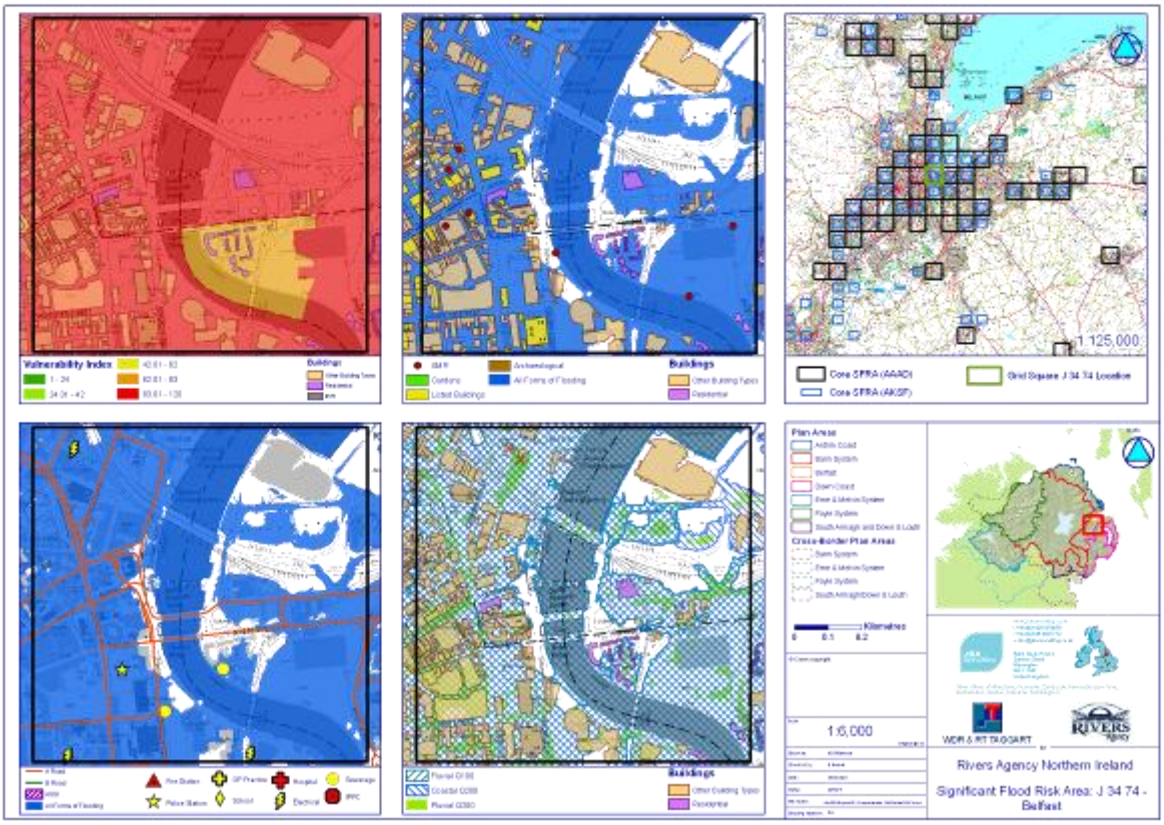


Figure G-2: Detailed flood source and receptors for example Core SFRA Down Coast J4845

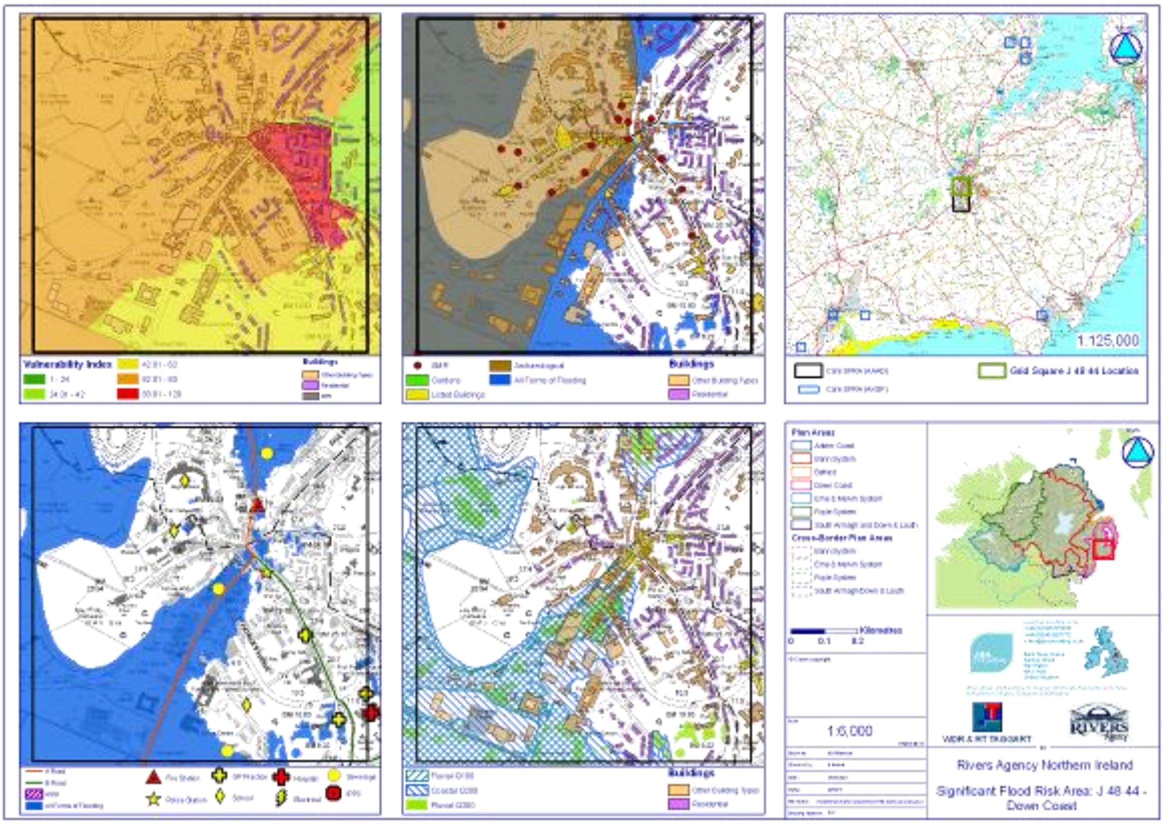


Figure G-3: Detailed flood source and receptor comparison for example Core SFRA Foyle System C4317

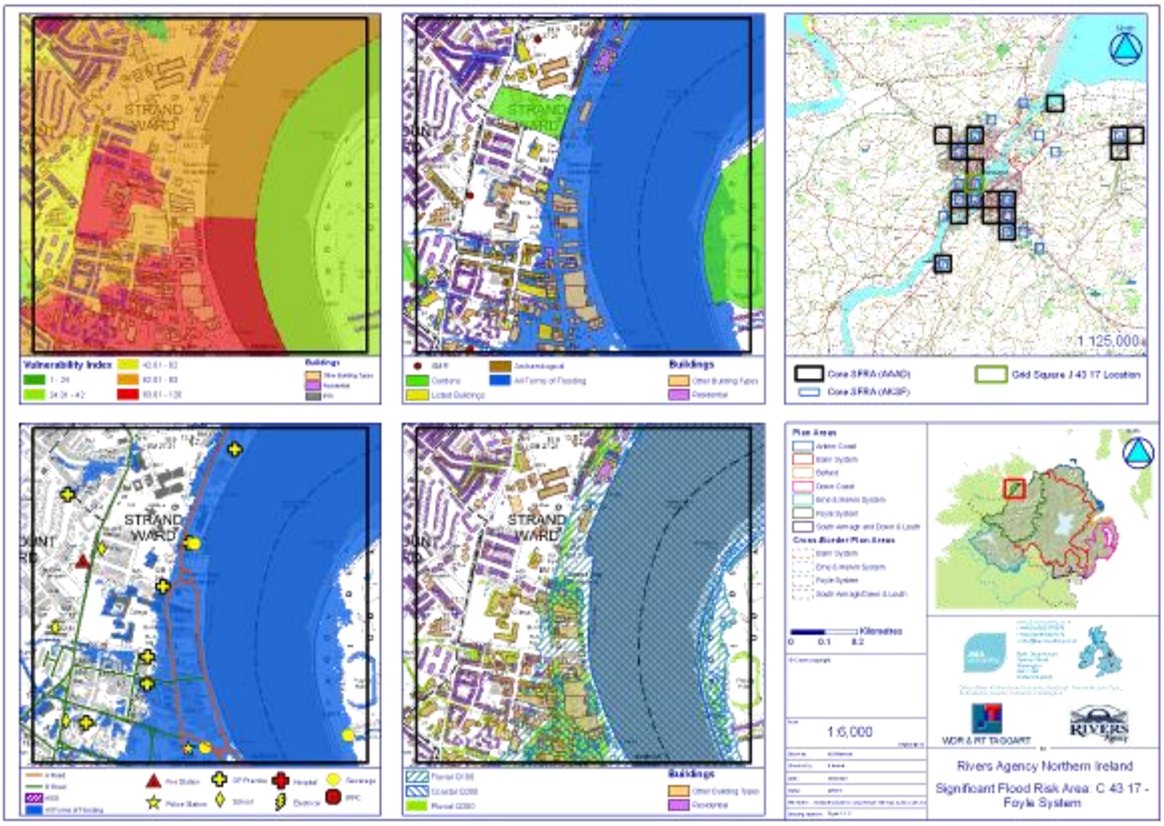


Figure G-4: Detailed flood source and receptor comparison for example Core SFRA Louth & South Coast J0826

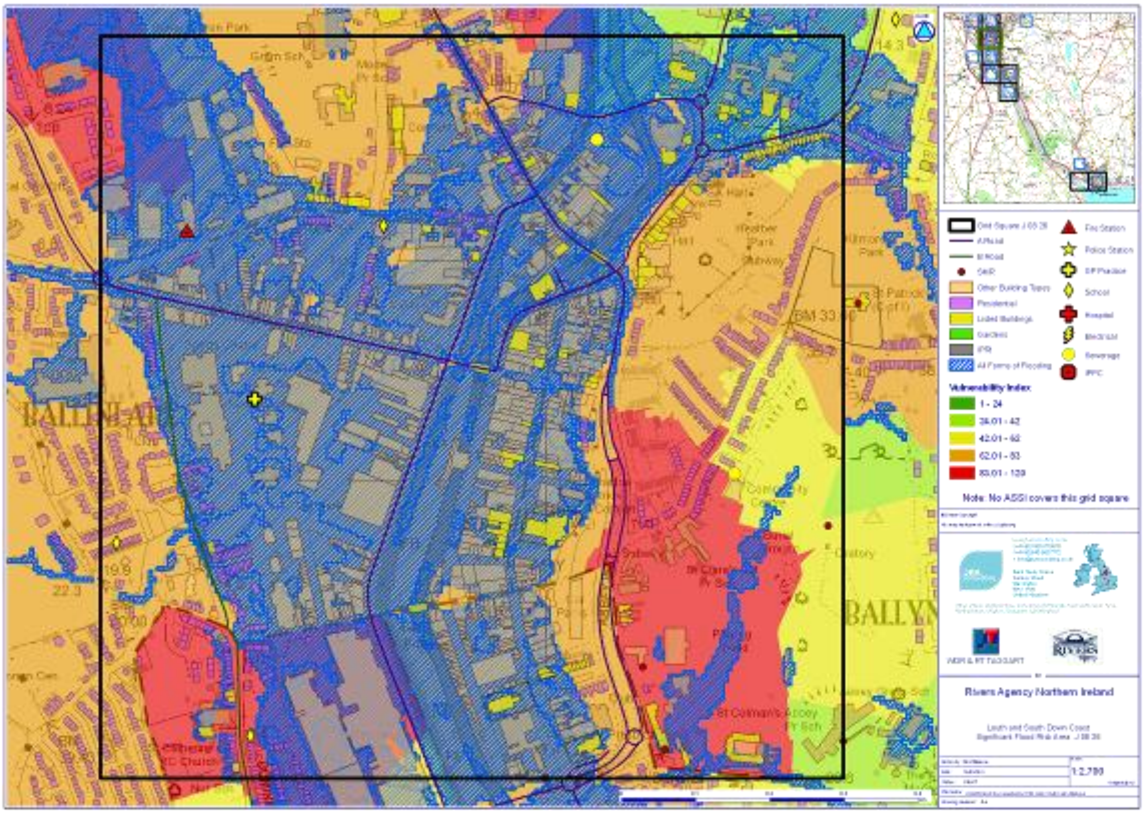
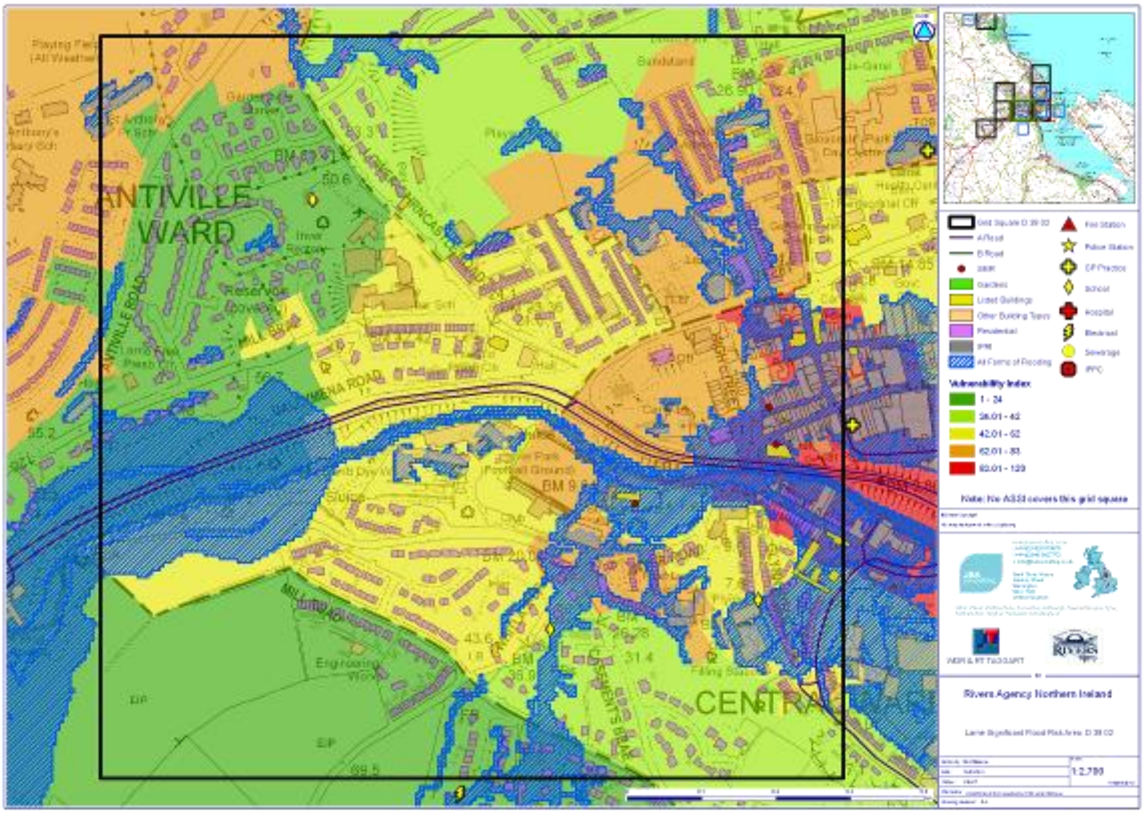


Figure G-5: Detailed flood source and receptor comparison for example Core SFRA Larne D3902



H. Assessment of Geomorphological sensitivity

H.1 Introduction

This appendix summarises the work that was undertaken to conduct a broad scale assessment of river reaches within Northern Ireland to identify those which are potentially at risk from significant sedimentation and deposition. The assessment has used a range of GIS tools including the JBA Consulting in-house ArcGIS package and the Watershed Toolbox. The Watershed Toolbox can be used to analyse the characteristics of a river network by splitting it up into a series of short river segments and then analysing the characteristics of each river segment in terms of the underlying digital datasets that might influence geomorphological activity such as drift maps or land classification. The analysis highlights stretches of watercourse with the greatest susceptibility to deposition, and the results were included in the maps in Appendix F.

H.2 Data Available

The following data was available for the assessment:

- Detailed river network of Northern Ireland
- Bare Earth DTM covering Northern Ireland made up of LiDAR and NextMap data
- Land Cover Map 2000
- CEH QMED data for entire river network
- Rivers Agency Flood Zones
- Google Earth

H.3 Pre-processing of river network data

The river network layer topology was ‘cleaned’ before it could be analysed using the Watershed Toolbox. As the study area covers the whole of Northern Ireland, the river network had to be split into catchments in order to make each dataset manageable. Six hydrologically independent drainage areas were used to derive six subsidiary river networks for which the following stages of analysis were carried out.

The polylines representing the river network were 'snapped' to ensure that individual polylines were connected properly at confluences and other joins. A flow direction was set for each river reach within the network. This was undertaken automatically using the flow direction filter which added arrows are to each river section to indicate the flow direction. Rivers were then inspected manually and if necessary their direction was corrected.

The Watershed Toolbox analyses the characteristics of a river network by splitting it up into a series of short river segments and analysing each river segment individually. The cleaned river network was therefore split into 500m segments, which is the standard reach length for river habitat assessments. Each river segment was then updated with ‘flows into’ and ‘receives flow from’ columns showing connectivity.

H.4 River Segment Analysis

The next stage of the analysis involved classifying the river segments based upon geomorphological variables. There are a number of variables which could be considered in the analysis but this was limited by data availability.

The variables that have been considered in this analysis are:

Gradient – a measure of the steepness of a channel. Steep reaches tend to have greater ability to transport sediment than shallow gradient reaches. Shallow gradient reaches are potential sites of sediment accumulation. The toolbox calculates the average channel gradient of each river segment based upon underlying DTM data. The DTM grid used in this analysis was at a 10m resolution which is deemed appropriate for the size of the area being considered.

Stream Power - expresses the rate at which energy is dissipated against the bed and banks of a river. It is calculated using the equation $\Omega = \rho g Q S$, where Ω is the stream power, ρ is the density of water (1000 kg/m3), g is acceleration due to gravity (9.8 m/s2), Q is hydraulic discharge (m^3/s), and S is the channel slope. The channel gradient also calculated by the Watershed Toolbox feeds into this equation as it represents channel slope. QMED values at the centre of each river segment are required for this calculation, QMED data from CEH for the Northern Ireland river network was available for this analysis. Generally, the higher the stream power the more likely the river is to have the potential to erode and transport sediment, low stream power may suggest that a river does not have sufficient energy to erode and transport sediment.

Land use – land management can influence the stability of the bed and banks of a river. On improved grassland livestock grazing may cause poaching and river bank instability and in woodland areas, dense root networks help to stabilise river banks. The percentage length of each segment flowing over each type of land use given in the CEH Land Cover Map 2000 (LCM 2000) is calculated. Each land use type is ranked in terms of its potential susceptibility to geomorphological activity.

Drift Geology - the material that underlies a river segment partially controls the stability of the bed and banks of the river. Rivers underlain by rock have the least susceptibility to erosion, whilst rivers underlain by blown sand or alluvium have the highest susceptibility to erosion. The percentage length of a segment flowing over each type of drift geology is calculated using the river segment analysis tool. Each type of drift geology has been assigned an instability score by JBA that is based upon the shear strength of the composite material and the Hjulstrom curve.

H.5 Stream Power

Stream power was calculated for each 500m river segment using the QMED data and calculated gradient values; this produced a highly detailed analysis of stream power over a large area. To determine the more regional changes in stream power across the river network, the network dataset was split into 5km segments using the toolbox and stream power was then calculated for each of these.

Once stream power had been calculated for each 500m river segment using the QMED data and calculated gradient values, the original river network dataset was split into 5km reaches using the toolbox. Stream power was then calculated for each 5km river segment. Each 5km segment overlays 10 of the original 500m segments derived from the river network. The stream power value calculated for a 5km segment represents the average stream power across the reach of 10 500m segments that it overlays. For each 500m segment, the overlaying 5km stream power value was subtracted from its own stream power value. If the resulting value for a 500m segment is negative it shows that the reach has a lower stream power than the average across the longer 5km reach of which it is part and indicates that deposition could potentially occur here.

H.6 Land Cover

The land cover analysis within the toolbox calculates the percentage of each river segment flowing over each land type in the Land Cover Map 2000. Each segment is assigned an instability score based upon the composition of land uses underlying it. The frequency distribution of the reach instability scores in the catchment is then divided into statistical quartiles with each segment being assigned a value of 1, 2, 3 or 4 depending upon which quartile it falls within based upon the calculated land instability score. Segments within the upper quartile (ranked 4) are likely to be the most unstable.

H.7 Drift Geology

The drift geology analysis is similar to the land cover analysis. The percentage of each river segment flowing over each drift geology type is calculated using the 250k superficial geology layer for Northern Ireland. An instability score is assigned to each reach and the scores are sorted into quartiles with the upper quartile representing segments that are most likely to be unstable in terms of geomorphology based upon geology.

H.8 Geomorphological Activity Index

The instability scores from the land cover and drift geology analysis were then used to calculate a Geomorphological Activity Index (GAI) which sums the individual instability scores to create a combined index to highlight the river reaches that are most likely to be active in terms of geomorphology.

Segments with a GAI score of 4 (most likely to be geomorphologically active) were then compared with the segments that had a stream power score of less than -20. Segments which had both of these attributes were considered to be the 'worst case' reaches in terms of their susceptibility to sediment deposition. Flood risk may be increased where reaches are most susceptible to deposition.

H.9 Refining Outputs

The validity of the results of the geomorphological analysis was investigated using Google Earth. The initial iteration of the analysis was based upon stream power and land cover only as drift geology data was not available at this point. A shapefile of the river segments with a stream power value of -50 or lower and a land instability score of 4 was converted into a 'kml' file and imported into Google Earth. Aerial photos of a selection of these river sections were examined to see if they contained depositional features such as shoals, minor bars, extensive bars and vegetated islands. A spreadsheet summary of the check was maintained. The aerial photo available on Google Earth for each river segment investigated was assigned a quality score from 1 to 5 where 1 represented very poor quality and 5 represented excellent quality as the photo quality influenced how well features could be identified.

Using 50 as the threshold value combined with a land cover classification of 4 identified highly segmented river reaches with the potential for deposition. In reality, long stretches of river would have the potential for deposition and this would decrease and increase steadily along river channels. Therefore a second iteration of the analysis was undertaken, this time the drift geology data was also available and was used to inform the assessment.

The percentage of each river segment flowing over each drift geology type was calculated using the 250k superficial geology layer for Northern Ireland. Quartile instability analysis was then performed on segments in the upper quartile are most likely to be unstable in terms of geomorphology based upon geology. The instability scores from the land cover and drift geology analysis can then be used to calculate a Geomorphological Activity Index (GAI) which sums the individual instability scores to create a combined index to highlight the river reaches that are most likely to be active in terms of geomorphology.

Segments with a GAI score of 4 (i.e. most likely to be geomorphologically active) were then compared with the segments that had a stream power score of less than -20 which was chosen as a more acceptable threshold than -50 in order to include more reaches with potential for deposition. Segments with a GAI score of 4 and a stream power score of -20 or less were considered to be the 'worst case' reaches in terms of their susceptibility to sediment deposition. Flood risk may be increased where reaches are most susceptible to deposition.
Segments assigned a GAI score of 4 and a stream power of less than -20 were identified within Google Earth to verify the existence of depositional features at their location as they were identified by the analysis as prone to deposition. Reaches were checked for the existence of the following depositional features such as:

- Gravel shoals
- Minor bars
- Extensive bars
- Vegetated islands

Reaches upstream and downstream of the river segments highlighted as being prone to deposition by the analysis were checked in Google Earth to determine whether they appeared to have more, less or the same amount of depositional features as the reach that had been highlighted through the analysis.

Another iteration of the analysis was undertaken using river reaches with a land instability score of 4 and a stream power value within the 1 percentile of the negative stream powers. This combination of variables was not much better in identifying key areas prone to deposition than the 'land instability score of 4 and stream power value of less than -50 iteration' and was therefore not taken forward.

H.10 Conclusions

Once the analysis had been refined and the drift geology data included within it, the method for highlighting areas prone to deposition became more robust. One of the main limitations of the data and processing was that 16% of the reaches within Northern Ireland were classified as having no gradient by the Watershed Toolbox. This occurred where the LiDAR level at the upstream extent of a 500m river reach was lower than the LiDAR level at the downstream extent, rather than assigning a negative gradient value, a value of -999 was applied to such reaches by the watershed tool. If this analysis were to be further refined this would be a key issue to address. In the current assessment this has mostly removed river reaches from the lower land parts of catchments nearer to the sea as these have lower gradients. Unfortunately due to the lower gradients they are the reaches where deposition is most likely to occur.

The river reaches picked out in this broad scale study with a GAI score of 4 and a stream power value of less than -20 give an indication of the watercourses most prone to deposition across Northern Ireland. It should be recognised that these are not the only reaches prone to deposition across Northern Ireland but where reaches are highlighted it could be that the surrounding area may have depositional issues contributing potentially to flood risk. Similarly where isolated reaches have been picked up by this analysis, it is unlikely that deposition only occurs within the 500m reach highlighted. In reality it would cover a longer length of river.

This analysis provides a broad-scale analysis approach to give an indication of where deposition is an issue in Northern Ireland and could be used to focus further, more detailed studies of deposition and flood risk in key areas based on the spatial distribution of river segments prone to distribution.

A shapefile of the river reaches with a GAI value of 4 and a stream power value of -20 or less was created and a sample of this output for Foyle System Sub-plan Area is illustrated in Figure E-7.