A SPATIAL UNDERSTANDING OF SIGNIFICANT FLOOD RISK IN NORTHERN IRELAND USING SOCIAL, ECONOMIC AND ENVIRONMENTAL FLOOD RISK METRICS BASED ON FLUVIAL, COASTAL, PLUVIAL AND HISTORICAL FLOODING

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Abstract
This paper reports on Phase 1 of a project to deliver a spatial understanding of areas of significant flood risk for Northern Ireland to inform a Preliminary Flood Risk Assessment (PFRA) under Articles 4 and 5 of the EC Floods Directive. The Directive requires the identification of areas where '*potential significant flood risk exists or might be considered likely to occur*', and emphasises historical events. To define flood risk, spatial information is required on potential sources of flooding (e.g. fluvial, coastal); pathways to receptors (e.g. defences, digital terrain model); the receptors (e.g. buildings) and their vulnerability. It is planned to progress Phase 2 of the PFRA for the rest of Northern Ireland using Phase 1 as the model, and once completed, it will all go to public consultation.

The Rivers Agency recently completed fluvial and coastal flood outlines for 3 probability events, and has historical outlines, which are all key to spatial understanding of flood risk. However, the Directive indicates the need to consider other sources of flooding. Recent flash flooding events have generated large damages, and recognising the significance, the Agency commissioned the production of pluvial outlines as part of this project.

In Phase 1, the fluvial, coastal, pluvial and historical outlines were queried for three pilot areas of Belfast, Newtownards and Omagh against a base-data of: building polygons; critical infrastructure and services (e.g. schools); IPPC sites; environmental sites; land cover; the National Census and derivatives including vulnerability and economic deprivation indices. A wide range of flood risk metrics were derived including: numbers of properties flooded; areas flooded; lengths of infrastructure flooded; *annual average* economic and agricultural damages. These flood risk metrics were derived over a national 1km grid to give a 'patchwork quilt' using the categories of social, economic and environmental flood risk over the pilot areas for the different sources of flood risk. Phase 2 will include additional data for cultural heritage not available for Phase 1. This type of visualisation has proven to be a powerful tool, and would also benefit spatial strategies and appraisals to direct development to lower risk areas.

Introduction

The EU Floods Directive recognizes the importance of sustainable management of flooding and aims to reduce the adverse consequences for human health, the environment, cultural heritage and economic activity. To this end, this paper reports on Phase 1 of the Northern Ireland PFRA which uses a top-down analyses of the spatial distribution of social, environmental and economic flood risk using flood risk metrics (or indicators). The use of flood risk metrics was recommended in recent government guidance on undertaking Regional FRA (DCLG, 2008) and a report for OPW (Adamson et al, 2008, OPW, 2008), where they were considered to '…facilitate a transparent of whether or not a particular location is subject to significant flood risk'. Data quality assessment and availability can limit the effectiveness of this approach, although the Directive states that the PFRA should be 'based on available or readily derivable information'. Additional drivers for inclusion of flood risk indicators range from a means of understanding and communicating current and future levels of flood risk, or to identify high-risk locations in order to determine the appropriate levels of flood warning (Adamson et al., 2008). This of course needs to be coupled with an appreciation of flood risk from all sources at a national scale and in relation to historic flooding:

Fluvial flooding: There are 6866 km of designated watercourse in Northern Ireland with 10% or 63,000 properties in the 1% AEP fluvial or 0.5% AEP Coastal floodplain (Rivers Agency, 2008), with 50% of these having some level of protection. Northern Ireland has one of the largest run-off per unit areas in the British Isles and a substantial number of rivers with flat lower reaches (DOE, 2008) with the potential for flood risk.

Pluvial flooding: Given the potentially high percentage runoff rates, there is clearly an increased potential for flash flooding from rapid surface water runoff of the kind witnessed in August 2008 (the most extreme rainfall since records began) and in July 2007. During the 2007 event, over 374mm rain fell over Northern Ireland, and nearly 50mm fell in 1 hour in East Belfast (estimated to have an AEP of 0.2% to 0.3%), affecting over 400 properties (Smyth et al., 2008). For the purpose of this project, pluvial flooding is considered to encompass gully and drainage exceedance or blockage and to some extent water building up because of high levels in receiving watercourses.

Coastal flooding: Coastal flooding is infrequent in Northern Ireland but is typically characterised by flows that are more rapid, increasing the potential hazard over river flooding (DOE, 2006).

Groundwater flooding: Groundwater flooding is uncommon in Northern Ireland (DOE, 2006). It occurs over and around aquifers where underlying geology is highly permeable with high capacity to receive and store rainfall.

Flooding from impounded water bodies: The Rivers Agency are commissioning a strategic investigation into the potential flooding from impounded water bodies.

Methodology

The approach taken was to first establish what geo-located data was available on social, environmental and economic receptors in Northern Ireland, and assess quality and formatting. The data was then queried using a bespoke ArcGIS tool, Flood Risk Lab[1] (metrics), in relation to whether it was predicted to be flooded according to the different available flood outlines. Flood risk metrics were then defined, the simplest being for example the number of flooded properties inside the 1% AEP fluvial outline for a given area of interest. For Northern Ireland, there was a considerable amount of base-data available, along with 6 fluvial and 6 coastal flood outlines, associated with 3 different design events with and without climate change. The Rivers Agency also commissioned the production of a map of areas susceptible to surface water flooding, and this was undertaken as part of the project to generate 2 pluvial outlines (present day and climate change). In addition some historical flood outlines and a defended area outline were available. The combination of base-data and the multiple outlines resulted in a wealth of flood risk metrics, requiring detailed spatial interpretation.

The process clearly required the definition of different 'sub-areas' over which to compare and visualise the flood risk metrics. At the national scale statistics such as '10% of properties are in the floodplain' can be defined, but this says little of how flood risk is distributed within the floodplain. At the local scale, uncertainties in the flooding outlines stemming from hydrology and hydraulic modelling mean that using an individual property or street would imply a level of precision that cannot be justified. A range of sub-areas at which to disaggregate flood risk were considered, but the use of a 1 km fixed grid of Northern Ireland had the benefit of being unchanging, with a constant area to allow like-for-like comparison without the need for area normalisation, and the misconceptions that can arise from visualisation of non-uniform areas (even when normalisation has been undertaken). The following base-data was used to derive the flood risk metrics over the 1km grid of Northern Ireland:

Base Data

Sources:

- Fluvial 10%, 1% and 0.1% AEP outlines with and without climate change;
- Coastal 10%, 0.5% and 0.1% AEP outlines with and without climate change;
- Pluvial outlines for predicted 0.5% AEP with and without climate change;
- Historical Outlines.

Pathways:

- OSNI 5m grid National Digital Terrain Model (DTM);
- 2m LiDAR data for Phase 1 pilot areas;
- Merged OSNI 5m and LiDAR degraded to 5m;

[1] FRiL is the JBA Consulting suite of flood risk analysis software developed in ArcGIS

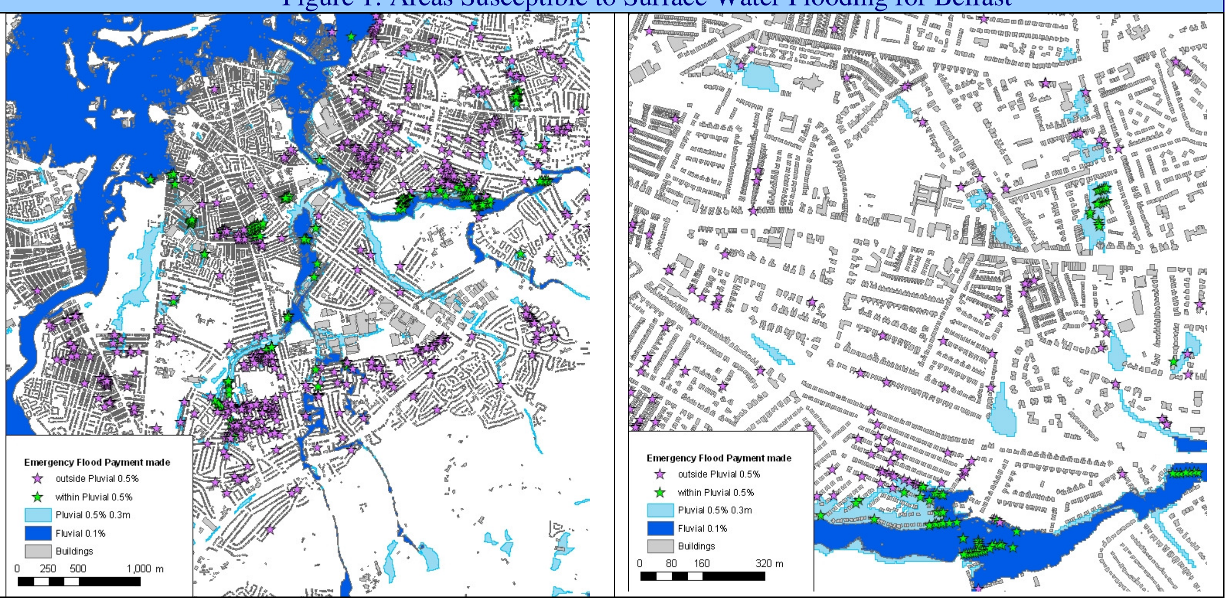
- Flood defences (and areas benefitting from defence);

Receptors:

- Building polygons (divided into 11 property types);
- Land Cover data;
- OS roads layer;
- Railway Line layer;
- Sewage treatment works;
- Electricity substations;
- Integrated Pollution Prevention and Control (IPPC) sites;
- Emergency Services (fire, police, hospital, GP surgeries);
- Census data (vulnerability and economic indices at Census Output Area).

The pluvial outlines above were derived using the blanket rainfall approach, whereby a design storm profile is used to add water to the DTM, and water is routed using a 2D raster-routing model JFLOW-GPU. This approach was piloted (see Hankin et al., 2008) in the Defra Making Space for Water Strategy, and has been used to produce the Areas Susceptible to Surface Water Flooding Map for England and Wales[2]. Figure 1 compares the new outline with the properties flooded and although the zoomed out figure on the left show a reasonable capture rate (green stars), the zoomed in figure on the right shows how the clusters of properties flooded (pink stars) outside the outline are often quite close to it. There are of course other potential sources of flooding via the drainage and sewer pathways that are not *explicitly* modelled which could have given rise to the observed flooding.

Figure 1: Areas Susceptible to Surface Water Flooding for Belfast



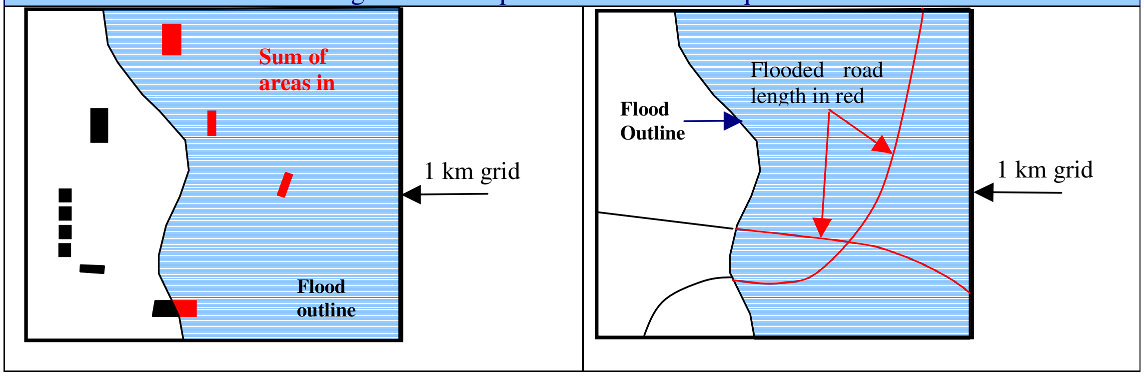
Flood risk metrics

The different flood risk metrics defined were based on the following fundamental metrics, some examples of which are shown in Figure 2:

- Count or number of receptors (number of properties flooded, number or critical services affected);
- Area of receptor flooded (Environmental site / building polygon);
- Length of linear receptor flooded (roads / railways).

[2] JBA Consulting used their cluster of GPU (graphics cards) PC's and 2D hydraulic routing model, JFLOW-GPU, to generate this map for the whole of England and Wales

Figure 2: Example Flood risk metric queries

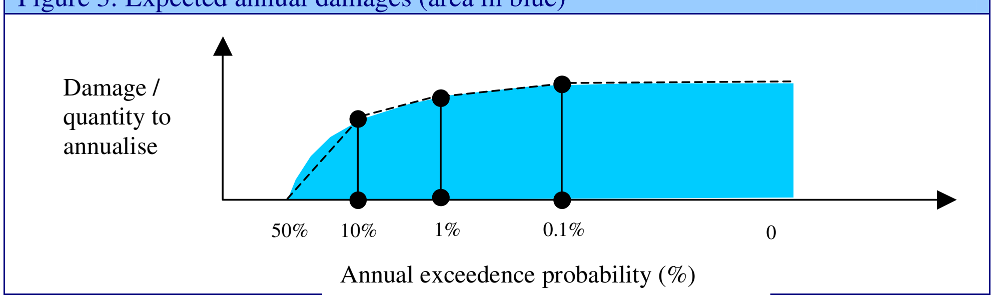


The key flood risk metrics were generated using Flood Risk Lab (metrics) which generated:

- Numbers of different building types flooded in any outline;
- Numbers of flooded critical services split into different categories and totalled;
- Numbers of people at risk;
- Number of IPPC sites flooded;
- Lengths of critical infrastructure flooded (roads and rail);
- Areas of flooded buildings;
- Area of flooded ASSI;
- Total and annual average damages of flooded buildings and agricultural land;
- A weighted vulnerability indicator and an economic deprivation index that account for the numbers of flooded properties of different vulnerability or deprivation scores;

These metrics were then combined with auxiliary data in Flood Risk Lab (metrics) such as the damage incurred per square metre when a property floods. This required detailed analysis of the building polygons and land classification, and followed methods from the Multi-Coloured Manual (Penning Roswell et al, 2005)

Figure 3: Expected annual damages (area in blue)



- The damage per unit area for different building classifications available for NI;
- The damage per unit area for different land classifications using the Land Cover 2000 maps;
- A vulnerability index based on a principal component analysis of 9 indicators of vulnerability at the Output Area level for the National Census[3]

The different metrics were then annualised to give the expected annual damages or 'expected flood risk metric', as described by Figure 3.

[3] This type of vulnerability analysis, which takes into account correlations between the Census variables, was developed by JBA Consulting for their work on National Vulnerability Map of England and Wales

Results

The summary information of the different metrics is given in Table 1 for the different flooding sources that were queried, and numerous figures such as Figure 4 were produced to give a spatial appreciation of flood risk. Similar figures were also derived for historic flooding outlines, to help understand the effectiveness of the whole approach, when comparing with local knowledge.

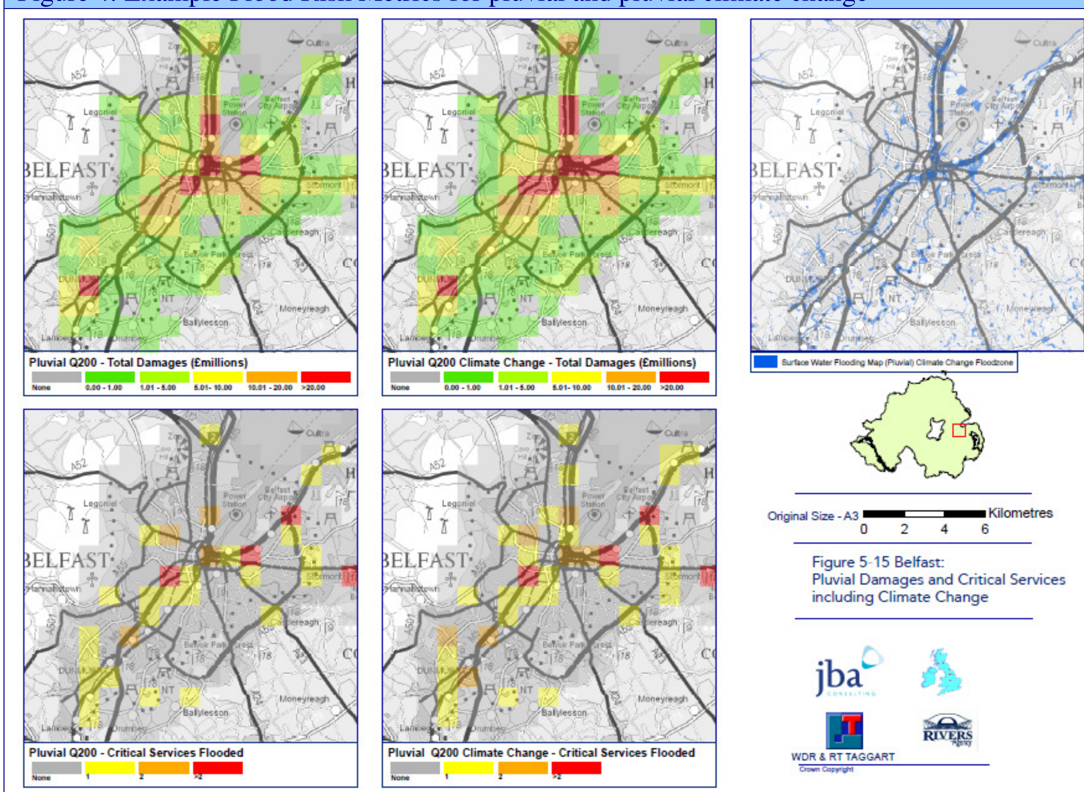
Table 1 and Figure 4 reveal an important characteristic of climate change sensitivity, in that the pluvial sensitivity appears to be much greater than for fluvial or coastal when comparing most metrics, including expected damages and expected number of people and critical services flooded.

Table 1: Totals of flood risk metrics (Phase 1 Areas) with climate change (cc) sensitivity

Flood Risk Metric	Annualised Fluvial	Annualised Fluvial with CC	Annualised Coastal	Annualised Coastal with CC	Pluvial	Pluvial with Climate Change	Defended Area Outline
Property Damage	£181.6m	£188.1m 3.6%	£92.7m	£100m 8.0%	£ 717m	£877m 22.3%	£170 m
Agricultural Damage	£29.6k	£30.2k 2.0%	£26.4k	£26.7k 1.1%	£ 124.1k	£144.6k 16.5%	£27.8k
Number of People at Risk	7394	7621 3.1%	3111	3322 6.8%	26503	32255 21.7%	5298
Vulnerability	1172	1224.2 4.5%	399.8	416.8 4.3%	7646	8042.9 5.2%	782.4
Economic Deprivation	533	556.3 4.4%	190	195.3 2.8%	3531.1	3718.4 5.3%	347.4
Critical Services	18	19 5.6%	8	9 12.5%	75	90 20.0%	27
Critical Infrastructure	47.8 km	49.5 km 3.6%	27.4 km	29.1km 6.2%	223.1	263.4 km 18.1%	25.9km
ASSI Area	0.22km^2	0.23 km^2 4.6%	3.58 km^2	3.48 km^2 -2.8%*	2.53 km^2	3.03 km^2 19.8%	0.02 km^2
Number of IPPC Sites	1.6	1.6 0.4%†	0.96	1.0 5.1%†	4	4 0%†	3

* this negative is because the coastal climate change flood outline is clipped differently to the non-climate change outline in the sea
† insignificant

Figure 4: Example Flood Risk Metrics for pluvial and pluvial climate change



Discussion

The multiple sources of flooding and large amount of base-data resulted in a large number of flood risk metrics, for instance, the results 'geodatabase' has feature classes with over 80 attributes for each flood outline that was queried. The annualisation process reduces the number of metrics by two thirds, but the information was further condensed by taking a spatial union of groups of flood risk metrics pertaining to key types of flood risk. To do this, the annualised metrics were scaled using a location/scale normalisation to give Social (includes human health), Economic (includes economic activity) and Environmental (to include cultural and heritage in Phase 2) Flood Risk Metrics, with and without climate change. The following relationships show how this was achieved for each category (all variables have been annualised and normalised):

Social

{vulnerability + economic deprivation + number of people + critical services + road lengths + rail lengths}fluvial + { }coastal + { }pluvial

Environment

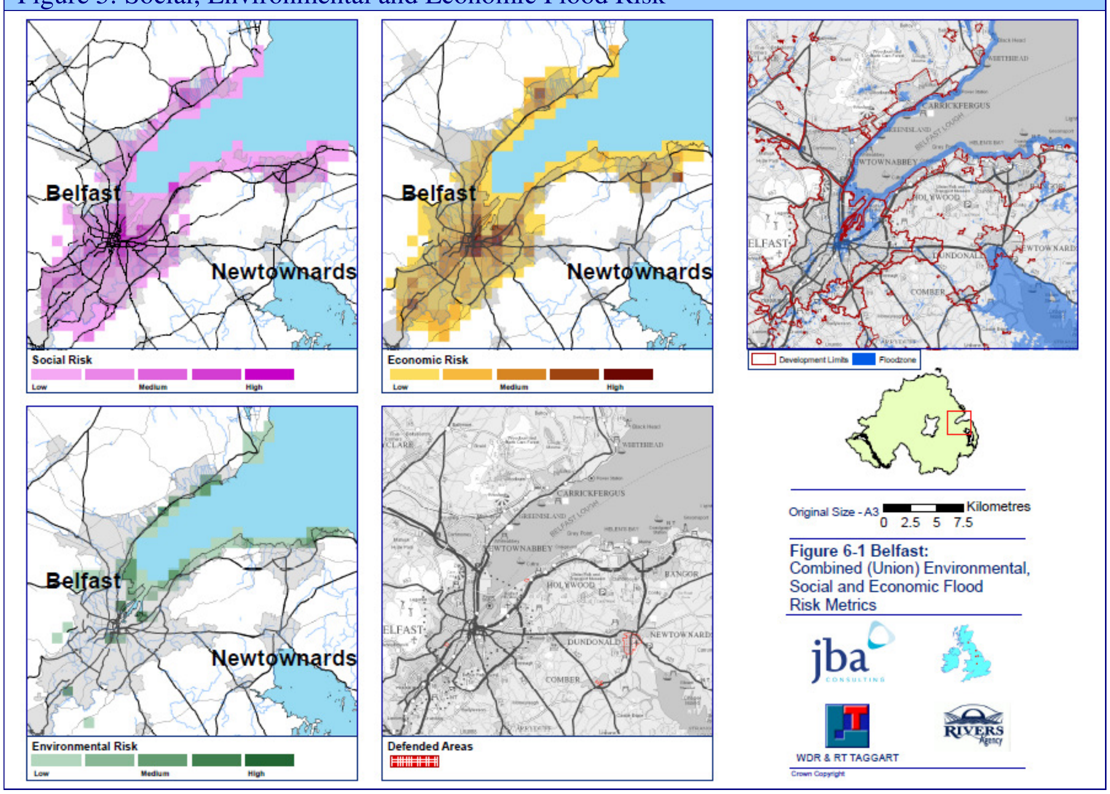
{flooded ASSI area + No. IPPC sites}fluvial + { }coastal + { }pluvial

Economic

{property damage + agricultural damage + road lengths}fluvial + { }coastal + { }pluvial

The spatial distribution of these flood risk metrics was then exported geographically to communicate social, environmental and economic flood risk on the 1km grid of the Phase 1 areas. Figure 5 shows darker shades for greater risk.

Figure 5: Social, Environmental and Economic Flood Risk



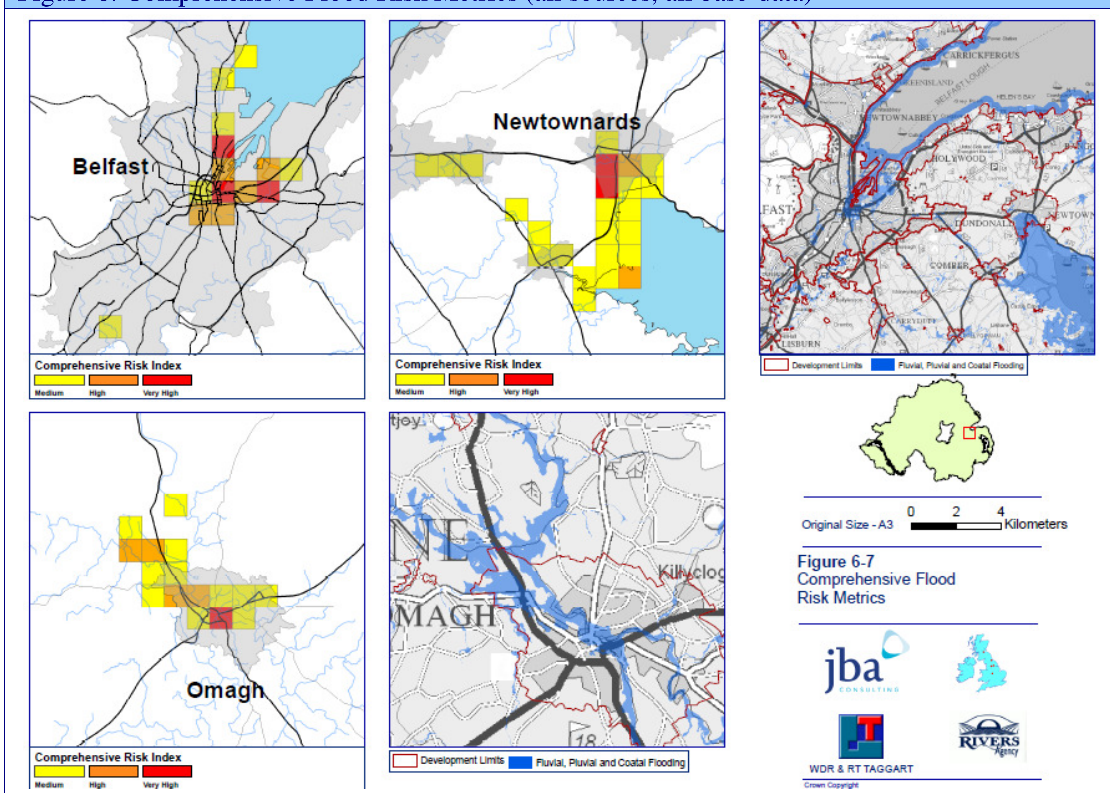
The top ten worst 1km grids were ranked using each of the social, environmental and economic metrics, the worst performing receiving a score of 10 down to 1. These scores were then added together give and overall ranking of flood risk from any category – to give the Comprehensive Flood Risk Metric in Table 2 and Figure 6.

Table 2: Belfast Areas of Significant Flood Risk

Grid Square	Social (ranking)	Environmental (ranking)	Economic (ranking)	Comprehensive Flood Risk Metric (combined Score based on rank)
J 34 76	6	10	6	22
J 34 74	10		10	20
J 36 74	9		9	18
J 36 75	4	9	3	16
J 34 75	8		7	15
J 34 73	7		8	15
J 35 74	5		5	10
J 33 73		8	2	10
J 40 88	3		4	7
J 29 68		7		7

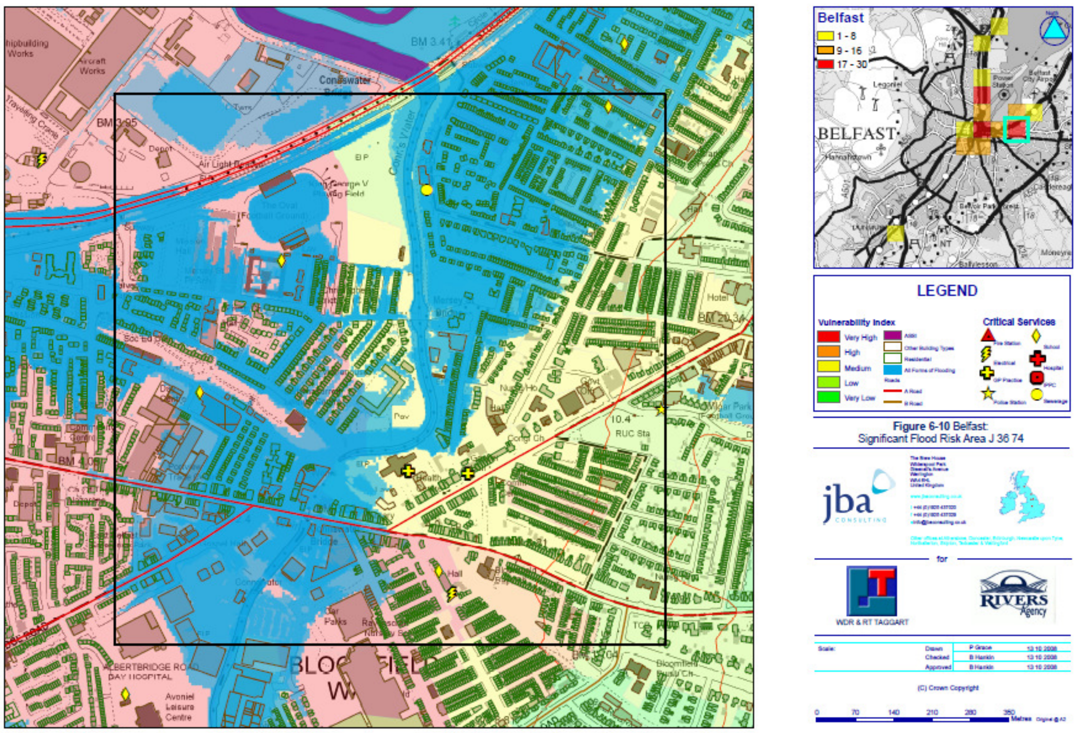
The areas with the greatest flood risk are highlighted in red in Table 2 and Figure 6. The threshold can clearly be set at different levels, although a value of 16 was used since this would capture anything that was ranked 5th worst for all 3 categories.

Figure 6: Comprehensive Flood Risk Metrics (all sources, all base-data)



Finally the grid squares that were identified as the worst using the whole approach were examined in detail, with all outlines and receptors. Figure 7 is typical of these 'red' grid squares, with a large number of residential properties flooding in an area of town that was considered to have a relatively high vulnerability and level of economic deprivation. Commercial buildings are shown as flooded along with key critical services (mainly in yellow) and critical infrastructure (red). Environmental risk is measured by area of flooded ASSI or IPPC sites, and these were present in some, but not all of the 1km grids that were identified.

Figure 7: Significant Flood Risk



Conclusions

This paper provides a new methodology for the appraisal of the spatial distribution of significant flood risk in Northern Ireland to meet the requirements of the EU Floods Directive, whilst taking into account best practice and the widest available set of base-data. The methodology is transparent, allows for inter-comparison of different areas, and allows for an appraisal of flood risk that is in-line with current thinking on sustainable flood risk management by considering social, environmental and economic flood risk. This was demonstrated by application of the approach to the three Phase 1 pilot areas of Belfast, Omagh and Newtownards, for which fluvial, coastal, pluvial flood risk and the impacts of climate change were considered, along with an analysis of defended areas and areas historically flooded. The following conclusions are made:

- A set of flood risk metrics were derived from a comprehensive base data for Northern Ireland using an ArcGIS query tool, Flood Risk Lab (metrics). This was applied to a regular 1km grid of Northern Ireland to give a spatial understanding of flood risk at an appropriate scale for a Preliminary Flood Risk Assessment.
- The spatial distribution of the key flood risk metrics was analysed, with maps indicating areas most at risk from fluvial, coastal, pluvial flooding along with the defended flood risk and the spatial distribution of historical flood risk for events where flood outlines were available;
- Climate change sensitivity to flooding damages is greatest for pluvial flooding (estimated at 22%), out of all the sources examined. This is almost in proportion to the 20% extra volume of water that

was added. The number of impacted critical services also increases by 20% averaged over the three pilot areas. Coastal flooding appears to be more sensitive to climate change than fluvial for most types of risk, including the number of people at risk;

- The spatial distribution of flood risk from historical flooding was also examined, to compare with historical accounts pertaining to the recorded severity of the impacts. This will provide a level of validation of the flood risk metrics approach.
- The *Flood Risk Metrics* were combined into groups representing social, environmental and economic flood risk from fluvial, pluvial or coastal flooding, to allow for a sustainable appraisal of flood risk over the three pilot areas ;
- A *Comprehensive Flood Risk Metric* was made using a ranking method, to give an understanding of areas of significant flood risk from any of the three categories for any of the flooding sources that were considered.
- The 1km grid squares with the highest comprehensive flood risk metric were analysed and were shown to contain severe flooding impacting key social, environmental and economic receptors;
- It is recommended that the spatial distributions of the Social (including human health), Economic (including economic activity) and Environmental (to include cultural heritage in Phase 2) Flood Risk Metrics and the Comprehensive Flood Risk Metric, along with the tables of the most impacted 1km grid cells are used to inform the Preliminary Flood Risk Assessment for Northern Ireland. This should be supplemented with the spatial distribution of historical flood risk, which required further corroboration with historical reports in Phase 2 of this project.

References

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