A further check of the Type 1 model results was undertaken by comparing the model outputs for the 1% AEP (1 in 100 annual chance) event with the results of the National Pluvial Mapping study carried out by HR Wallingford on behalf of the Office of Public Works[9].

Figure 3.6 overleaf presents a comparison of the maximum flood depths predicted by the Type 1 model and the Rapid Flood Spreading Model (RFSM) used in the National Pluvial Mapping study. It is apparent that there are differences in outputs between the two model results.

This comparison of the model results should be interpreted with caution as both models are based on different input datasets (e.g. rainfall depth, allowance for drainage infiltration) and use different grid resolutions, numerical algorithms and assumptions to compute the routing of the rainfall runoff. Overall taking account of the different approaches used, the following points should also be noted:

- The RFSM, being built on a national scale, is necessarily coarse. It divides the country up into Impact Zones (IZ), and routes flow through these zones, averaging the velocity for each IZ. Runoff flow is calculated at each IZ boundary and flood depth is calculated on a 10m grid within each IZ, based on the average velocity computed. As such, the RFSM does not take into account diffusion of momentum through hydraulic friction and instead runoff flow is routed through the IZ 10m grid, flowing to the lowest point.
- The simplified physics within the RFSM computational engine explain why the runoff flow predicted by the RFSM fills the depressions at the Grand Canal/River Dodder area to a significant depth (shown in Figure 3.6). It ignores roughness and inertia and simply cascades through the model to fill depressions that the TUFLOW model, which does take into account roughness and inertia, predicts would not fill, as roughness and obstacles mean that the flow does not necessarily reach the lowest point.
- Also a major difference between the RFSM and the TUFLOW Type 1 models is the allowance for drainage infiltration. A uniform value of 15mm/hr is assumed in the RFSM for urban areas. This is a much higher rate in comparison to the drainage capacity based rates for the actual drainage system used in this study and shown in Table 3.3.

In summary the processes behind the two models vary in detail and approach (parameters used); one provides a national level pluvial screening of areas at potential risk of pluvial flooding (using the RFSM based approach), and the Type 1 Model provides a more detailed assessment at a city-wide scale (taking into consideration local factors and parameters).

[9] H.R. Wallingford, Flood Risk Assessment and Management Programme, National Pluvial Screening Project for Ireland, Report EX 6335, 2.0, November 2010

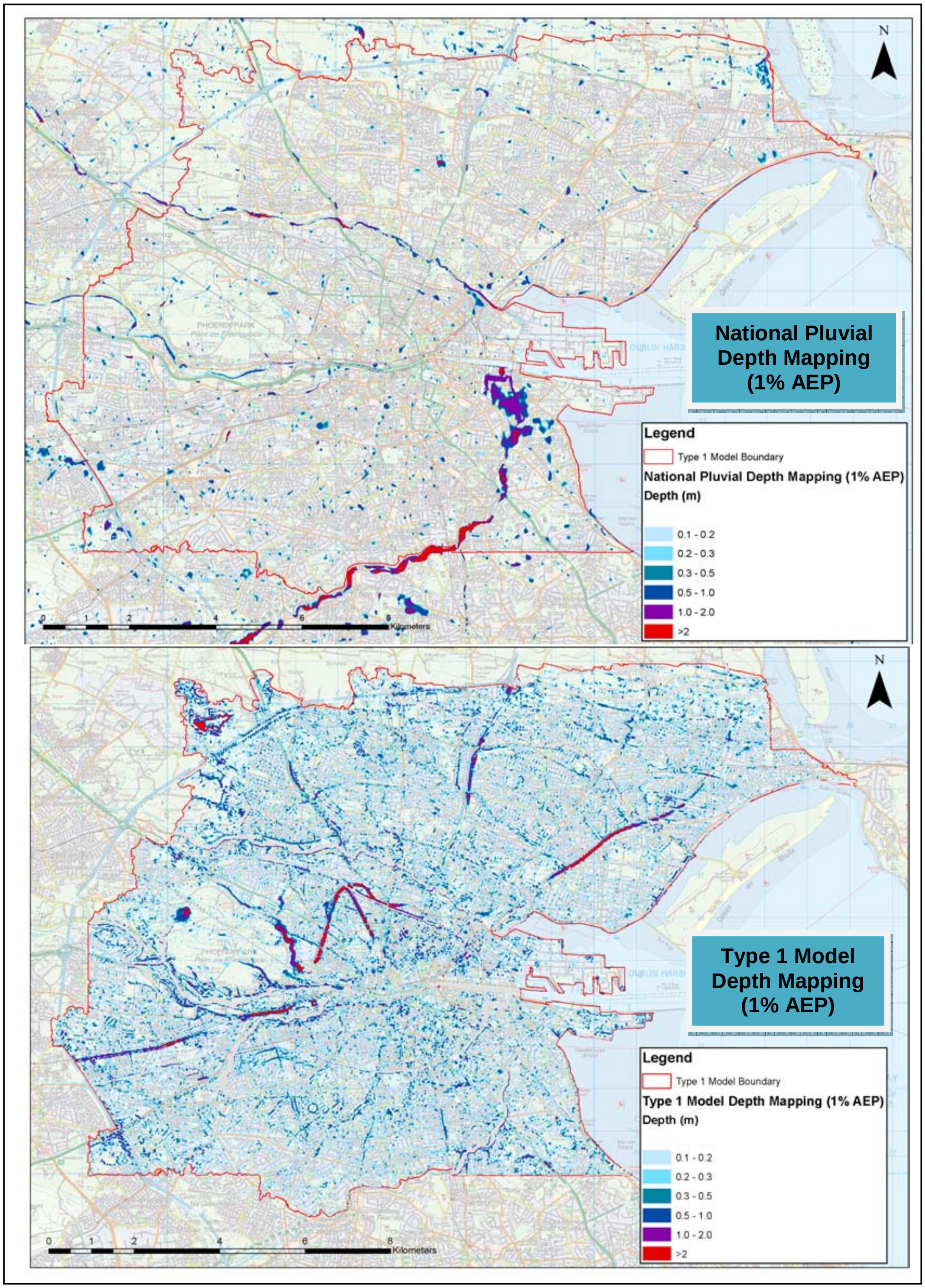

Figure 3.6: Maximum flood depths predicted by the Type 1 models and RFSM model during a 1% AEP (1 in 100 year annual chance) event

3.4 Design Event Runs

Following the verification exercise, the Type 1 hydraulic models were run to simulate pluvial flooding associated with a series of storm events with various durations and annual probabilities. Climate change was also considered for the 1% annual exceedance probability event. It should be noted that the magnitude of the 1% AEP event with climate change is approximately equivalent to a 0.5% AEP event (1 in 200 annual chance).

Rainfall profiles associated with these events were derived using the methodology described in Section 3.2.

Table 3.6 shows the matrix of rainfall events (annual probability and duration) run with the hydraulic models.

Table 3.6: Matrix of rainfall events run with the Type 1 Hydraulic model

Type 1 Model	Annual Probability and Duration											
	10% (1 in 10)			2% (1 in 50)			1% (1 in 100)			1%+Climate Change (1 in 200 equivalent)		
	1hr	3hr	5hr	1hr	3hr	5hr	1hr	3hr	5hr	1hr	3hr	5hr
Model 1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Model 2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Model 3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Model 4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Model 5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Model 6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

3.5 Key Assumptions and Limitations

Model grid resolution

The model accuracy is a function of the base DTM (LiDAR data) and the resolution of the model grid. The model uses a regular 25m cell size with breaklines to represent key hydraulic features which may have a significant impact on the propagation of rainfall runoff across the study area. However, smaller features at sub-cell scale (e.g. narrow streets, kerbs, and building basements), which may also influence shallow surface water flow, are not explicitly represented.

Rainfall infiltration

The Type 1 model schematisations account for a limited representation of the urban drainage systems that essentially rely on an estimation of the drainage network capacity translated into a loss factor applied to the rainfall. Whilst this assumption is deemed appropriate for the level of detail required by this study, the current model schematisation does not represent the complex interaction that might occur between the overland flow and the drainage network, or the spatial and temporal responses of the drainage system to events of different magnitudes.

Model performance

Issues associated with model convergence are common when using the Direct Rainfall approach over a large 2D model domain that contains steep slopes. All simulations were run using the Double Precision build within TUFLOW to ensure model convergence within acceptable tolerances (+/-1% of Mass Balance error). However, in very steep areas where the 25m grid does not allow for a smooth representation of the slope, instead introducing step changes in the level between one cell and the adjacent one, some convergence issues remained. This resulted in the model overstating hazard rating and depth values at very steep areas and therefore depth and hazard rating values should be interpreted with caution in such locations.

Key learning outcomes from Section 3 with regard to **City-wide Pluvial Modelling** are as follows:

- The Type 1 Hydraulic Modelling approach is described including the data used to construct the model, and the development of the city-wide model based on a 25m grid cell size.

- The key aspects of the model are described including the assumptions and approach with regard to how the rainfall is applied to the model, and key modelling parameters. This includes:
  - the capacity of the drainage system;
  - infiltration into the ground;
  - hydraulic friction of different land surfaces for the overland flow component; and
  - model boundary conditions including the rainfall input to the model and the downstream boundary conditions, for example, a river or the sea at the downstream end of the model.

- The performance of the model is verified against two flood events – August 2008 and July 2009. The model is then used for different design events which cover a three Annual Exceedance Probabilities (AEP) (10%, 2% and 1%) and three storm durations (1 hour, 3 hours and 5 hours).

SECTION 4 CITY-WIDE PLUVIAL FLOOD HAZARD AND RISK MAPPING

4.1 City-wide Pluvial Flood Depth and Hazard Rating Maps

Type 1 Pluvial Flood maps were produced using the hydraulic model outputs. TUFLOW produces results such as maximum depths, velocity and hazard rating as 2D grids of 12.5m resolution. These outputs were directly used to produce the flood depth and hazard rating maps associated with the model runs scenarios listed in Table 3.6 (see Section 3.4).

Flood Depth maps were produced assuming a threshold flood level of 100mm for clarity and to avoid reporting all surfaces modelled as being flooded. In addition, flooding along watercourses, main rivers and canal corridors, as well as the coastal fringe, was ‘masked’ and not considered as pluvial flooding.

It should be noted that model output data is available to show areas of flooding less than 100mm if required. However 100mm is considered as a practical threshold above which pluvial flooding could start, or result in significant impacts. Some impacts could still however occur at shallower depths.

It is important to distinguish between Flood Hazard mapping and Flood Hazard rating mapping. Flood Hazard, as defined under Article 6(4) of the EU Directive 2007/60/EC on the assessment and management of flood risks (the Floods Directive), explicitly lists Flood Extent, Flood Depth and Flow Velocity as elements to be included in Flood Hazard mapping. Flood Hazard rating combines depth and velocity together, as described below,

Flood hazards to people can be defined as the potential for a flood event to cause harm to those affected by it. In most cases, injuries or deaths occur when flooding is deep or fast flowing or both. In the United Kingdom, Defra (Department for Environment, Food and Rural Affairs) has developed a methodology to determine the likely hazard that flooding poses to people, based on depth and velocity[9]. This methodology has been applied to the City-wide modelling results to determine where pluvial flooding may be severe enough to potentially cause a risk of injury or loss of life.

According to the Defra methodology, the Flood Hazard rating is calculated as a function of depth and velocity:

$$\text{Flood Hazard Rating} = d * (v + n) + DF$$

Where:

d	= depth of flooding (m)
v	= velocity of flood waters (m/s)
n	= a constant of 0.5
DF	= debris factor (see below)

[9] Defra (2008) Supplementary Note on Flood Hazard Ratings and Thresholds for Development Planning and Control Purposes

The debris factor represents the potential that deep, fast flowing flood waters might mobilise loose objects and carry them along within the flow. This can be a major source of injuries during flood events. Mobilisation of debris is heavily dependent on the dominant land use, as well as the depth and velocity of the flooding. For this study, taking into account that the modelled area is a predominantly urbanised area, the values adopted for the debris factor are detailed in Table 4.1.

Table 4.1: Debris Factor definition

Depths (d)	Debris Factor
0 to 0.25 m	0
0.25 to 0.75 m	1
d > 0.75 and/or v > 2	1

The Flood Hazard Rating score calculated using the above formula is converted to degrees of flood hazard, as shown in Table 4.2.

Table 4.2: Flood Hazard classification defined by Defra

Flood Hazard Rating Threshold	Degree of Flood Hazard	Hazard to people classification
< 0.75	**Low**	**Caution** – "Flood zone with shallow flowing water or deep standing water"
0.75 – 1.25	**Moderate**	**Dangerous for Some** – includes children, the elderly and the infirm
1.25 – 2.00	**Significant**	**Dangerous for Most** – includes the general public
> 2.00	**Extreme**	**Dangerous for All** – includes the emergency services

Examples of the Depth, Velocity and Hazard Rating outputs based on the modelling undertaken are displayed in Figure 4.1 overleaf. With specific regard to the requirements of Article 6 (4) of the Floods Directive, Flood Hazard mapping is required for extent, depth and velocity. For flood extent, this may be taken as the "outline" around those cells that are shown to have a flood depth of greater than 100mm in Figure 4.1.

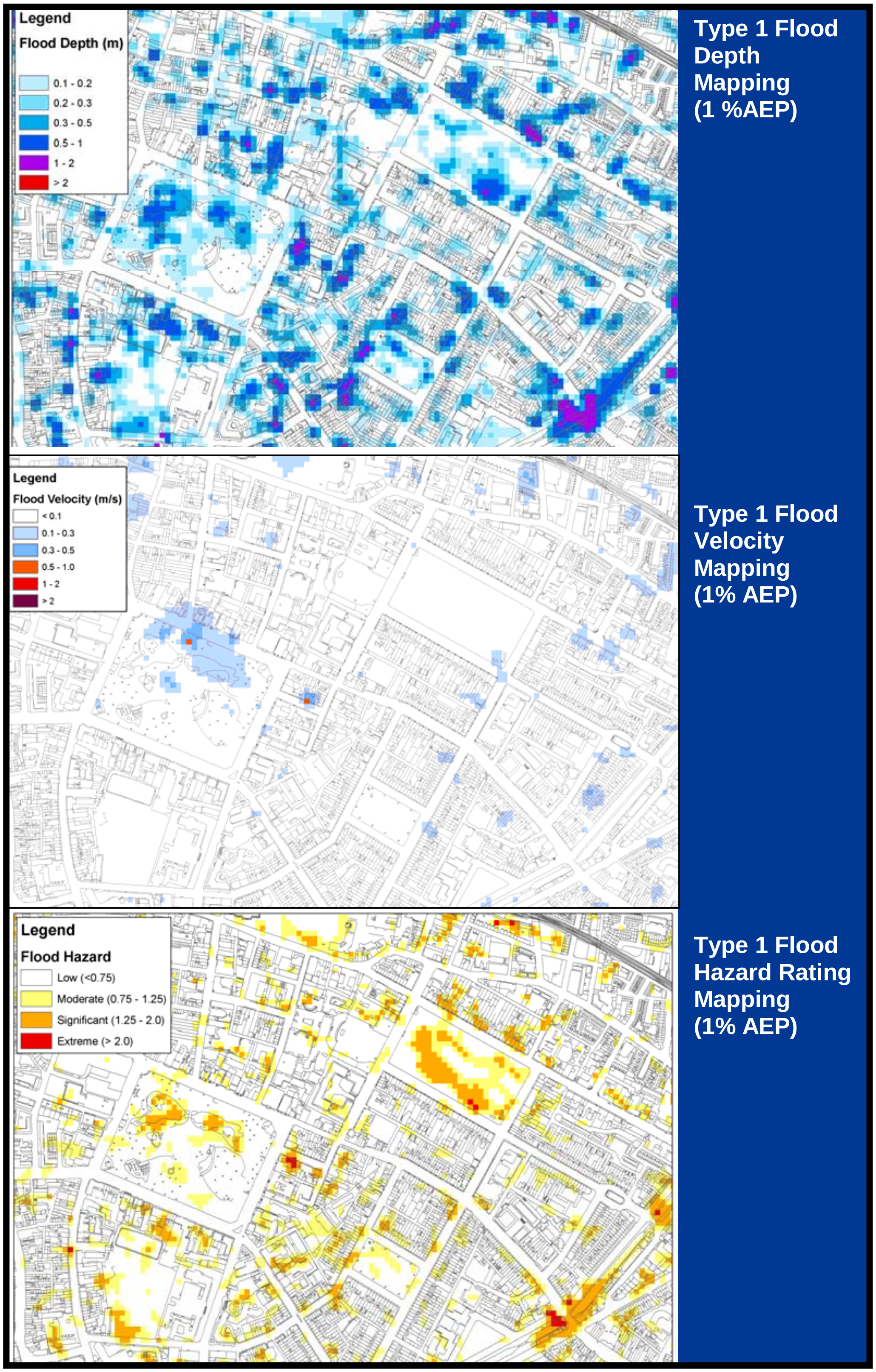

Figure 4.1: Examples of the Type 1 Pluvial Mapping[10]

[10] These examples demonstrate how the pluvial maps correspond to the provisions of Article 6(4) of the EU Directive 2007/60/EC on the assessment and management of flood risks.

4.2 City-wide Pluvial Flood Risk Maps

The City-wide risk assessment was based upon the susceptibility of receptors to pluvial flooding during a particular design event (see Section 3.4). This was achieved using Geographical Information System (GIS) tools by first assigning pluvial flood depth values derived from the Type 1 mapping to individual receptors.

The following receptor groups were appraised and used in conjunction with the Type 1 Depth mapping as the basis of the risk assessment:

- Risk to Human Health and Critical Infrastructure
- Risk to the Economy
- Risk to the Environment and Cultural Heritage

Pluvial Flood Risk Maps for each receptor group are presented in Appendix V2-F.

4.2.1 Receptor Groups

Risk to Human Health and Critical Infrastructure

The postal GeoDirectory and supporting datasets provided by Dublin City Council were used to determine those properties and critical infrastructure potentially at risk from pluvial flooding. Table 4.3 provides a breakdown of the individual receptors identified.

Table 4.3: Human Health and Critical Infrastructure Individual receptors

Human Health & Critical Infrastructure Individual Receptors	
Individual Properties	Airports
Nursing Homes	Railway Network
Residential Care Homes	NRA Roads
Schools	Pumping Stations
Rail Stations	Electricity stations / sub-stations
Health Centres	Telecommunication stations / sub-stations
Garda Stations	Water / Wastewater Plants
Fire Stations	Electricity / Oil / Gas stations / sub-stations
Hospitals	Indicative *basement* locations (source GDSDS[11])
Civil Defence Offices	

An important consideration which was assessed separately as a stand alone receptor group was the presence of *basement* properties throughout the Dublin City area. Using the available information from the GDSDS project (basement polygons used in the drainage assessment), the indicative locations of basements were included in the risk assessment. It should be noted that this dataset does not necessarily represent actual basement locations and is not the result of a detailed basement assessment or survey across Dublin. We recommend that further refinement and augmentation of the basement database is undertaken.

[11] Greater Dublin Strategic Drainage Study (GDSDS)

Risk to the Economy

Flood damages were estimated using the Jacobs Flood Depth Estimation System (FDES) software, which determines an economic valuation of flood damages for each individual property within the study area, for each design rainfall event considered (10%,, 2%,, 1% & 0.5% AEP)..

FDES is a GIS tool which uses the TUFLOW Type 1 depth results and points of interest (properties, critical infrastructure etc) to calculate a corresponding economic damage per cell using the methodologies and values set out in “The Benefits of Flood and Coastal Defence: A Manual of Assessment Techniques” - “Multi-Coloured Manual” (MCM)[12].

The economic damages are derived using the damage values for each of the four design rainfall event considered, to give Present Value (PV) damages. This includes both tangible and intangible damages, both of which were accounted for during the development of the Risk to Economy Maps. OPW guidance for the National Catchment Flood Risk Assessment and Management (CFRAM) Studies recommends that intangibles are assumed as equal to the contributing damages of residential properties and small businesses. However, this study did not specifically identify small businesses and therefore the contributing damages of each residential property were doubled to account for intangible damages. Due to the level of assessment (City-wide) and the model output resolution, this is considered to be an appropriate approach for this level of evaluation.

Risk to the Environment and Cultural Heritage

Table 4.4 provides a breakdown of the environmental and cultural heritage receptor datasets provided by Dublin City Council (or downloaded from relevant internet sources on behalf of Dublin City Council) which were used to determine those sites potentially at risk.

Table 4.4: Environment and Cultural Heritage Individual receptors

Environment & Cultural Heritage Individual Receptors
IPPC Licensed sites
WFD Water Status (Less than good)
Natura 2000 sites
Natural Heritage Areas (including proposed)
Record of Monuments and Places
Sites of Monuments Record
Record of Protected Structures
National Inventory of Architectural Heritage
Architectural Conservation Areas

[12] Flood Hazard Research Centre, The Benefits of Flood and Coastal Defence: Techniques and Data for 2003, Middlesex University (known as Multi Coloured Manual (MCM)).

4.2.2 Methodology

Overview

The City-wide Pluvial Flood Risk Maps were produced using the 3hr duration storm event, i.e. the duration determined as the most representative of critical conditions for Dublin City. Figure 4.2 below summarises the two risk assessment methodologies applied to the Human Health & Critical Infrastructure and Environment & Cultural Heritage receptor groups, and that applied to represent risk to Economy.

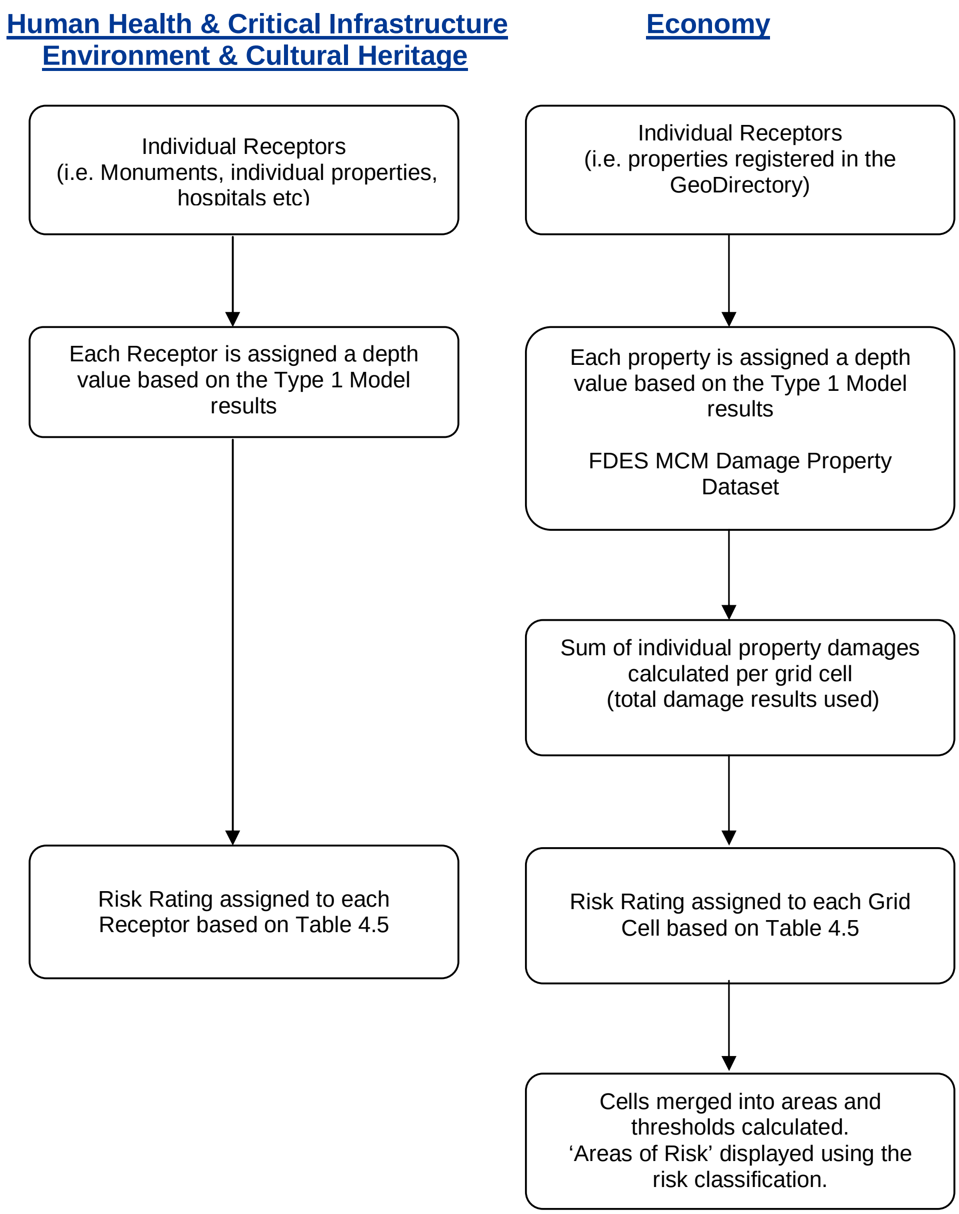

Figure 4.2: Pluvial Flood Risk Mapping Methodology

Table 4.5 outlines the risk ratings defined for the City-wide pluvial flood risk assessment. Type 1 Model Depth outputs available for the 10%, 2%, 1% and 0.5% AEP events were used to help define these risk ratings which were applied to the receptors and grid cells (as indicated by Figure 4.2).

Table 4.5: Outline of Flood Risk Categorisation

Risk (Rating)	Receptor Groups		
	Human Health & Critical Infrastructure (refer to Table 4.3 for receptors).	**Environment & Cultural Heritage (refer to Table 4.4 for receptors).**	**Economy**
High Receptor Risk (3)	Receptor with a flood depth **>100mm for a 10%AEP** event.	Receptor with a flood depth **>100mm for a 10%AEP** event.	25m square cell generates a total economic PV damage value **>€300,000.**
Medium Receptor Risk (2)	Receptor with a flood depth **>100mm for a 1%AEP** event.	Receptor with a flood depth **>100mm for a 1%AEP** event.	25m square cell generates a total economic PV damage value between **€35,000 and €300,000.**
Low Receptor Risk (1)	Receptor with a flood depth **>100mm for a 0.5%AEP** event.	Receptor with a flood depth **>100mm for a 0.5%AEP** event.	25m square cell generates a total economic PV damage value >**€0 and <€35,000.**
Marginal Receptor Risk[13] (0)	Receptor with a flood depth of **<100mm during all events**.	Receptor with a flood depth <**100mm during all events**	25m square cell generates a **nominal** economic PV damage value

The pluvial flood risk for each of the receptor groups is illustrated using these risk ratings (refer to Appendix V2-F for the City-wide Pluvial Flood Risk Maps).

Considerations Specific to Receptor Groups

Human Health & Critical Infrastructure and Environment & Cultural Heritage

As indicated by Figure 4.2, this process involved 3 basic steps; plot receptors, assign pluvial flood depth values using outputs from the Type 1 modelling and then classify each receptor using the risk ratings tabulated in Table 4.5. This was applied to all receptors with the exception of the indicative basement locations.

To consider the indicative basement locations in the City-wide pluvial flood risk assessment, the basement polygons referred to in Table 4.3 were applied to the maps following the risk rating step. The presence of an indicative basement location triggered an increase in an existing risk rating to the next higher rating, either 'medium' or 'high' risk.

[13] "Marginal Receptor Risk" indicates a receptor or flood cell that has the potential to flood but does not fall into any of the above categories.

Economy

Risk to economy was assessed by collating the predicted value of economic 'damage' for individual properties into an overall damage value for an 'Area of Risk'.

Figure 4.3 illustrates an example of how 'Areas of Risk' are defined for the economic risk assessment process.

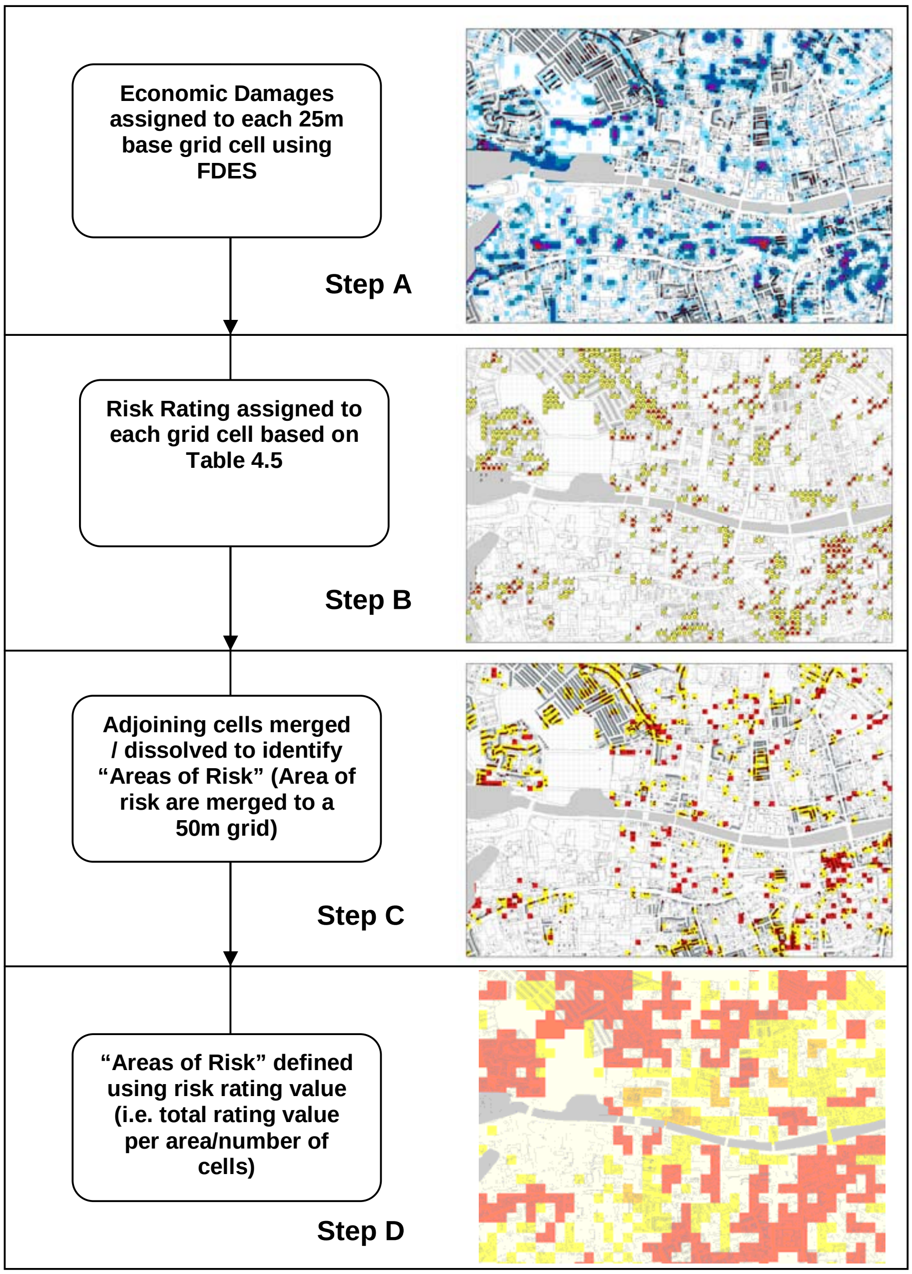

Figure 4.3 – 'Areas of Risk' Classification Methodology

As indicated above, the economic damages were assessed on a 25m grid basis with the total sum of the contributing damages from each property being assigned to each grid cell. It is important to note that the total PV damages results were used to calculate the damages within each grid cell.

Once risk ratings are applied to each 25m grid cell, the boundaries (50m) of the "Areas of Risk" were then identified by filtering out adjoining cells (excluding diagonal and individual cells) and merging the remaining cells to form an "area of risk".

This filtering was done by merging adjoining cells based on rating (as listed in Table 4.5) and spatial location (i.e. only adjoining cells with a risk rating ≥1 were merged into cell groups initially and a count field added to identify the number of cells per area). As a result, the merged output following Step B had cell groups which could be queried to exclude individual and diagonal cells based on cell count.

To identify a risk rating for each 'Area of Risk', the total sum of the individual cell rating values were divided by the total number of cells within the 'Area of Risk' boundary. These values are presented in Table 4.5 as High = 3, Medium = 2, Low = 1 and Marginal= 0.

Area of Risk classification =
total number of cells in group / sum of individual risk rating for each cell

The output from the above query allowed for the following threshold values[14] to be used to classify an "Area of Risk".

- Area Threshold: >2.2 (Area of High Risk);
- Area Threshold: 2 - 2.2 (Area of Medium Risk);
- Area Threshold: >0 - 2 (Area of Low Risk); and
- Area Threshold: =0 (Area of Marginal Risk).

The City-wide Pluvial Flood Risk Maps produced using the approach outlined above are provided in Appendix V2-F.

[14] The threshold values ranges produced reflect the limited number of risk rating values (i.e. 1, 2 or 3) as a result the output from the area of risk classification fell within the bands above.

Key learning outcomes from Section 4 with regard to **City-wide Pluvial Flood Hazard and Risk Mapping** are as follows:

- The approach to developing hazard and risk mapping on a city-wide basis is described. The model output produced includes **flood depth** and the associated **flow velocities** for the overland flow component of the model.

- The flood depth and the flow velocity outputs form the basis for identifying **flood hazard rating**. The additional consideration of debris which can be mobilised during a flood is also taken into account as this can increase the flood hazard rating. Flood hazard rating is defined as:

  Flood Hazard = depth x (velocity + 0.5) + Debris Factor

- **Flood risk** mapping is developed by considering the consequences of flooding to three receptor groups during a 3 hour rainfall event (the critical duration) as follows:
  - Human Health and Critical Infrastructure;
  - Economy; and
  - Environment and Cultural Heritage.

For each of these risk receptor groups, the risk is categorised as Marginal, Low, Medium or High. The risk maps produced are included in Appendix V2 E and F.

SECTION 5 CONCLUSIONS AND RECOMMENDED AREAS FOR DETAILED MODELLING

5.1 Conclusions of City-wide (Type 1) Modelling

The modelling approach adopted to produce hazard rating (with hazard being a function of flood depth and flow velocity) and risk maps appropriate to the scale of Dublin City Council's administrative boundary was based on flood routing calculation at 25m resolution (although depth and hazard rating maps have been produced at a finer resolution of 12.5m).

The modelling takes into account hydraulic friction, rainfall infiltration, allowance for below-ground drainage and obstacles. It aims to achieve a reasonable accuracy of prediction of flood extent, flood depths and hazard rating in the areas at risk of pluvial flooding appropriate for city-wide mapping. These results can be regarded as providing a reasonable indication of probable significant flood hazard and risk areas. However, as noted in earlier sections, flooding in urban areas is influenced by the capacity of the drainage system, particularly for low to medium storm events. Although the flooding locations for the 1% (1 in 100) annual probability event, and others, may well be reasonably represented using the Type 1 approach; complex rainfall runoff interactions with the drainage system and localised flood routing obstacles (kerbs, walls etc.) are not accounted for. The limitations of the city-wide modelling and mapping should be recognised and where investigation of flood risk in more detail is justified, these aspects can be considered further through more detailed 'Type 2' modelling and mapping (as documented in Volume Four for selected Pilot Areas).

The Type 1 Pluvial Flood Risk Assessment and Mapping indicates a high level of pluvial flood risk across many parts of Dublin with a large proportion of properties contributing potentially significant damages. The mapping also indicates that many receptors are currently at risk of pluvial flooding. A key consideration during the assessment was the presence of basements. When indicative basement locations were included in the appraisal (refer to Appendix V2-F) they triggered a significant increase in the number of areas of High Risk. There are however a number of limitations with the current indicative basement dataset and, given the importance of basement flooding, this justifies further review and augmentation of this dataset to refine the appraisal.

Selected Pilot Areas for Type 2 – Detailed Modelling

The City-wide Type 1 model results and maps were appraised with Dublin City Council representatives. As a result, five Pilot Areas within Dublin City Council's administrative boundaries have been identified for further detailed investigation of potential pluvial flood risk as part of the Dublin FloodResilienCity project. It is considered that further more detailed appraisal of these Pilot Areas will inform and guide appraisal in other higher risk areas across Dublin where more detailed assessment may be justified.

Table 5.1 outlines the details of each of the selected Pilot Areas and Figure 5.1 illustrates the model boundaries proposed for the detailed (Type 2) modelling and pluvial flood risk assessment. This detailed assessment represents the various processes involved more fully, further quantifies the estimated pluvial flood depth,