



# EU Interreg IVB FloodResilientCity Project

## Dublin City Report

### Interim Review and recommendations following the Dublin flood event of 24<sup>th</sup> October 2011



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## Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Background and Context	1
1.2	The Dublin Flood Initiative and Dublin FloodResilienCity Project	1
1.3	Report Structure	1
1.4	Drawings	1
<b>2</b>	<b>Overview of Events</b>	<b>2</b>
2.1	Introduction	2
2.2	Review of Forecasts and Warnings	3
2.3	Overall hydro-meteorological consideration	1
2.4	How the event unfolded on the ground	2
2.5	Probability of the October 2011 event	4
2.6	A comparison with past events	7
2.7	Why was flooding associated with the October 2011 event so great?	8
2.8	Event Conclusion	8
<b>3</b>	<b>Flooding Mechanisms and Impacts</b>	<b>9</b>
3.1	Types of Flooding	9
3.2	Flooding in October 2011	10
<b>4</b>	<b>Mitigation Measures</b>	<b>15</b>
4.1	The Basis for Identifying Mitigation Measures	15
4.2	Mitigation Measures	16
4.3	Additional Influencing Factors	24
4.4	Measures Identified for Each Administrative Area	26
<b>5</b>	<b>Conclusions and Recommendations</b>	<b>30</b>
5.1	Conclusions	30
5.2	Principal findings from data review	31
5.3	Recommendations	34
<b>Appendices</b>		
Appendix A	Drawings	
Appendix B	Radar Rainfall Information	
Appendix C	Hyetographs	
Appendix D	Probability of the event at each raingauge	
Appendix E	Flood Risk Mitigation Measures	
Appendix F	References	

# 1 Introduction

## 1.1 Background and Context

The following report reviews the extreme rainfall event of 23<sup>rd</sup> and 24<sup>th</sup> October 2011 and extensive flooding which occurred in Dublin City. It provides an evaluation of the event and flooding mechanisms, and outlines potential resilience measures for the proactive management of flood risk to the City which can be considered in the light of this event.

This report should be considered in the context of the Dublin Flood Initiative the Dublin FloodResilienCity Project and ongoing programmes of improvement works to the operation and maintenance of flood defence assets within the City.

There were over 1,100 reported instances of flooding within the City (recorded as of 28<sup>th</sup> November 2011). The flooding resulted in property damage, disruption to travel and tragically the death of one person in the City.

This review, and the conclusions and recommendations, are based on site visits which we undertook to key locations affected by the flooding; discussions with Dublin City Council staff; and on analysis of data available to Dublin City Council and provided to us up to 28<sup>th</sup> November 2011. Conclusions and recommendations have however been structured to give flexibility for subsequent revision of actions or responses that might be considered.

## 1.2 The Dublin Flood Initiative and Dublin FloodResilienCity Project

Over the years it has become apparent that Dublin faces a number of significant flood risks. Historically, it has been known that these include:

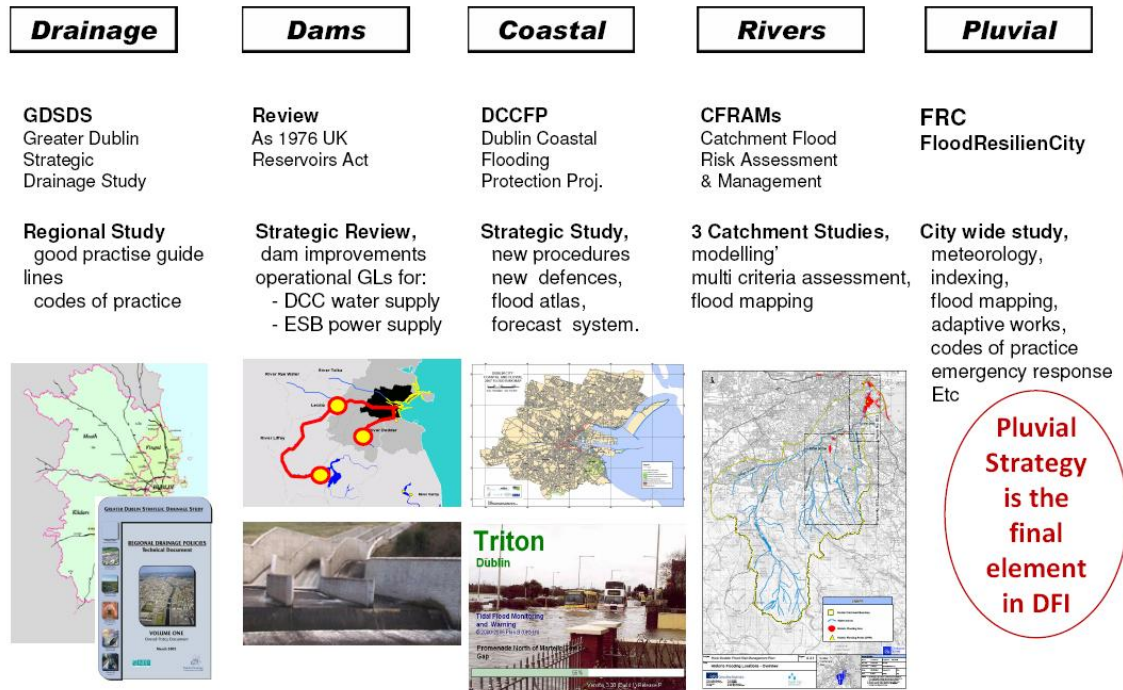
1. **Coastal** – flooding of areas adjacent to the coast or tidal estuaries.
2. **Riverine** – or ‘fluvial’ flooding due to river bank overtopping and/or flood defence collapse.
3. **Drainage** – flooding due to failure or inadequacies or flow exceedance (surcharging) of the drainage system.
4. **Dam Break** – flooding associated with dam failure, either actual failure or extreme discharge released from the dams when in danger of over topping. Rigorous inspection procedures are designed to minimise this risk.

Several events (notably in 2008, 2009), including this latest event (24<sup>th</sup> October 2011), have occurred when flooding was predominantly caused by the high intensity of the rain (sudden and extremely heavy), and before the runoff had the chance to enter any drainage network or watercourse system. Such flooding, which is characterised by surface flows and ponding is generally known as:

5. **Pluvial** or surface water flooding.

The collective strategy for managing all of these flood risks and combinations thereof is known as the **Dublin Flood Initiative**, or **DFI**.

The DFI proactively responds to the need to address flood risks and develop a unified and fully integrated flood risk management strategy. It also aims to raise the level of awareness and participation through policy makers, professionals and the general public. The DFI also recognises specific aspects of flood risk associated with garden flats and underground car parks.



**Figure 1.1: Dublin Flood Initiative**

**Dublin FloodResilienCity Project**

In the early 2000's Dublin City Council recognised that to successfully address flood risks Transnational<sup>1</sup> knowledge and shared experience at European level were required.

Dublin has benefited from being a participant in a number of EU Interreg<sup>2</sup> transnational projects. This involvement started with the EU Interreg Programme IIIB SAFER<sup>3</sup> project, which addressed the coastal flood risk.

Dublin is currently participating in the EU Interreg IVB Programme 2007/13 as one of eleven partner organisations, drawn from eight European cities, which form the **FloodResilienCity Project**.

The overriding aim of the Dublin work package programme in the FloodResilienCity Project is to assist in the development of a **Pluvial Flood Risk Management** strategy for Dublin.

<sup>1</sup> Transnational collaboration with other EU partner authorities and organisations.

<sup>2</sup> Interreg – an EU programme which promotes spatial harmonisation across member states and funds transnational projects intended to develop good practice templates for application across member states.

<sup>3</sup> Strategies and Actions for Flood Emergency Risk Management 2003 to 2008 – addressed the marine flood risk to Dublin & south Fingal coastlines.

**Pluvial flooding** (also known as surface water flooding) occurs when heavy rainfall results in water flowing across the ground surface and the capacity of local drainage (both natural and man-made) is overwhelmed – surface ponding occurs sometimes to a significant depth. The route the water takes and the depth of flooding will depend on local features and can be difficult to predict.

The FRC (FloodResilienCity) programme addresses Objective 2.2 of EU Interreg Priority 2 (Managing Resources & Risks) <sup>4</sup>

Overall the project aims at *‘integrating the increasing demand for more houses and other buildings in urban areas with the increasing need for more and better flood risk management measures’* in cities along rivers.



This will not only address the increasing flood risk from pluvial flooding to the city but will play a key role in meeting the wider Interreg IVB FloodResilienCity programme through the development of innovative approaches and techniques in pluvial flood risk management and considering trends in climate change impacts.

The project applies an integrated approach to sustainable flood risk management which has been developed and tested by the Scottish Government. This approach, known as the 4A’s Model, comprises the four key aspects to be addressed in flood risk management plans and policies in the partner cities: **Awareness, Avoidance, Alleivation and Assistance.**

Through the European Water Association (EWA) and the EC Working Group F (WGF), which advises on Floods Directive implementation issues, Dublin City Council has already supported European initiatives which aim to take forward understanding of pluvial flood risk across Europe and evolution of good management practice. These include participation in an EWA Expert Meeting on Pluvial Flooding and a questionnaire survey the results of which fed in to the WGF Workshop on Flash Floods and Pluvial Flooding and subsequent reporting.

The work programme under the Dublin FloodResilienCity is well advanced and this report aims to be consistent with possible outcomes from that project.

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<sup>4</sup> “To promote an innovative approach to risk management and prevention, in particular water management (effects of the high concentration of human activities in coastal areas and river valleys; impacts of sea level rise on coastal areas and flood risk; the marine environment) in the context of climate change.”

## 1.3

### Report Structure

This Report adopts the following structure:

**Section 2** – Overview of the flooding event of 24<sup>th</sup> October 2011.

- *Describes the hydro-meteorological (weather) event*

**Section 3** – Flooding mechanisms and impacts

- *Describes the impacts associated with the flooding for each administration area and the likely mechanisms of the flooding*

**Section 4** – Mitigation measures

- *Describes measures which can be considered to alleviate or reduce the flood risk based on the impacts of the October 2011 event*

**Section 5** – Conclusions and Recommendations

- *Summarises the main conclusions from data analysis of the flooding event and provides some key recommendations for the future*

## 1.4

### Drawings

The flood incidents shown in the drawings within this report are based on information received and represent all areas where flooding is known to have occurred (based on records as of 28<sup>th</sup> November 2011). The information displayed on these drawings, such as the specific type of flooding, may be altered in the light of additional post 28<sup>th</sup> November information.

It should also be noted that garden flat flooding has been identified where possible but does not necessarily include all instances where garden flat flooding has occurred.

Flood instances and other flood attributes are shown for each Dublin administrative area within drawings included in [Appendix A](#). City-wide summary plans are also included.

## 2 Overview of Events

### 2.1 Introduction

The flood event of the 24<sup>th</sup> October 2011 was caused primarily by two weather events. The first medium rainfall intensity event initially started at approximately 10am on the 23<sup>rd</sup> October, ending at approximately midnight on the 23<sup>rd</sup>/24<sup>th</sup> October. A second high intensity rainfall event followed from around 9am through to around 10pm on the 24<sup>th</sup> October. The following section outlines some of the detail behind these events. Some additional information on the radar data provided by Met Éireann is included in **Appendix B**.

The cause of the flooding on 23<sup>rd</sup> and 24<sup>th</sup> October was extreme rainfall which exceeded the capacity of the drainage system and local watercourses and in turn gave rise to a combination of pluvial and fluvial flooding.

It is currently not possible in advance to predict when, where and to what extent such flooding will occur. Met Éireann, in a post event analysis, have stated that:

*The limits on the available forecasting/ modelling systems do not permit the fine detail on the locations of the intense bursts of heavy rain that actually fell on 24 October in Dublin to be predicted by Met Éireann.*

It appears that in the period from 4pm up until 10pm on Monday 24 October 2011, when the worst of the rain ceased, cumulative amounts of typically between 60 and 90 mm of rain fell, indicating an average rainfall intensity of 15mm per hour sustained for between a four and six hour period. Rainfall of 60 to 90 mm over a four to six hour period is a very unusual occurrence.

Following flood events in recent years, much of Dublin City Council's resources have been put into flood investigations. In most cases these investigations have confirmed that the drainage network was overloaded and often surcharged with resultant flooding.

The urban drainage system of culverts, pipes and road drainage gullies has been constructed over the last 200 + years. Drainage networks will all flow full in a 1 in 1 to 1 in 5 annual chance (probability) rainfall event. In a more extreme event these will be surcharged up to road level where no more flow can enter through road gullies. In a 1 in 10 to 1 in 30 annual chance rainfall event and events higher than these, severe road flooding and property flooding will result.

Dublin City Council radically revised its gully cleaning programme in 2004, and this programme has proved to be very successful in dealing with varying amounts of rain right up to close on the 60 mm of rain that fell on 24 October 2011. The events of the 24 October 2011 and in particular the quantity of rain that fell in the short space of time from 4 to 8pm meant that the drainage network filled, became surcharged and did not allow further flows into the drainage system.

The probability of the combined rainfall events across the 23<sup>rd</sup> and 24<sup>th</sup> October, has been estimated to be in the order of a 1 in 100 annual chance in any one year in some locations and between 1 in 50 and 1 in 100 chance across some 80% of Dublin.

The design standard of much of the existing drainage system in Dublin is such that an event of this magnitude will inevitably result in flooding and that the resilience and emergency response procedures of the city are as important as the physical flood resistance measures in place.

## 2.2 Review of Forecasts and Warnings

The first warning of the impending heavy rainfall was issued by Met Éireann on the evening of Saturday 22<sup>nd</sup> October. This correctly indicated the period of rainfall, and the forecast for accumulations of 40-70mm over the period, although subsequently exceeded, these amounts in a forecast are indicative of very severe conditions. The initial warning was re-issued and updated during 23<sup>rd</sup> October, with a final update in the early evening (~18hrs) of 24<sup>th</sup> October, advising that 30-50mm had already fallen and a further 15-30mm was likely over the period up to midnight. These again are significant quantities to be included in a forecast. The issue of the final update closely followed the sudden surge of flooding reports received by Dublin City Council from 1700hrs onwards.

The preparations of forecasts are governed by the availability of the output from model runs. The available lead times for forecasts and warnings are inevitably constrained by a) the timing of model runs at 6-hour intervals (at 00, 06, 12 and 18hrs UTZ), and b) by the time taken for ingestion of incoming data, processing the data and model run time. Discussion with Met Éireann indicates that the standard time taken to produce the model forecast is approximately 2.5 hours. The spatial definition of model forecasts can be improved by running a high-resolution model, but these rely on boundary conditions from the local area model, e.g. HIRLAM, being available for a run to be made. Met Éireann are experimenting with a high-resolution model (Harmony), which they anticipate would add a further 1-1.25 hours on forecast output time. In a report on the analysis of a similarly complex frontal-convective event over Cornwall in 2010 (Reference 1), although the high definition models, such as the UK 4 km and 1.5m grid models did resolve localised high rainfall, it is pointed out that forecasting for specific small catchments and rivers is still problematical.

A further major complexity in this event was certainly the close succession of two events in a relatively short space of time. Whereas the overall conditions forecast for both events may individually not have indicated exceptional severity, combination of two forecasts for moderate to heavy rainfall, would suggest increased impacts. Additionally, the change in the receptor conditions (saturated ground, full watercourses and culverts) over the event, and the fact that highest rainfall intensities took place at the end of the second storm, compounded conditions in the worst possible way.

It should be noted that the Met Éireann warnings are aimed up public service bodies in general, and are not specific to particular needs, e.g. for Dublin City Council flood event management. The identification of forecast content, timing and confidence, are all items that need careful consideration by both parties. As forecasts may precede a developing event by some hours, methods need to be developed to enable updating of local conditions. Rainfall occurrence can be monitored by telemetry raingauges and radar information, but this event has shown that antecedent and co-incident conditions, e.g. tides, state of rivers and storm drains, all need to form part of a real time monitoring and decision support system (being developed as part of the DFI).

2.3

Overall hydro-meteorological consideration

A concise summary of the meteorological conditions on 24<sup>th</sup> October has been issued by Met Éireann on their website (Reference 2). This presents some illustrations of forecast model output (HIRLAM) and radar imagery from the most active part of the storm, which shows a concentration of rainfall activity along the eastern side of Ireland. Examination of the North Atlantic weather charts produced at 6-hour intervals by the UK Met Office (Figure 2.1), shows that the dominant feature over 23<sup>rd</sup> and 24<sup>th</sup> October was a complex low pressure system moving across Ireland from the west, accompanied by somewhat complex and slow moving fronts. One of these fronts remained almost stationary for several hours just east of Ireland on 23<sup>rd</sup> October, which resulted in several hours of generally light to moderate rainfall over Dublin.

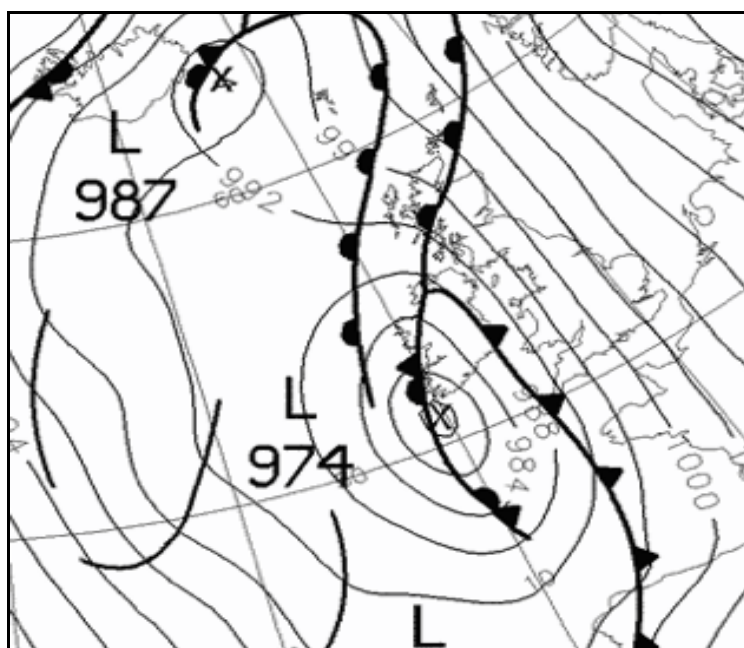


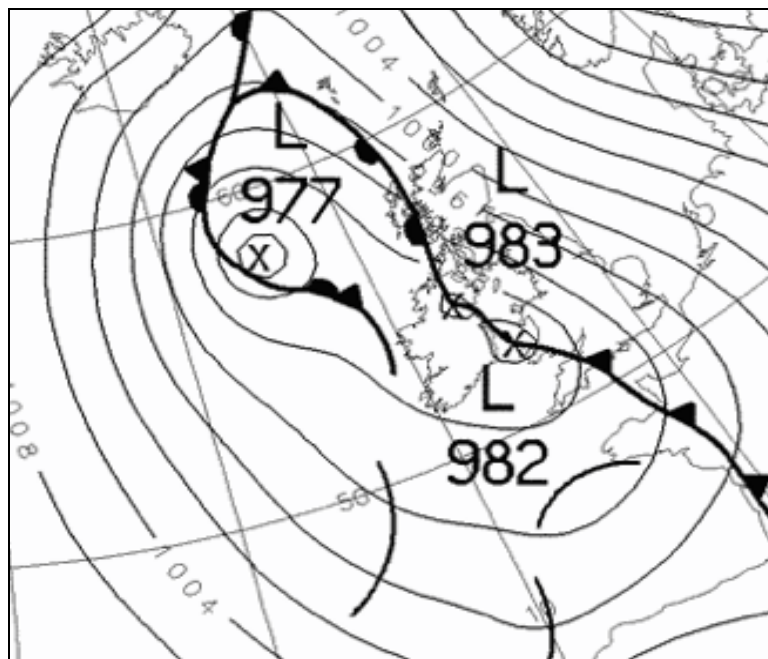
Figure 2.1: Synoptic situation, 1800 UTC (6pm Dublin) 23<sup>rd</sup> October 2011

Although this particular weather feature moved away, a small secondary low had formed between South East Ireland and the Bristol Channel by 1200 UTC (midday) on 24<sup>th</sup> October. This low pressure system and its associated fronts moved towards Ireland, and by 1800 UTC (6pm) lay very close to the east coast and Dublin (Figure 2.2). It was around this time that the heaviest rainfall on 24<sup>th</sup> October was recorded. Over most of the 2-day period, the position of the fronts parallel to, and to the east of the coast, would have provided an area of atmospheric ‘uplift’, fed by south-easterly or southerly winds. The uplift and precipitation would have been enhanced by the effects of the coast and the upland areas south of Dublin.

Over the two days of the event, the persistent winds from a broadly south-easterly direction were also strong with mean wind speeds recorded at Dublin Airport of 13.9 knots on 23 October and 12.7 knots on 24 October. The tidal records that we obtained showed that sea level did not exceed the lowest warning threshold. No tide warnings were issued, but in their first warning message, Met Éireann had indicated the possibility of tidal flooding on the east coast. Dublin City Council assessed the tidal early warning system and this indicated that there was not likely to be a significant risk of tidal flooding (as forecast by Met Éireann) which proved to be correct. It is important to note that the strength and direction of wind had potential to enhance the level of high

tides over 3-4 tidal cycles during the period. If this had occurred, these conditions might have exacerbated flooding from drainage systems due to tide-locking at discharge points.

In accordance with City flood protocol a monitoring and assessment team from Drainage reviewed the information.



**Figure 2.2: Synoptic situation 1800 UTC (6pm Dublin) 24<sup>th</sup> October 2011**

## 2.4 How the event unfolded on the ground

As indicated by the weather charts above, there were two distinct periods of rainfall within the two calendar days. All stations received more rainfall between 9am and 10pm on Monday 24<sup>th</sup> October (13 hours duration) than from 00hrs on 23<sup>rd</sup> October to 9am on 24 October (33 hours duration). The exception to this was Dun Laoghaire Harbour, where the raingauge recorded more on 23<sup>rd</sup> than 24<sup>th</sup>. This could reflect its closeness to the first set of approaching fronts, but Met Éireann (personal communication) has indicated that this site does have exposure problems which can result in over or under-estimation.

The total volume of rainfall up to 9am on 24<sup>th</sup> October was lowest in Southern Dublin, specifically to the west and south-west of the city. The heaviest 1-hour falls were concentrated to the east and south-east of the city.

A summary of the total rainfall over the two days is given in Table 2.1 overleaf.

**Table 2.1: Rainfall summary for 23<sup>rd</sup> and 24<sup>th</sup> October 2011**

Station name	48-hour total rainfall, mm	Rainfall between 00hrs 23/10 to 09hrs 24/10	Rainfall between 09hrs-22hrs 24/10	Max 1-hour rainfall, 24/10 *	Timing of max. rainfall
Roundwood	92.6	42.2	50.4	11.6	1830-1930
Ballymore	70.4	24.8	45.6	10.4	1500-1600
Bohenabreena	105.8	35.2	70.6	17.2	1745-1845
Ringsend	94.6	21.2	73.4	26.6	1845-1945
UCD Horticulture	77.2	27.8	49.4	14.6	1815-1915
Ballymun	86.2	17.0	69.2	19.4	1815-1915
Grange	87.8	17.2	70.6	25.6	1845-1945
Civic Offices	107.4	31.0	76.4	25.4	1445-1545
Phoenix Park	88.0	17.0	71.0	19.0	1645-1745
Dun Laoghaire Harbour	135.3	79.2	56.3	29.3	1345-1445
Brittas	99.4	10.6	88.8	17.4	1600-1700
Corkagh Park	97.0	9.6	87.4	22.0	1400-1500
HQ Tallaght	97.6	11.8	85.8	21.4	1500-1600
Johnstown	104.0	16.4	87.6	21.2	1700-1800

\* The Max 1-hour rainfall figures can be used to compare with other events and the DDF

Hyetographs (a graphical representation of the distribution of rainfall over time) for a selection of the gauges listed in Table 2.1 are shown in Figures C1 to C5 in **Appendix C**. The gauges for which this data is included in Appendix C are shaded in Table 2.1. These are representative of the spread of rainfall conditions across the city and environs.

A summary of the observations from this data is as follows:

- The first period of rainfall took place from 11am to midnight on 23rd October, with rain commencing slightly earlier from 7am – 9am at Dun Laoghaire, the Civic Offices and around Phoenix Park.
- Rainfall over this period was of low intensity, rarely being greater than 2mm in 15 minutes, except at Dun Laoghaire where during the period from 3.30pm to 6pm, 15-minute falls were consistently between 2mm and 4mm. This period produced a total fall of 24.8mm.
- Rainfall on 24th October generally commenced around 11am (as it did on 23rd October), but had commenced earlier at Civic Offices (7.15am) and Phoenix Park (9.15am).
- During this period, rainfall mostly followed a distinct pattern of an early period of increasing light to moderate rainfall, followed by a lull of 1-2 hours when rainfall was only light, but culminating in 2 hours of heavy rainfall, which contained the peaks recorded in orange in Table 2.1.

By way of example, Figure 2.3 shows the hyetograph for Ballymun, which is representative of North Dublin. All of the salient points noted above can be seen in Figure 2.3.

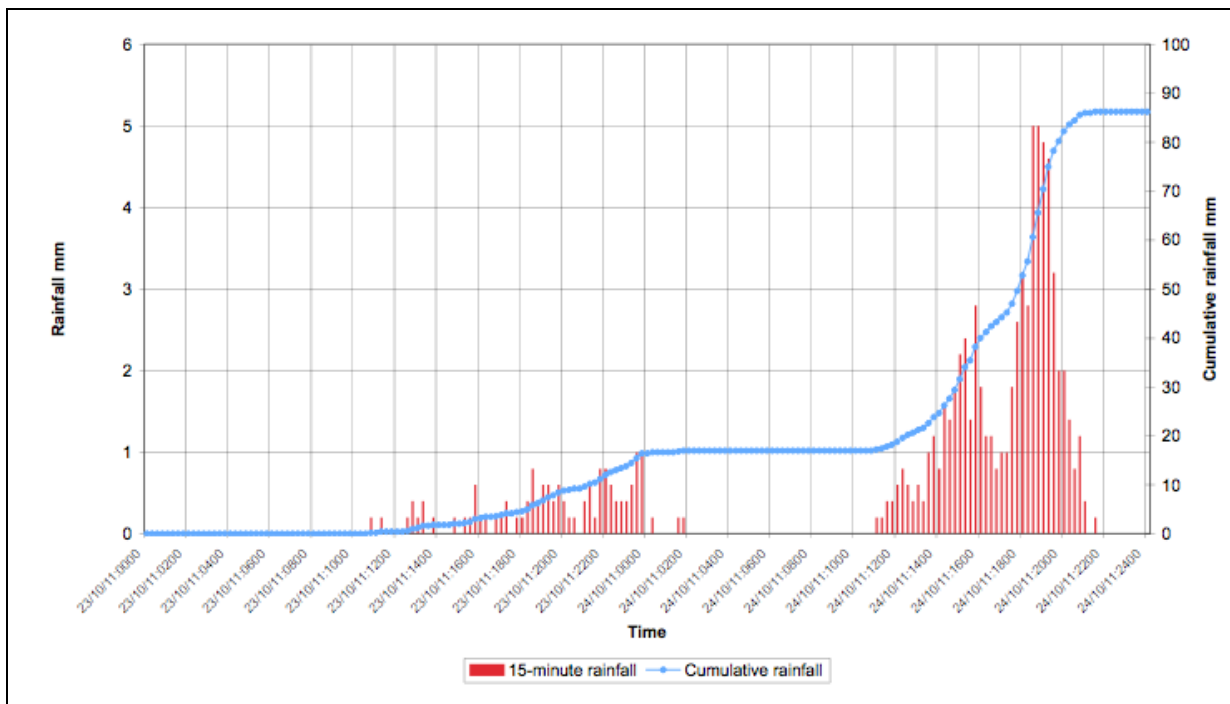


Figure 2.3: Hyetograph for Ballymun, North Dublin, 23<sup>rd</sup> to 24<sup>th</sup> October

## 2.5 Probability of the October 2011 event

A review of data collected by Dublin City Council from the Council telemetry network, and raingauges operated by Met Éireann and Dun Laoghaire Harbour Authority has allowed a post-event estimation of rainfall over time to be evaluated and a maximum fall over a particular duration to be extracted. Evaluation of rainfall totals for periods of 15 minutes, 30 minutes, 1 hour, 2 hours and 3 hours during the second rain event on 24<sup>th</sup> October, is summarised in Table 2.2.

Table 2.2: Maximum rainfall by duration for 24<sup>th</sup> October 2011

Raingauge	Duration				
	15 min	30 min	1 hr	2 hrs	3 hrs
Roundwood	4.4	7.8	12.0	17.0	20.4
Ballymore	3.2	6.0	10.4	18.4	24.6
Bohenabreena	5.2	10.0	18.0	15.0	25.0
Ringsend	8.2	16.0	26.8	37.2	42.0
UCD Horticulture	6.0	10.8	15.0	19.8	25.0
Ballymun	5.2	10.2	19.6	31.2	38.0
Grange	8.2	15.0	25.6	34.4	39.2
Civic Offices	7.4	14.4	25.6	38.6	45.6
Phoenix Park	5.5	10.4	19.3	30.6	40.7
Dun Laoghaire Harbour	10.9	19.7	29.7	35.6	39.0

Table 2.2 shows that the highest rainfall totals for these different durations was experienced in the vicinity of gauges at Ringsend, Grange, the Civic Offices and

Phoenix Park. The four highest totals in each column are shaded **blue**, noting that the gauge at Dun Laoghaire may have been affected by spray (and is therefore a different shade of **blue**).

For each of the five Dublin City Council administrative areas the frequency, or probability, of these rainfall depths and durations can be estimated (depth-duration-frequency analysis). The gauges selected as being representative of the five Dublin City Council areas for these purposes are as follows:

- North Central Area – **Ballymun**
- North West Area – **Phoenix Park**
- Central Area - **Civic Offices**
- South Central – **Johnstown**
- South East – **Ringsend**

The analysis is shown in Tables D1 to D5 in **Appendix D**. The principal findings from the analysis are that:

- Rainfall totals for all locations, for durations of 1 hour and longer, all exceed the 1 in 10 annual chance event;
- Most rainfall totals lie between the 1 in 20 and 1 in 50 annual chance events;
- Some totals exceed the 1 in 50 annual chance events up to around a 1 in 100 annual chance or probability.

The periods of analysis for these parts of the event all occurred during the final stage of the storm. As mentioned previously, the general period of rainfall on 24<sup>th</sup> October mostly commenced at about 11am. Using the same reference stations for the five Dublin City Council Operational Areas identified above (and as included in Appendix D) rainfall over the total storm period from 9am to 10pm is compared with depth-duration-frequency estimates for 9 and 12 hours, for a range of different event probabilities.

Table 2.3 presents a comparison with the DDF estimate of representative grid-square in each Operational Area with a raingauge representative of that area. The name of the raingauge comes below the lines for the two DDF duration estimates. Results reveal that the total storm rainfall has a much lower probability (or annual chance) than the short period of higher intensity rainfall. For these longer durations (9 and 12 hours) all storm totals exceed the 1 in 50 annual chance events, as shown in **blue** in Table 2.3, with the total at Johnstown being in excess of the **1 in 100 annual chance event**, shown in **red**.

**Table 2.3: Storm total rainfall, 9am to 10pm 24 October 2011, for representative rainfall station and annual chance rainfall (all in mm)**

Duration and reference station	Annual Chance (probability)			
	1 in 10	1 in 20	1 in 50	1 in 100
9 hours	40.6	47.4	57.7	66.7
12 hours	44.9	52.2	63.2	72.9
<b>Ballymun (Nth Cent)</b>			69.2	
9 hours	43.0	51.0	63.2	74.1
12 hours	47.5	56.0	69.2	80.9
<b>Phoenix Park (Nth West)</b>			71.0	
9 hours	42.7	50.5	62.7	73.6
12 hours	47.1	55.6	68.7	80.3
<b>Civic Offices (Central)</b>				76.4
9 hours	44.4	53.2	66.8	79.1
12 hours	49.0	59.5	73.2	86.4
<b>Johnstown (Sth Cent)</b>				87.6
9 hours	44.5	52.9	65.8	77.4
12 hours	49.1	58.2	72.1	84.6
<b>Ringsend (Sth East)</b>			73.4	

Dublin City Council has reported that a rainfall of 61.6mm occurred over a 6-hour period, and this exceeded the 1 in 100 annual chance event for this duration. The results in Table 2.2 and 2.3 certainly infer that exceedence of a 1 in 100 chance occurred somewhere between durations of 3 hours and 9 hours. Using the 3 stations from Table 2.2 with the largest 3-hour rainfall, 6-hour totals were extracted and compared with the representative Operational Area DDF value for the 1 in 100 annual chance 6-hour rainfall, as in Table 2.4. Results confirm that the 6-hour DDF value was exceeded at the Civic Offices, and closely approached at Phoenix Park and Ringsend. It must be noted that as the interpolated values of DDF vary across the Dublin area, this sort of localised variation in probability is inherent. The variation in quantities is small, so in no way detracts from the undoubted severity of the event.

**Table 2.4. Comparison of 6-hour DDF 1 in 100 annual chance rainfall with maximum 6-hour rainfall at selected raingauges.**

Location	DDF 1 in 100 chance, 6-hour rainfall	Maximum 6-hour rainfall, 24 October 2011
Phoenix Park	64.0	60.5
Civic Offices	65.0	68.8
Ringsend	68.4	61.6

**2.6**

**A comparison with past events**

Flooding occurred during two recent summer rainfall events, 9<sup>th</sup> August 2008 and 2<sup>nd</sup> July 2009, which were events characterised as short duration, intense downpours. Another major rainfall event of 13<sup>th</sup>-14<sup>th</sup> November 2002, exhibited many characteristics similar to the events of 23<sup>rd</sup>-24<sup>th</sup> October and caused widespread fluvial and pluvial flooding in Dublin City.

The 2008 and 2009 events only lasted 3 to 4 hours, but although total rainfalls were less than the recent event, rainfall depths were still significant, and short term intensities (for example the 1 hour rainfall totals) were generally greater. Summary statistics are given in Table 2.5.

**Table 2.5: Maximum total rainfall and hourly rainfall in previous major events**

Event date	Largest total rainfall, mm	Location	1-hour maximum rainfall, mm	Location
9 August 2008	67.1	Dublin Airport	24.1	Dublin Airport
2 July 2009	48.0	Mater Dei	31.6	Mater Dei
14 November 2002	72.4	Dublin Airport	14.6	Trinity College

Analyses of rainfall data for the 2008 and 2009 events produced maximum rainfall intensities between 15 minutes and 3 hours. The same information has been extracted from data for the maximum portion of the event of 24<sup>th</sup> October 2011 and these are compared in Table 2.6.

**Table 2.6: Maximum rainfall in short durations**

Duration	9 <sup>th</sup> August 2008, Phoenix Park		2 <sup>nd</sup> July 2009, Mater Dei		24 <sup>th</sup> October 2011, Civic Offices	
	Depth (mm)	Intensity (mm/hr)	Depth (mm)	Intensity (mm/hr)	Depth (mm)	Intensity (mm/hr)
15 minutes	15.4	61.6	12.2	48.8	7.4	29.6
30 minutes	20.6	41.2	17.6	35.2	14.4	28.8
1 hour	33.5	33.5	32.2	32.2	25.6	25.6
2 hours	38.8	19.4	44.0	22.0	38.6	19.3
3 hours	42.7	14.2	45.2	15.1	45.6	15.2

Up to and including a duration of 1 hour, the maximum rainfalls of 24<sup>th</sup> October are less than the depths that occurred in the two summer storms. At 2 and 3 hours duration, the rainfall at some of the locations on 24<sup>th</sup> October reached the same depths as the previous 2008 and 2009 major events.

The October 2011 event produced 2-day rainfall totals in excess of the November 2002 storm, but it must be noted that during the 2002 event, rainfall was continuous over about 22 hours, with continuous rainfall totals for November 2002 similar to or greater than totals in either of the two separate events on 23<sup>rd</sup> October and 24<sup>th</sup> October. A

significant feature of the November 2002 storm was that it resulted from very similar weather patterns to the October 2011 events. The weather charts showed a small, active low-pressure area immediately to the south and east of Ireland, with fronts close to and crossing the east coast. The movement of fronts in November 2002 seems to have been more to the north-west, but similarities to the October 2011 event suggest that this particular meteorological pattern should be taken as indicative of a possible critical rainfall event taking place, and important in forecasting for future events.

## 2.7 Why was flooding associated with the October 2011 event so great?

The main differences between the October 2011 event and previous events described in Section 2.6 were that the heaviest rainfall on the 24<sup>th</sup> October occurred towards the end of the event, but this had also been preceded by several hours of rainfall on the previous day (23<sup>rd</sup> October).

Rainfall on the 23<sup>rd</sup> October raised water levels within the drainage and watercourse network throughout the Dublin City area. On its own the volume and intensity of the rainfall on the 23<sup>rd</sup> October would not have resulted in significant flooding. However, with the rainfall event on the 24<sup>th</sup> October following closely afterwards, with rivers and some parts of the drainage systems possibly still containing increased volumes of water, when coupled with the highest intensity peak rainfall at the end of the event on the 24<sup>th</sup>, the combination resulted in extensive flooding which exceeded the capacity in both the river and drainage network.

## 2.8 Event Conclusion

In conclusion, the combined event of the 23<sup>rd</sup> and 24<sup>th</sup> October must be considered as extreme. Significant and sustained rainfall resulted in a combination of both fluvial and pluvial flooding across much of the wider Dublin area. Rainfall on the 23<sup>rd</sup> October raised water levels within the watercourse and drainage network. When followed by the exceptionally heavy rainfall on 24<sup>th</sup> October this in turn led to surcharging and exceedance of the capacity of much of the existing watercourse and drainage network. This in turn gave rise to both fluvial and pluvial flooding. The lead in time up to the event was very short and once the watercourse and drainage capacity was exceeded there was little that could be done. It is not currently possible to predict in advance when, where and to what extent such flooding will occur.

Analysis shows that the extreme rainfall probability was around a 1 in 100 chance in any one year in some locations and between a 1 in 50 and 1 in 100 annual chance across some 80% of Dublin. Met Éireann reported rainfall intensity in the order of 15mm per hour on a number of occasions during the 9 hour event, an uncommon occurrence and one that Met Éireann are currently unable to predict.

## 3 Flooding Mechanisms and Impacts

### 3.1 Types of Flooding

Floods can happen anywhere at anytime. As well as flooding from rivers and the sea, flooding can arise from rising groundwater levels, sewer system surcharging, burst water mains and overland flow and ponding from heavy rainfall. Even if you live miles away from the coastline or a river, there's still a chance flooding could affect you.

The following provides a general review of common sources of flooding that can affect urban areas:

- River flooding** (also known as fluvial flooding) occurs when a watercourse cannot accommodate the volume of water draining into it from the surrounding land. It is generally infrequent, but flooding can occur both rapidly or over a long duration depending on the topography of the catchment. Watercourses are more likely to be overwhelmed when rainwater cannot be absorbed into the land onto which it falls. It might be very steep, water logged, or built over. Rapid melting of snow also leads to river flooding in some cases, as well as obstructions such as collapsed buildings/walls.

Flooding from **small urban watercourses** can also be a particular problem in urban areas even though the catchment area may be small. Impermeable 'sealed' surfaces in built up areas can result in increased and more rapid runoff to these small watercourses such that flows in the watercourse can build up rapidly and result in flash flooding. Urban watercourses are often culverted over long sections and the entrances to these culverts, even though screened, can often be flooding 'hotspots'. These watercourses are also often constricted in places resulting in bottlenecks which can make flooding worse. Debris, both natural and man-made also often accumulates in urban watercourses which not only constricts the watercourse but can accumulate at culvert screens and even block these screens in extreme cases.

- Coastal flooding** that results from a combination of high tides and stormy conditions. If low atmospheric pressure coincides with a high tide, a tidal surge may happen which can cause serious flooding.
- Pluvial flooding** (also known as surface water flooding) occurs when heavy rainfall results in water flowing across the ground surface and the capacity of local drainage (both natural and man-made) is overwhelmed – surface ponding occurs sometimes to a significant depth. The route the water takes and the depth of flooding will depend on local features and can be difficult to predict.
- Sewer flooding** that occurs when 'combined' sewers (which carry both foul sewage and stormwater) are overwhelmed by heavy rainfall or when they become blocked, or can be attributed to infrastructure failure (e.g. pumping station failure). The likelihood of flooding depends on the capacity of the local sewerage system. Land and property can be flooded with water contaminated with raw sewage as a result. Rivers can also become polluted by sewer overflows. In urban areas, pluvial flooding and sewer flooding often combine, polluting the floodwater. It should be noted that in some newer developments foul sewage and stormwater is conveyed in 'separate' systems. In such cases flooding due to heavy rainfall is usually associated with the stormwater system.

- **Groundwater flooding** that occurs when water levels in the ground rise above surface levels. It is most likely to occur in areas underlain by permeable rocks, called aquifers. These can be extensive, regional aquifers, such as chalk or sandstone, or may be more local sand or river gravels in valley bottoms underlain by less permeable rocks.
- **Reservoir flooding** - some reservoirs hold large volumes of water above ground level. Although the safety record for reservoirs is excellent, it is still possible that a dam could fail. This would result in a large volume of water being released very quickly.

## 3.2 Flooding in October 2011

Due to the nature of the rainfall event on 23<sup>rd</sup>/24<sup>th</sup> October, many of the types of flooding described in Section 3.1 were observed. Flooding from the sea and from reservoirs was not directly experienced within Dublin and flooding from groundwater was also unlikely to have taken place in this case.

Flooding within all 5 administrative districts of the City was experienced, as was flooding throughout the East region (including Wicklow, South Dublin County and Monaghan). However, not all types of flooding occurred in each district. A review of over 1100 reported incidents has been undertaken and the results have been used to evaluate flooding both across Dublin as a whole and within the 5 districts.

These incidents have been mapped to show the likely type of flooding which occurred as indicated in Figures 1.1 to 1.6 in **Appendix A**. The severity of the flooding incident has also been assessed where such information is available and this has also been mapped as indicated in Figures 2.1 to 2.6 in **Appendix A**. The order of severity ranges from garden flat flooding which is considered to be the most severe both in terms of damage and risk to life, to flooding of commercial premises, to flooding of houses at street level, to flooding of land as the least severe category.

### 3.2.1 Dublin wide observations and characteristics

The City of Dublin has a complex drainage system of Rivers, Canals, Surface water Sewers, Foul Sewers and Urban Watercourses which have both culverted and open channel sections. Interactions between the individual parts of the drainage system vary according to specific location and the types of water being managed. River Catchments do not align with political boundaries and most Dublin Rivers originate in other Local Authority Areas.

The Rivers Poddle and Dodder drain much of the southern part of the city and South Dublin County areas further south; these rivers feed into the Liffey within the city centre.

To the west, the River Liffey and River Camac drain much of the west and centre of the city and criss-cross the Grand Canal, finally exiting in Dublin Bay. They also drain areas of Kildare County and South Dublin County.

To the north the Tolka River and its tributaries drain areas to the north of the Royal canal and areas of County Meath before discharging to Dublin Bay.

There are many smaller watercourses within wider Dublin. Including those listed above, some 43 have been identified in total. Many of these are culverted streams that are rarely visible on the surface. Others have both culverted and open channel sections.

Therefore, when flooding does occur it is often difficult to be clear on the exact flooding source.

The event of 23<sup>rd</sup>/24<sup>th</sup> October saw flooding associated with both pluvial and fluvial sources on a large scale. While some flooding occurred from the larger rivers in some places large river flooding would have been very much worse had flood defences walls and embankments not already been constructed over extensive lengths of these rivers. For example, the flood protection scheme on the River Tolka has been completed and there were no flooding issues associated with the River Tolka on 24<sup>th</sup> October despite it having the fifth highest recorded flow on record. Flooding from small urban watercourses does however appear to be a particular feature of this event as well as pluvial flooding.

Review of Figure 1.1 in [Appendix A](#) shows not only the widespread nature of the flooding but also characteristic ‘clusters’ of incidents in many locations. The majority of clusters appear to be a combination of pluvial and fluvial flooding with many incidents clustered along urban watercourse routes. This is not surprising as where the watercourse is culverted below ground the natural slope of the land is towards that watercourse route and hence pluvial flooding is more likely due to the topography alone. However flooding may also arise directly from the urban watercourse from:

- Access manholes to the culverted watercourse if the flow is surcharged (under pressure) along culvert.
  - Open channel sections of the watercourse.
- or
- Overflowing from entrances to culverted sections either due to the culvert capacity being exceeded or blockage of the entrance screen by debris (either partial or full).

In many of the flatter areas toward the coast the flooding appears to be either pluvial alone or a combination of pluvial and sewer flooding. In flat areas this is not surprising as the flat topography means that it can be more difficult for surface water to drain away. Also sewer gradients are very flat and the sewers may be more prone to surcharging especially if discharge to tidal sections of river is constrained by high tides (as appears to be the case). Sewerage systems in flatter areas may also be dependant on pumping and failure of pumps (as occurred in some locations) is likely to give rise to flooding.

Examination of Figure 2.1 in [Appendix A](#) suggests that where information on the type of impact of flooding is available i.e. the type of property affected which gives an approximate indication of the severity of the flooding in terms of impact, the greatest severity or impact appears to be more to the south of Dublin in terms of reported **garden flat flooding**. However it was noted during site visits that garden flats which are likely to have been affected by flooding have not always been reported as clearly identifying garden flat flooding. Hence the flooding of garden flat properties may have been much more extensive than indicated in Figure 2.1 and it is possible that garden flat flooding could have occurred at locations for which information on the type of property affected by flooding was not reported. This proportion of the reported ‘unknown severity’ locations is uncertain. There are thought to be around 18,000 garden flat properties across Dublin.

Flooding of houses at street level was more widely spread across Dublin with over 1100 incidents spread across the entire city. The least severe class of reported flood incident, flooding of land only, was reported right across the Dublin urban area confirming the widespread extent of this event.

**3.2.2**

**Flooding in the five districts of Dublin**

**North Central Area**

See Figures 1.2 and 2.2 in Appendix A.

Flooding in the North Central area in general appears to have resulted from a combination of pluvial and fluvial flooding associated with the Rivers Naniken and Wad. A number of known areas flooded along the course of the Naniken and Wad. Flooding occurred of both properties and roads.

In the north west of this district flooding has been attributed to some known foul drainage problems where flooding has occurred in the last three years. Pluvial impacts were associated with highway drainage and open parkland around the Kilbarrack area.

Other sporadic instances of sewer flooding and pluvial flooding were identified throughout this district.

Disruptions in this district included property flooding/damage, traffic issues, and flooded car parks.

**North West Area**

See Figures 1.3 and 2.3 in Appendix A.

Flooding in the northern part of the North West area in general appears to have been caused by a combination of pluvial and fluvial flooding associated with the Wad River.

In the southern part flooding has been attributed to mainly pluvial flooding exacerbated by surcharged drainage in the area with sporadic instances of sewer flooding.

Disruptions in this district included property flooding/damage, traffic issues due to impassable roads and flooded footpaths.

**Central Area**

See Figures 1.4 and 2.4 in Appendix A.

The central area experienced significant flooding in the vicinity of East Wall and Cabra. The flooding at East Wall can be mainly attributed to known issues with the existing drainage system and are likely to be caused by pluvial flooding. Reports from Seaview Terrace, and the low lying area of Church Road, further suggest localised drainage issues in this area.

In Cabra the flooding appears to have been mainly associated with the fluvial flooding of the Bradogue River in combination with pluvial flooding and limited capacity in the surface drainage system.

Pluvial flooding attributed to limited capacity in the surface drainage system occurred in a residential area to the north east of Phoenix Park.

Other sporadic instances of sewer flooding and pluvial flooding were identified throughout this district.

**South Central Area**

See Figures 1.5 and 2.5 in Appendix A.

Flooding in the South central area was dominated by flooding associated with the Camac river, which burst its banks at a number of locations in Kilmainham and Inchicore. Flooding was particularly severe in and around Lady’s Lane/Millbrook Terrace. It was reported that flood levels exceeded the height of the flood wall at the foot of Lady’s Lane by around 1m. Flooding associated with the Camac River was reportedly exacerbated by floodwater backing up within highway drainage systems and surface water sewers.



**Flood damage at Millbrook Terrace**

A large amount of flooding occurred in the Harold’s Cross area. This was again attributable to a combined pluvial and fluvial event, with water overtopping the banks of the River Poddle with backing up of drainage systems. This was particularly evident at Poddle Park Road and Cloyne Road, Kimmage. The Poddle is largely culverted under Harolds Cross and it is possible that overtopping at the screened inlet to this culvert might have contributed to rapid inundation of this area. This would however need to be further investigated.

As with the other districts, other sporadic instances of sewer flooding and pluvial flooding were identified throughout.

Disruptions in this district included property flooding/damage and traffic issues due to impassable roads. Garden flat flooding was identified in Harold’s Cross causing a risk to life and public safety.

**South East Area**

See Figures 1.6 and 2.6 in Appendix A.

The south eastern district experienced extensive flooding in local areas covering Pearse Square, Lansdowne, Ringsend, Sandymount and Ballsbridge attributable to low lying land and in particular the backing up and surcharging of the largely combined surface and foul sewer system which combined with pluvial flooding.

Significant flooding occurred to garden flat properties at Pearse Square with severe damage to some but fortunately no reported injury or loss of life. The source of flooding appears to be a combination of pluvial flooding and backing up/surcharging from the sewer system due to stormwater in the combined drainage system.



**Flood damage at Pearse Square**

A local flooding issue in the south east of this district (southern Sandymount, in the vicinity of St. John’s Road was

attributable to the capacity of the pumping station here. Garden flat flooding was identified in this area.

The western part of this district was characterised by mainly local sporadic instances of sewer flooding and pluvial flooding. Part of Harold’s Cross area is located within this district (see the South Central Area above).

Some river flooding from the Dodder was reported but this may be associated with partial blockage at one of the bridge crossings due to scaffolding which had been erected associated with bridge repairs.

Disruptions in this district included property flooding/damage and traffic issues due to impassable roads. Garden flat flooding was identified at a number of locations in this district with a potential for risk to life and public safety.

### 3.2.3 Public Safety and Risk to Life issues in relation to the October 2011 flood

There are a number of potential risks to public safety and potential loss of life during flooding of this nature and severity. These include:

- Rapid inundation of either deep ponding areas or garden flats. Regrettably a fatality occurred at a garden flat location during this event.
- High velocity surface water flow along steeply sloping roads and streets – even shallow depths of high velocity flow can be dangerous for pedestrians and even occupants of vehicles.
- High velocity flow along urban watercourses or deep and fast flow in larger rivers poses a risk to anyone swept into the watercourse. This can also be a risk for those in any vehicle swept into the river or even a smaller watercourse.
- Culvert entrances – anyone swept into an urban watercourse is in even more severe danger if swept into a culverted section of the watercourse – this is one reason why culvert entrances (unless very large) are screened. Even if screened people can still become trapped at the screen and submerged.
- Structural damage to buildings adjacent to watercourses due to undermining or high velocity flows – this occurred at Kilmainham where a building collapsed, though fortunately no injury was reported.
- Collapse or breaching of flood defences – this can occur if defences are overtopped, or undermined and can lead to rapid inundation and high velocity flow. For this reason flood defences are designed to high standards.
- Open manholes where the cover may have ‘blown’ due to surcharging – even in shallow flooding open manholes are unlikely to be visible and great care must be exercised if walking through even quiescent floodwater.

These and other public and responder safety issues must be considered by flood response personnel. They must also be taken into consideration when considering flood resilience and mitigation measures.

# 4 Mitigation Measures

## 4.1 The Basis for Identifying Mitigation Measures

The preceding chapter includes details on the sources of the flooding, the specific mechanisms by which flooding occurred, and the impacts that resulted.

Figure 4.1 provides a high level summary of the different flooding sources, mechanisms and impacts which is a useful reference point for considering different mitigation measures to reduce flood risk. The left hand column shows the typical Source-Pathway-Receptor approach to flood risk management. The right hand column shows how this approach can be applied to the 24<sup>th</sup> October event that affected Dublin.

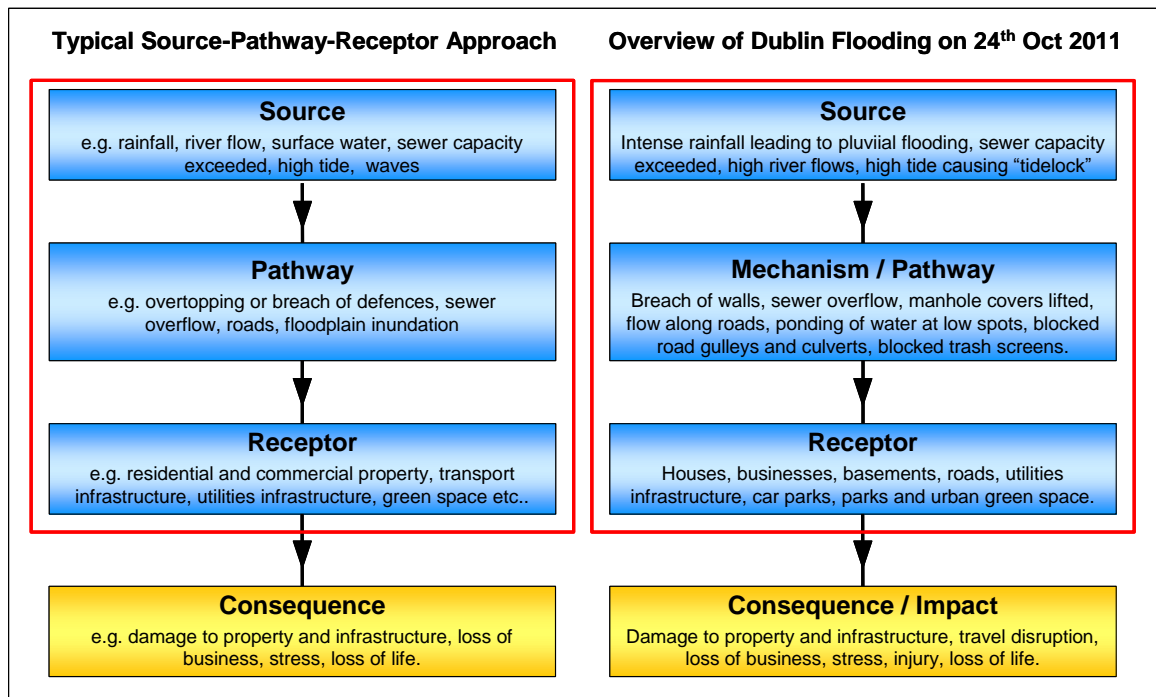
**Source** – The origin of the flood hazard e.g. heavy rainfall or high river flows.

**Pathway** – The route that the flood hazard takes to reach a Receptor.

**Receptor** – The entity that is harmed e.g. a person, property, or infrastructure.

For example, in the event of heavy rainfall (the source) flood waters flow over the top of a river bank and across the flood plain (the pathway) and inundate housing (the receptor). This combination of factors leads to material damage (the consequence).

**Consequence** – An impact such as economic, social or environmental damage.



**Figure 4.1: Source-Pathway-Receptor approach and the 24<sup>th</sup> October Event**

In Figure 4.1 (right hand column) the different sources, mechanisms and impacts are “pooled” and it does not imply that during the 24<sup>th</sup> October event **every** source combined with **every** mechanism to give **every** impact.

To those that are affected by flooding, it is the **consequence** or **impact** that is most clearly identified. However, to develop appropriate mitigation measures – measures to reduce the impact of flooding in future – it is important to understand the **source-pathway-receptor** links to enable mitigation measures to be targeted appropriately.

## 4.2 Mitigation Measures

A wide range of mitigation measures have been identified as part of the Dublin FloodResilienCity Project and are to be included within *Code of Practice 2 - Corrective and Adaptive Measures* (CoP2) which is currently in preparation. The analysis of the 24<sup>th</sup> October event indicates that it included flooding from river/urban watercourse sources (fluvial flooding) as well as pluvial (surface water) flooding. The list of generic measures considered has therefore been expanded to address fluvial flood risk, as the focus of the FloodResilienCity Project is primarily on pluvial flooding.

Tables E1 to E4 within **Appendix E** summarise a wide range of measures, grouped under the following categories:

- **Generic Measures** – those which can be applied universally across the whole of the Dublin administrative area and aim to raise the overall level of resilience to flooding. They apply to areas of high risk and lesser risk and therefore cover areas where the level of risk does not justify investment in Site Specific Resilience measures.
- **Community Flood Resilience Measures** require engagement and participation at community or householder level. Specific actions may be required to implement building resistance and resilience measures and ownership of that responsibility will be an important element of effective resilience raising.
- **Site Specific Resilience Measures** are normally applicable only in areas of identified high risk. They are likely to involve capital investment and there may be an ongoing maintenance commitment. The site specific measures are grouped under those that focus on **pluvial / surface** water flooding and those that focus on **fluvial / urban** watercourse flooding.

Based on the mitigation options described in **Appendix E** (Tables E1 to E4), the effectiveness of these measures can be evaluated in terms of how they can be used to mitigate the risk from three primary sources:

1. **Pluvial flooding** – flooding as a direct result of intense rainfall flowing across the ground, typically over roads and other hard surfaces, but this can also occur over grassed areas. This includes flooding due to water not being able to get into underground pipes and drains because they are full. The capacity of the sewerage and drainage system can therefore have a significant influence on pluvial flooding.
2. **Sewerage and drainage flooding** – flooding due to water coming out of drains, due to, for example, manholes covers being pushed up by the pressure of water in the drainage system.
3. **Fluvial flooding** – flooding from rivers and small urban streams as a result of the watercourses bursting their banks.

The key question to assist in evaluating different measures is:

- What is the potential overall impact of the measure on the flood risk from this source?

The measures can also be evaluated in terms of their overall effectiveness in the short term and in the longer term. To do this, the following key questions must be considered:

- How quickly can measures be put in place having regard to the statutory, legal, planning, procurement, staff and financial resources required?
- Over what timeframe are the benefits of the measure realised?
- What is the scale of the benefits that can be achieved through the measure?

In evaluating the effectiveness in the short or long term, a scoring system has been applied that considers these questions, as applied to the different flood sources. The basis for the scoring system is outlined in Table 4.1.

**Table 4.1: Basis for evaluating effectiveness of measures**

Factor	Key question	Scoring System
<b>Flood Risk</b>		
Pluvial	What is the potential overall impact on <b>pluvial</b> flood risk?	1 = not significant 2 = moderate 3 = significant
Sewerage / Drainage	What is the potential overall impact on <b>sewerage / drainage</b> flood risk?	
Fluvial	What is the potential overall impact on <b>fluvial</b> flood risk?	
<b>Total flood risk score</b> is the sum of the three individual scores – maximum score of 9		
<b>Implementation</b> timeframe	How quickly can measures be put in place?	3 = <2 years 2 = 2-5 years 1 = >5 years
<b>Benefit</b> timeframe	Over what timeframe will there be a positive return on investment?	3 = <2 year 2 = 2-10 years 1 = >10 years
<b>Scale</b> of benefits	What is the scale or geographic extent of the benefits that can potentially be achieved through the measure?	1 = small / highly localised 2 = medium / local or district level 3 = large / citywide

The total evaluated score for effectiveness is calculated as follows:

$$\text{Effectiveness score} = \text{Total flood risk score} \times \text{Implementation Score} \times \text{Benefit score} \times \text{Scale score}$$

It should be noted that where measures that can be implemented in less than one year i.e. measures with an Implementation Score of 3, only the **short term effectiveness** score is calculated, while for those measures that take longer to implement i.e. measures with an Implementation Score of less than 3, only the **long term effectiveness** score is calculated. Hence for each measure, either the short term effectiveness or long term effectiveness is evaluated, not both.

Table 4.2, parts (a) and (b) below, outlines each of the measures considered, including a summary comment on the effectiveness of measures where appropriate. Beyond the factors considered in relation to the effectiveness of different measures, as developed through the scoring system described in Table 4.1, the comments in Table 4.2 also take note of other aspects such as:

- Where the benefits are realised in relation to where the measure is implemented.
- The cumulative nature of some measures which increases their effectiveness over time.
- The links between some measures that must be made to increase effectiveness.
- Some of the limitations often associated with measures.

The evaluation of the effectiveness of measures in the short or long term is a complex process. It is emphasised that the effectiveness **rating** of “High”, “Medium” or “Low” as shown in Table 4.2 should be considered only as a generic guide. It is quite possible that a low score results from, for example, the scale of the measure (being small), or that it only addresses one source of flooding.

The most effective measures – those with a “High” rating – in Tables 4.2 (a) and (b) are highlighted in **green** and those with a “Moderate” rating in **yellow**.

**Table 4.2(a): Summary of Mitigation Measures and Effectiveness (Generic Measures and Community Measures)**

Flood Mitigation Measure		Source (S) / Pathway (P) / Receptor (R) / Non-structural (N-S)	Short Term Effectiveness SCORE	Short Term Effectiveness RATING (1)	Long Term Effectiveness SCORE	Long Term Effectiveness RATING (1)	Comment
Generic Measures	Planning and Building Control	N-S	-	-	54	high	Long term effectiveness is cumulative as the implementation of the policy increases over time.
	Flood Warning and Enhancement of Flood Emergency Management	N-S	-	-	60	high	Long term effectiveness is cumulative as the implementation of the policy increases over time
	Development Policy and Urban Land-use Management	N-S	-	-	54	high	Long term effectiveness is cumulative as the implementation of the policy increases over time
	Access Protection	R	30	moderate	-	-	Receptor protection is highly localised. Benefit to single (or small groups of) properties.
	Enhanced Maintenance	P	108	high	-	-	Maintenance of existing assets and systems can bring significant benefits over a wide scale. Ongoing commitment required, having regard to legal responsibilities of riparian owners.
	Green Roofs	S	-	-	24	low	Easier to implement on new build than retrofit. Benefit is remote from where the works are done. Large scale needed to have significant impact.
	Aggregated Micro-Storage	S / P	-	-	20	low	Technically difficult due to the need for “smart control” to optimise how multiple small storage areas are used.
	Other Generic SuDS	S / P	-	-	56	high	Benefit is remote from where the works are done. Large scale needed to have significant impact. Effectiveness will increase over time if linked to Planning and Development Policy.
	Rain Gardens	S	36	moderate	-	-	Benefit is remote from where the works are done. Large scale needed to have significant impact.
	Gully Enhancement and ‘Gully Gardens’	P	-	-	24	low	Requires high level of implementation across large areas to have significant benefit. Retrofit unlikely but scope to build in to new developments.
Vegetation Management	P	72	high	-	-	Vegetation management on existing watercourses can bring significant benefits over a wide scale. Rapid implementation, having regard to the legal responsibilities of riparian owners	
Community Flood Resilience Measure	Awareness Raising and Education	N-S	45	moderate	-	-	Should be coupled with other non-structural measures for maximum effectiveness. Awareness raising on <b>Receptor</b> measures likely to have greater uptake than <b>Source</b> measures. Can be commenced quickly, but the real benefit will be over a longer timeframe as the geographic spread increases.
	Rainwater Harvesting including Leaky-Butts	S	30	moderate	-	-	Easier to implement on new build than retrofit. Benefit is remote from where the works are done. Large scale needed to have significant impact.
	Domestic Rain Gardens	S	30	moderate	-	-	Benefit is remote from where the works are done. Large scale needed to have significant impact.
	External Resistance Measures	R	45	moderate	-	-	Receptor protection is highly localised. Benefit to single (or small groups of) properties. Rapid implementation possible.
	Internal Resilience Measures	R	22.5	low	-	-	Receptor protection is highly localised. Benefit to single (or small groups of) properties. Rapid implementation possible.
	Specific Garden flat Measures including Riser-Steps	R	54	high	-	-	Receptor protection is highly localised. Benefit to single (or small groups of) properties. Rapid implementation possible. Benefit could however be great.

**Notes:** (1) The Low, Moderate and High ratings are based on the following effectiveness scores: Low: <30; Moderate: 30-50; High: >50.

**Table 4.2(b): Summary of Mitigation Measures and Effectiveness (Site Specific Measures)**

Flood Mitigation Measure		Source (S) / Pathway (P) / Receptor (R) / Non-structural (N-S)	Short Term Effectiveness SCORE	Short Term Effectiveness RATING (1)	Long Term Effectiveness SCORE	Long Term Effectiveness RATING (1)	Comment
Site Specific Measures – Surface Water and Pluvial Flooding	Fringe Interception / Storage and Land Management	P	-	-	30	moderate	Most appropriate in the urban / rural fringe. Longer term benefit through cumulative benefits from multiple sites.
	Enhance Existing Storage	P	-	-	40	moderate	Makes best use of existing assets. If large scale storage, has potential to benefit large areas, although large storage areas in urban areas is not common.
	SuD's storage	S	-	-	40	moderate	Benefit is generally remote from where the works are done. Large scale needed to have significant impact. Effectiveness will increase over time if linked to Planning and Development Policy (e.g. the practice of paving over gardens needs to be examined)
	GreenWaterSpace Storage	S / P	-	-	32	moderate	Makes best use of existing open space to provide opportunities for new storage areas. Limited by existing green space and current land use.
	SuD's Infiltration	S	-	-	40	moderate	Benefit is remote from where the works are done. Large scale needed to have significant impact. Effectiveness will increase over time if linked to Planning and Development Policy.
	Surface Conveyance (carrying capacity) (Streets as Streams Roads as Rivers)	P	-	-	48	moderate	Controlling flood waters by channelling along roads will require close co-operation with Highways. Implication for road design and surfacing.
	Bio Swales	P	-	-	32	moderate	Requires high level of implementation across large areas to have significant benefit. Benefit is remote from where the works are done. Best scope is in new developments and peri-urban areas where there is sufficient space.
	Below Ground Conveyance	P	-	-	21	low	Typically comprises a series of small / medium capital projects. May move flood risk downstream. Can be complicated by utility service diversions required.
	Separation of Foul and Surface water sewers	P	-	-	21	low	Typically comprises a series of small / medium capital projects. Can be complicated by utility service diversions required. Potentially significant public health and water quality benefits.
	Temporary and Demountable Defences	P / R	-	-	24	low	Good lead time required for implementation. A high degree of well co-ordinated logistics and emergency planning is required to mobilise and construct defences before the onset of flooding.
Site Specific Measures – River Flooding	Flow diversion - culvert or channel	P	-	-	20	low	Typically a significant capital project. Sufficient space for new open watercourse generally only possible on urban fringes. Major culvert in urban areas can be complicated by utility service diversions required. May move flood risk downstream.
	Increase conveyance	P	-	-	40	moderate	Removal of local bottleneck may pass flood risk downstream. For longer sections requires space for channel enlargement.
	Flood walls	P	-	-	25	low	Typically a significant capital project. Can introduce surface water flood risk when river levels are high.
	Flood embankments	P	-	-	20	low	Typically a significant capital project. Can introduce surface water flood risk when river levels are high. Space required for embankments is likely to limit this measure to urban fringes.
	Minor works - defence raising, infilling gaps etc.	P	-	-	40	moderate	Significant reduction in flood risk is possible through identification of weak spots and implementing localised works.
	Major Flood Storage - online or offline	P	-	-	15	low	Large scale storage has potential to benefit large areas at risk from specific watercourses, although large storage areas in urban areas are not common.

**Notes:** (1) The Low, Moderate and High ratings are based on the following effectiveness scores: Low: <30; Moderate: 30-50; High: >50.

The following broad conclusions may be drawn from the analysis of the measures considered in Table 4.2, with high level categories of measures identified, supported by examples where appropriate.

#### 4.2.1 Category A – Non-structural Measures

Many **non-structural measures** can be relatively easy to implement quickly, but the real benefit is over the long term once the measure is “acted upon” and increases in scale over time. For example, planning policy regarding SuDS for new developments may be relatively quick to implement. However, it may be many years before there are sufficient new developments with SuDS in place to reap the benefits of lower runoff from the development area. These measures can be applied at a city-wide level.

#### 4.2.2 Category B – Source Control Measures

**Source control measures** vary in difficulty of implementation, and can be affected by whether they are proposed for new developments or retrofitted. For example, the simplest small-scale rainwater harvesting systems (water butts installed at domestic properties) can be very quick and easy to install. By contrast, a green roof cannot just simply be added to a property without significant amendments to the design. New builds, on the other hand, can have more complex (and more effective) rainwater harvesting systems and green roofs included as part of the design. These measures can be applied at a very localised level, but their implementation can be widespread, supported through policy and other non-structural measures.

#### 4.2.3 Category C – Receptor Protection Measures

**Individual receptor measures** have a clear link between the works being done and the benefit provided. For example, simple installation of flood boards at the entrance to a house, or riser steps to prevent flood water flowing directly into a garden flat, reduces the risk of flooding to that property. These measures are more likely to be implemented by the public and the benefit can easily be realised in the first flood event that is avoided. As for specific source control measures, they can be undertaken at a very local level i.e. one property at a time, but their implementation can be widespread.

#### 4.2.4 Category D – Maintenance Measures

**Maintenance of existing systems**, such as vegetation clearance (having regard to riparian owners), drain and gully clearance, removal of blockages from trash screens and ensuring the adequate operation of flap valves, are all likely to bring the biggest benefits over the shortest timeframe.

#### 4.2.5 Category E – Minor Works and Enhancements

**Minor works** to improve conditions at a local level are likely to bring significant benefits for a relatively low investment. The standard of protection of the works may not increase substantially, but the reliability of the measure may well be improved. Examples include improved trash screens to reduce the risk of blockage at culvert entrances, and strengthened (or replaced) short sections of wall that may be vulnerable to failure. Other minor works measures such as infilling gaps, raising low spots on defences, increasing the capacity of a short culvert section, or removing a constriction may well increase the standard of protection of the system as a whole. Whilst these

measures may require modest capital investments they can be considered to be “one-off” maintenance activities to enhance existing systems.

#### 4.2.6 Category F – Capital Options

**Capital options** may take several years to implement and typically the timeframe over which the benefits are realised may be a few decades. However, it is important to note that the benefits may be accrued much quicker. For example, if a significant flood event follows very soon after completion of the scheme, and the scheme performs as it is designed to, the damage avoided in that single event could outweigh the cost of the scheme (the recent flood defences constructed along the lower reaches of the River Dodder could be considered as a good example of this in relation to the recent flooding). However, there is no guarantee that this will be the case, and it may be many years before the scheme is put to the test.

The principles outlined above for the six categories of measures are demonstrated in Figure 4.2. This shows:

- How the timeframe for implementation and the time taken to get the benefits back from the measures varies – as plotted on the horizontal and vertical axes for typical measures in each category, shown in the blue boxes (one per category).
- How the scale of some measures changes over time, influencing their effectiveness – Category A and Category B measures.
- How the implementation for some measures continues for many years – indicated by “up” arrows for some measures.
- Other factors that can lead to the maximum benefits being gained from the measure – as indicated by the notes in the orange boxes that would cause the measure to “move to the left” – increasing its effectiveness.

For all measures being considered, Figure 4.2 provides a useful high level assessment of effectiveness for the short and long term.

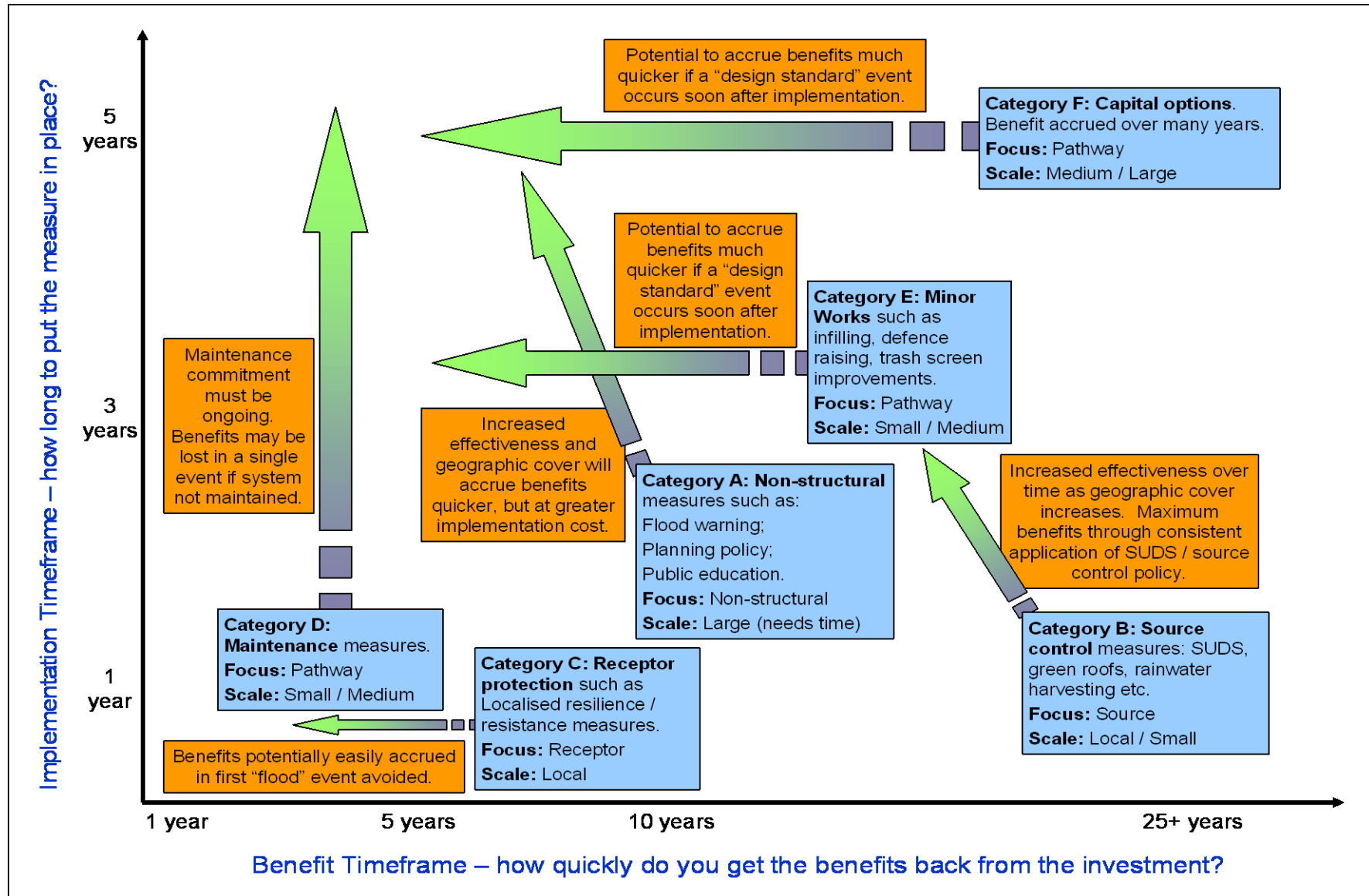


Figure 4.2: Implementation and Benefit Timeframes for Measures

### 4.3 Additional Influencing Factors

In evaluating the effectiveness of different measures, it is important to also consider other factors that influence flood risk from different sources.

Table 4.3 below identifies a range of factors that can influence the severity or scale of flooding from different sources. It is emphasised that these are “typical” levels of influence, and so for each specific flood risk within an area it is important to consider how these factors may truly influence flood risk based on specific conditions at a site.

The influencing factors broadly fit into two categories:

- **Weather and climate-related factors**
- and
- **Operational factors.**

Clearly, operating authorities have no influence over the weather and climate related factors. By contrast, the operational factors are in the control of operating authorities. However, both types of influencing factors must be taken into account when developing appropriate flood risk management strategies and measures.

**Table 4.3: Factors typically influencing the impact from various flood sources**

Flood Risk Source	Drainage (1)	Pluvial (1)	Small Streams (non-tidal) (1)	Rivers (non- tidal) (1)	Rivers (tidal) (1)	Coastal (1)	Dam- breach** (1)	Total Score	Average Score	Overall Influence (2)
<b>Weather and Climate Related factors</b>										
Extreme Tide levels	3	1	0	0	4	4	0	12	1.7	M
Wind direction / strength	0	1	1	2	2	4	3	13	1.9	M
Short Duration Extreme Rainfall	4	4	4	3	2	0	3	20	2.8	H
Long Duration Extreme Rainfall	3	3	3	4	2	0	4	19	2.7	H
Soil Moisture Deficit	3	4	3	4	2	0	4	20	2.9	H
Climate Change	2	3	3	2	3	4	3	20	2.9	H
<b>Operational factors</b>										
Screen Maintenance	0	0	4	4	2	0	0	10	1.4	L
Gully / Culvert / Outfall Maintenance	4	3	1	1	3	2	0	14	2.0	M
Channel Maintenance	0	1	4	2	1	0	0	8	1.1	L
Wall / Embankment Maintenance	1	1	2	2	4	4	0	14	2.0	M
Flood Warning*	1	2	2	2	3	3	2	15	2.1	M
Emergency Planning*	1	2	2	2	2	3	4	16	2.3	M

**Notes:**

(1) Scoring: Significance of Influencing Factor on Severity of Flood Risk in terms of Impact: 0 – Not significant; 1 – Low; 2 – Moderate; 3 – High; 4 - Very High.

(2) Overall influence: <1.5 – Low; 1.5 - 2.5 – Moderate; >2.5 High.

\* in some flood situations such a pluvial, it may not be possible to provide sufficient advance warning.

\*\* Dublin City Council dams are regularly inspected are designed to a standard equivalent to a theoretical Probable Maximum Flood.

Table 4.3 shows that overall, the weather and climate related factors give rise to the highest aggregate influence on all flood risks. However, it is important not to look at this in isolation as some factors are critical in terms of their influence on some flood risk sources, but not on all sources. Table 4.3 therefore also highlights those flood sources that are highly influenced by particular factors, as indicated by the orange shading.

It is emphasised that because of the generic nature of Table 4.3, no weighting is applied to each of the factors because the importance of one over another is strongly dependent on the **pathway** and **receptor**. When considering multiple flood risks in a location, weighting different factors in terms of overall importance may be appropriate.

This matrix should therefore be used when looking at specific locations, to ensure that any measures or action plans being considered take due account of these influencing factors in the evaluation, planning, design and operations stages.

#### 4.4 Measures Identified for Each Administrative Area

The analysis of the data gather for the flood event of 24<sup>th</sup> October highlighted a number of existing problems in specific areas, for which measures are considered, as well as identifying broader scale measures to be applied across the whole of the Dublin area.

In each of the following sections, the emphasis is on identifying “early wins” and measures that are clearly appropriate based on the findings of the flood event review. The measures identified do not imply that these are the solution to the problem – they are recommended as part of the solution, and in many cases will be most effective when combined with other measures. Those “other measures” are not necessarily apparent at this stage, and further investigation and development of measures will be required.

The measures proposed are also identified as falling in to one of the six categories identified in Section 4.2 as follows:

- Category A – Non-structural Measures
- Category B – Source Control Measures
- Category C – Receptor Protection Measures
- Category D – Maintenance Measures
- Category E – Minor Works and Enhancements
- Category F – Capital Options<sup>5</sup>

In identifying the measures described in each of the following sections, due account has been taken of the evaluation tools and models described above as follows:

- **Source-Pathway-Receptor** Model shown in Figure 4.1;
- **Effectiveness Scoring** Method from Table 4.1, as applied to the Measures in Table 4.2;
- **Implementation and Benefit Timeframes** of measures, as shown on Figure 4.2;
- **Additional Influencing Factors** as listed in Table 4.3.

<sup>5</sup> As river catchments do not align with Local Authority boundaries, flood risk reduction schemes generally require full catchment studies before significant capital works can be constructed.

For **all areas** early consideration and emphasis must be given to **measures that reduce the risk of injury and risk to life**. For garden flats and below-ground facilities consideration should be given to the possibility of installing water level warning alarms and means to ensure quick egress from the garden flat or facility is possible should it start to flood.

#### 4.4.1 North Central Area

Within this area, Dublin City Council have completed a full catchment study for the Wad catchment and are currently moving towards construction.

A combination of minor work/designated pathway measures (Category E), receptor measures (Category C) and maintenance measures (Category D) should be considered in the North Central area. These are outlined as follows:

- a) Reducing risk associated with combined pluvial and fluvial flooding in the vicinity of the Naniken River will require local receptor measures to be considered where risk is greatest. A number of properties are known to have flooded in past events, some works such as Swales have been incorporated locally, but in major events the capacity of the Swales can be overwhelmed and individual property measures should be explored.
- b) The existing pumping stations maintenance programme at Clontarf should be reviewed to ensure the system is resilient to extreme events.
- c) In the Kilbarrack area, designated pathway measures should be explored. Flooding of highways and open parkland was experienced.

#### 4.4.2 North West Area

A combination of receptor measures (Category C), maintenance measures (Category D) and minor work/designated pathway measures (Category E) should be considered in the North West area. These are outlined as follows:

- a) Reducing risk associated with combined pluvial and fluvial flooding in the vicinity of the Wad Rivers will require local receptor measures (e.g. individual property protection, door boards and air brick covers) to be considered where risk is greatest. The WAD strategy outlines a number of measures for flood risk reduction in the area and properties known to flood would likely benefit from local receptor control.
- b) Improved maintenance measures (category D) should be considered in the southern part of this area. A number of gully capacity issues were reported which resulted in pluvial flooding. The capacity of these gullies should be reviewed.
- c) A number of foul sewer flooding incidents were reported in the south of the area. Minor works and enhancements should be considered alongside designated pathway measures for surface water in the vicinity, this will help ensure foul sewers are not surcharged by surface water in extreme events.

#### 4.4.3 Central Area

A combination of receptor measures (Category C), maintenance measures (Category D) and minor work/designated pathway measures (Category E) should be considered in the Central area. These are outlined as follows:

- a) A number of known combined pluvial/fluvial flooding issues in East Wall will require a combination of receptor measures (resistance and resilience measures) and improved maintenance to address local problems. Designated storage is unlikely to be feasible due to the density of the developed area, however minor works to kerb heights and gully capacity may keep flooding in roads at some key locations. This approach would need to be linked with community resilience partnering.
- b) In the Cabra area, flooding from fluvial sources was noted. The capacity of the Bradogue river should be investigated and minor improvement works considered. Pathway and maintenance measures for surface water in the Cabra area should also be investigated due to the interaction between pluvial and fluvial flooding in the area. A number of overflowing gullies were reported, but this is most likely attributed to the capacity of the system.
- c) Maintenance measures in the vicinity of Phoenix Park should be reviewed to maintain gully capacity in the area.
- d) Local receptor measures should be explored in Ashtown where pluvial water storage is partly addressed by recently implemented swales, but in extreme events the capacity of the swale can be exceeded.

#### 4.4.4 South Central Area

A combination of non-structural measures (Category A), receptor measures (Category C), maintenance measures (Category D), minor work/designated pathway measures (Category E) and capital measures (Category F) should be considered in the South Central area. These are outlined as follows:

- a) Maintenance measures should be investigated for the Camac and the Poddle<sup>6</sup>. The Camac burst its banks in several locations, this was particularly bad in and around Lady's Lane, Kilmainham and Inchcore. Both receptor measures and where appropriate capital measures should be considered where these can be economically justified. The capacity of culverted as well as open sections of the Poddle should be examined and screening arrangements reviewed.
- b) Maintenance of highways drainage systems should also be explored due to the interaction between Pluvial and Fluvial flooding around the Camac.
- c) Receptor measures should be considered a priority in the Harolds Cross area. A number of garden flats posing risk to life are present. The combined Pluvial and Fluvial risk from the Poddle was also particularly evident at Poddle Park and Cloyne Road, Kimmage.
- d) Non structural measures in the Harolds Cross area should also be explored. Some form of property based flood alarm system is important to consider where the risk to life is present along with safe and quick means of escape. Should flood warnings be possible this would also be beneficial. **Such measures could also have significant benefit for other areas and should be considered more widely.**

<sup>6</sup> Note: Following a meeting held between Dublin City Council and the Office of Public Works to consider the flooding on 24<sup>th</sup> October, the Office of Public Works are prepared as part of the River Liffey CFRAMS, which is at an early stage and due to report in December 2015 (earliest), to bring forward a study of the Camac River and the Poddle River in order to identify potential improvement schemes. Both these rivers involve works in more than one Local Authority.

**4.4.5**

**South East Area**

A combination of non-structural measures (Category A), receptor measures (Category C), maintenance measures (Category D), and capital measures (Category F) should be considered in the South East area. These are outlined as follows:

- a) Major capital works should be considered to separate the combined foul and surface water system in the vicinity of Pearse Square, Lansdowne, Ringsend, Sandymount and Ballsbridge.
- b) Non structural measures in the Pearse Square, Lansdowne, Ringsend, Sandymount and Ballsbridge area should also be explored. Some form of property based flood alarm system is important to consider where the risk to life is present along with safe and quick means of escape. Should flood warnings be possible this would also be beneficial. Garden flat flooding was particularly severe at Pearse Square and early consideration should be given to measures for this area, including community resilience measures.
- c) Maintenance measures associated with the pumping of surface water from southern Sandymount, in the vicinity of St. John’s Road, should be considered. Garden flat flooding in this area also poses a risk and non-structural measures should also be explored. Some form of property based flood alarm system is important to consider where the risk to life is present along with safe and quick means of escape from garden flat or underground facilities. Should flood warnings be possible this would also be beneficial.
- d) A number of foul sewer flooding incidents were reported in the west of the area. Minor works and enhancements should be considered alongside designated pathway measures for surface water in the vicinity, this will help ensure foul sewers are not surcharged by surface water in extreme events.

# 5 Conclusions and Recommendations

## 5.1 Conclusions

### 5.1.1 General Observations

The flood event of 23<sup>rd</sup>/24<sup>th</sup> October cannot be solely attributed to one cause. The combination of two rainfall events over the two day period combined with the overtopping and surcharging of a number of flood management assets led to a complex scenario that resulted in flooding across the city. Flooding from all main urban and fluvial sources was experienced, which impacted each of the 5 districts in the City to varying degrees.

The City Council made efficient and timely decisions to retain staff on the afternoon/evening of the 24<sup>th</sup> October, despite initial indications that the rainfall event was unlikely to be larger than that experienced on the 23<sup>rd</sup> October. This enabled the council to implement its emergency response plans as soon as the risk of flooding became apparent.

Council staff and the emergency services effectively combined their resources to manage the incident as proactively as possible, but due to the intensity of rainfall during the latter part of the event and the subsequent city wide flooding that occurred, resources were severally stretched and communications were put under considerable strain. Over 1100 flood incidents were reported and the Fire Service response centre struggled to cope with the volume of calls.

Although, in many cases Council staff were unable to directly intervene to reduce the impact of flooding on the ground due to the extreme nature of the flood event, their presence was very much welcomed by the public. Staff were able to help redirect traffic and protect the public from moving into flooded areas. However, some members of council staff did feel helpless when faced with the significant flooding and felt that they should have been able to do more, but to do so would have posed a risk to Council worker’s lives.

Particularly successful flood risk management and drainage asset improvements included;

- Flood defence improvements alongside local property resilience measures to protect property that had flooded during past events in 2002 and 2008, prevented a number of properties from flooding on this occasion.
- Proactive gully management in Holly Bank Road, a known ‘Hot Spot’, kept flood waters low and prevented local property flooding.
- Swales constructed in the North West district, built to protect 14 properties performed well and prevented flooding to 10 at risk properties.
- Recently constructed flood defences along main rivers prevented the situation from being much worse.

Dublin’s drainage system is extremely complex, consisting of both natural open and culverted water courses. A review of a 1991 publication on the historic rivers of Dublin reveals some 43 ‘river’ channels within the city, many of which have been lost or now run underground in capped culverts and channels, these watercourses play a

significant part in the transport of surface water from the urban areas of Dublin. Many of these watercourses are significantly constrained by their capacity and restrict the conveyance of surface water during an extreme rainfall event.

## 5.2 Principal findings from data review

### 5.2.1 Rain fall analysis and event probability

It is of particular relevance that the Met Éireann warning issued for 23<sup>rd</sup> October was for similar rainfall to that which fell on the City on 1<sup>st</sup> October 2011 which amounted to 60 mm and that event did not cause any major or significant flooding in the City.

The initial rainfall event of 23<sup>rd</sup> October was not of a particularly large intensity, depositing an average 25mm of rain across the city. However, water levels in both the Rivers and Urban Drainage system (surface water sewers and highways drains) would have been significantly charged by this event. While there was no specific flooding associated with this initial rainfall the charging of the watercourses would have been significant.

Rainfall on the 24<sup>th</sup> October, which across most of Dublin followed a 1 to 2 hour period of no rain, lasted for between 8 to 10 hours, with the intensity peaking towards the end of the event around 22mm per hour. This resulted in significant charging of a virtually full, city wide, drainage system. Peak rainfall intensity at the end of the event resulted in surcharging of both the watercourses and urban drainage systems across Dublin.

The probability of the combined rainfall events across the 23<sup>rd</sup> and 24<sup>th</sup> October, has been estimated to be in the order of a 1 in 100 annual chance (probability) in any one year in some locations and between 1 in 50 and 1 in 100 chance across some 80% of Dublin.

The existing urban drainage infrastructure varies in design standard, from older drainage networks, some of which have combined surface and foul systems in the city centre, to more recent separate systems on the cities northern and southern outskirts. During this flood event both old and new systems were overwhelmed in many instances.

The design standard of much of the existing drainage system in Dublin is such that an event of this magnitude will inevitably result in flooding and that the resilience and emergency response procedures of the city are as important as the physical flood resilience and resistance measures in place.

### 5.2.2 Flooding in each district

#### North Central Area

**Key observations: Flooding from Fluvial and Pluvial sources, isolated sewer flooding and isolated infrastructure failure.**

- In the North Central area both land and property was flooded, likely to have been caused by a combination of pluvial and fluvial flooding associated with the Rivers Naniken and Wad, with a number of known ‘hot-spot’ areas impacted. Flooding of this type is commonly caused where surface water cannot enter a full watercourse

and ‘backs-up’, resulting in highway and surface water systems becoming overwhelmed.

- Records show that past flood events have resulted in Sewer flooding in the Beaumont area. Sewer flooding was again experienced in this area, but on this occasion a larger surface water component was observed.
- Pluvial impacts were associated with highway drainage and open parkland around the Kilbarrack area.
- Other sporadic instances of sewer flooding and pluvial flooding were also identified throughout this district.
- Disruptions in this district included property flooding/damage, traffic issues, and flooded car parks.

### North West Area

**Key observations:** *Flooding from Fluvial and Pluvial sources, isolated sewer flooding with some infrastructure damage.*

- Flooding in the northern part of this area was generally caused by a combination of pluvial and fluvial flooding associated with the Wad River.
- To the south, pluvial flooding occurred due to surcharged surface drainage systems with sporadic instances of sewer flooding.
- Disruptions in this district included property flooding/damage, traffic issues due to impassable roads and flooded footpaths. It was also noted that a wall collapsed at Ballygall Crescent.

### Central Area

**Key observations:** *Flooding from Fluvial and Pluvial sources, at known ‘hot-spot’ locations, minor and isolated sewer flooding with some relatively new infrastructure overwhelmed.*

- Significant flooding in the vicinity of East Wall was experienced. This flooding was mainly attributed to known issues with the existing drainage system, likely to have been caused by pluvial flooding, due to surcharging of the surface drainage system.
- In Cabra, flooding appears to be mainly associated with the fluvial flooding of the Bradogue River in combination with pluvial flooding.
- Pluvial flooding attributed to capacity in the surface drainage system occurred in a residential area to the north east of Phoenix Park.
- Other sporadic instances of sewer flooding and pluvial flooding were identified throughout this district.

## South Central Area

**Key observations:** *Significant flooding from Fluvial and Pluvial sources, which posed significant risk to life, potential blocking of key infrastructure and some minor and isolated sewer flooding.*

- Flooding associated with the Camac river, which burst its banks at a number of locations in Kilmainham and Inchicore was observed. Flooding was particularly severe in and around Lady's Lane area where flooding associated with the Camac River was exacerbated by physical constriction of the watercourse and by pluvial flooding backing up within the highway drainage system and surface water sewers. Collapse of a building adjacent to the watercourse was reported in this area and damage in general was severe.
- Extensive flooding occurred in the Harold's Cross area. This was again attributable to a combined pluvial and fluvial event, with water overtopping the banks of the River Poddle upstream of the culverted section and significant backing up of drainage systems. This was particularly evident at Poddle Park Road and Cloyne Road, Kimmage.
- Blocking of screens on the Poddle may have reduced flow capacity in some areas. Due to their design, these could not have been cleaned during the event without significant risk to operational staff.
- As with the other districts, sporadic instances of sewer flooding and pluvial flooding were identified.
- Disruptions in this district included property flooding/damage and traffic issues due to impassable roads. **Garden flat flooding** was identified in Harold's Cross causing a risk to life and significant **public safety** issues. This is however a **much wider issue** due to the very large number of garden flat properties across Dublin. The risk also applies to **below-ground facilities** such as low level car parks or loading areas to commercial premises.

## South East Area

**Key observations:** *Flooding from Fluvial and Pluvial sources, known 'hot-spot' locations from combined Foul and Surface water systems, significant risk to life due to garden flat flooding and minor and isolated sewer flooding incidents .*

- Extensive flooding in local areas covering Pearse Square, Lansdowne, Ringsend, Sandymount and Ballsbridge attributable to low lying land and in particular the backing up of the largely combined surface and foul sewer system was observed.
- Local flooding in the south east of this district, Sandymount, in the vicinity of St. John's Road was attributable to the capacity of the pumping station here. Garden flat flooding was also experienced in this area.
- The western part of this district was characterised by local sporadic instances of sewer flooding and pluvial flooding. Part of Harold's Cross area is located within this district (see the South Central Area above).
- Disruptions in this district included property flooding/damage and traffic issues due to impassable roads. Garden flat flooding was identified at a number of locations in this district but notably at Pearse Square causing a risk to life and public safety as well as severe damage. It was fortunate that there was no reported injury or loss of life.

5.3

Recommendations

A number of recommendations are presented based on this flood event review. These draw upon data supplied up to 28<sup>th</sup> November, observations made on site during a number of site visits and from face to face meetings on Friday 2<sup>nd</sup> December 2011 with key Dublin City Council staff involved in the management and response to the flood.

The following recommendations fall into a number categories and have been grouped to reflect key areas. These should be **considered in conjunction with the Mitigation Measures outlined in Section 4.4.**

In introducing new policy measures it may be that legislative changes can be considered both a national and local level to support or reinforce these.

While property owners in general and riparian owners (i.e. property owners whose curtilage is either bordered or traversed by a watercourse) have particular responsibilities in relation to the prevention of flooding and protection of their own property (Reference 3), the State, including Dublin City Council, has traditionally played a major role both in dealing with the effects of flooding and taking action to minimise the risk of future flooding. However, current legislation relating to flood risk management under which Local Authorities operate is restrictive and deficient in some aspects (Reference 4), and requires review at a national level in order to implement recent national flood risk management policies. Changes in flood risk legislation have recently been implemented in the UK and these include clarification of responsibilities.

5.3.1

Flooding mechanisms and assets operation

1. ***The risk associated with Historic Rivers in Dublin must be assessed in the strategic management of flood risk across the city.*** It is clear from this event that there is a close interaction between the small watercourses and pluvial flood events. The capacity of the assets, both open channel and culverted sections, should be risk assessed and any flood risk management asset be recorded. Early attention should be given to constrained and/or steeply sloping sections of open watercourse such as the Camac at Kilmainham.
2. ***In the more 'leafy' suburbs of the city, consideration should given to enhanced maintenance of road gullies and drains.*** High intensity rain events can often push leaves into gully pots and cause blockage. Whilst it is not feasible for the council to dedicate resource purely to clearing leaves that might block gullies, it would perhaps be possible for community representatives to assist in known hot-spot locations.
3. ***The performance of trash 'racks and screens' during flood events should be reviewed and culvert capacity should be considered.*** In a number of locations across the city, especially on the River Poddle, trash screens and racks need to be cleaned manually. In a flood event they can rapidly block and access cannot be obtained to clean them until flood water has receded. Effective screen design is an important consideration. In an event such as experienced on the 23<sup>rd</sup> and 24<sup>th</sup> October, it is unlikely that there is sufficient time to clean the screens between events and therefore they can act as serious constrictions. The culvert capacity in itself can act as a constriction. Although effective screen design and monitoring aim to minimise the risk of blockage during a flood event, the event itself can introduce debris on such screens and racks. CCTV may be used at known 'hotspot' locations to monitor this risk. Safety issues for clearance of screens need to be considered.

4. **‘Roads as Rivers’**. As part of broad city-wide flood risk management and incident response planning the use of non-essential roads for water conveyance and parking areas, or other open space, for flood storage should be considered ideally one in conjunction with the other. Communicating such considerations must be carefully handled with the public and emergency services such that it is understood that some roads may be impassable during a flood event.

### 5.3.2 Community Resistance and Resilience

5. **Establish a series of Resilience Groups across Dublin**. Resilience groups were piloted at East Wall, along the River Dodder and at Sandymount. These have had limited success to date, with only the community at East Wall retaining some involvement. It is recommended that key community groups should be approached following this event.
6. **A thorough review of the flood risk to garden flats and other below-ground infrastructure across the city should be prioritised**. This is a **primary and priority recommendation**. The potential for rapid inundation of garden flat properties poses a significant risk to life and public safety in a flood event and owners/property managers should be made aware of the potential risk. This also applies to other below-ground infrastructure such as low level car parks or loading areas. Even low level sections of transportation systems such as the rail network may pose a risk to public safety. **Simple but effective measures** can also be considered as an early response, such as the installation of audible as well as visible water level alarm systems, but also ensuring that a quick means of egress exists should flooding start to occur.

## Appendix A Drawings

Included in this appendix are the following drawings:

### **Figures 1.1 – 1.6**

Identified flood type at reported flood locations for Dublin City and each administration area.

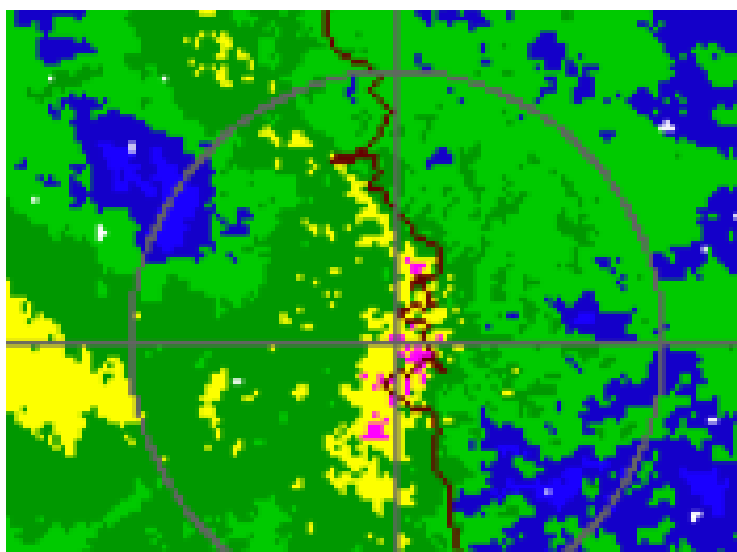
### **Figures 2.1 – 2.6**

Identified flood severity at reported flood locations for Dublin City and each administration area.

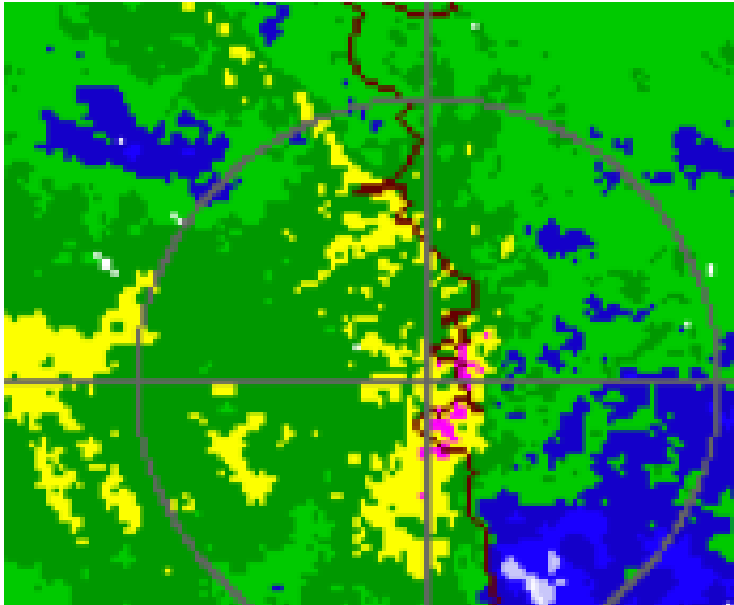
## Appendix B Radar Rainfall Information

Met Éireann has provided images of rainfall intensity at 15-minute intervals for the period covering the most intense part of the rainfall event of 24 October, from 1500UTZ to 2000UTZ. Note that UTZ equates to Greenwich Mean Time, so are 1 hour later than BST in Dublin in October. The images, produced by the high-resolution weather radar at Dublin Airport, show intensity averaged for 1km pixels. The salient features revealed on the localised nature of the rainfall, its persistence and lack of movement, and sustained intensities exceeding 9.2mm/hr and reaching more than 20mm/hr at times.

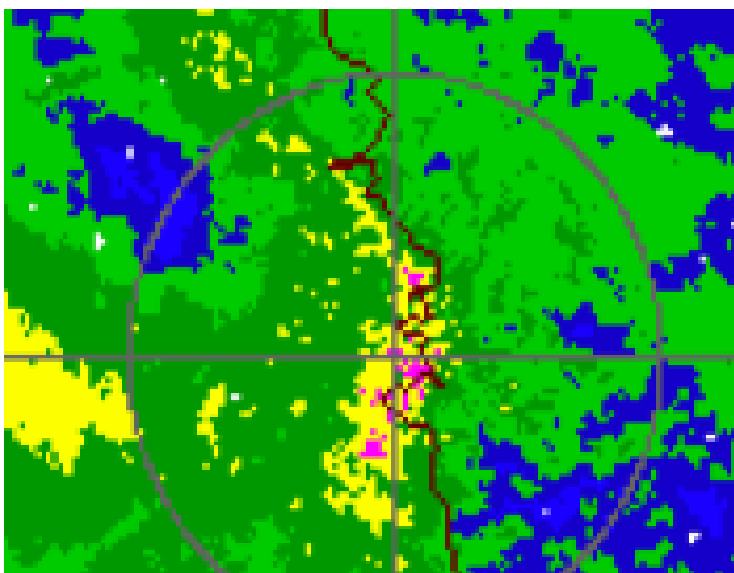
From 1500 to 1630 there are two distinct areas of rainfall, one lying about 80-100km west of Dublin, the other from the west of the city out to about 50km. Both bands are elongated south to north, with the western band being more active (larger area of high intensity) during this period. After 1630, both bands become narrower and begin to segment. By 1730-1745, both bands have become much more localised, and the western is producing only light-moderate rain (3.7mm/hr). During this time, and continuing up to 1945, the eastern band remains just inland from the coast, extending from the north of the Wicklow Mountains to about 20km north of Dublin Airport. Peak intensities stay high, and are illustrated by the following sequence of three accumulations from 1800-1830.



a) Average rainfall intensity 1745-1800 UTZ, 24 October 2011



b) Average rainfall intensity 1800-1815 UTZ, 24 October 2011



c) Average rainfall intensity 1815-1830 UTZ, 24 October 2011

Note that the circle on the images is a 50km radius centred on Dublin Airport Radar.

Individual areas of intense rainfall are only of a few pixels in extent. This indicates that localised convection may have been triggered by small-scale uplift, driven by the influence of the coast and uplands on the frontal alignment, and prevailing wind.

# Appendix C Hyetographs

Hyetographs (a graphical representation of the distribution of rainfall over time) showing 15-minute rainfall and cumulative rainfall are provided for the meteorological stations in Figures C1 to C5:

- Ballymun
- Ringsend
- Phoenix Park
- Roundwood
- Brittas

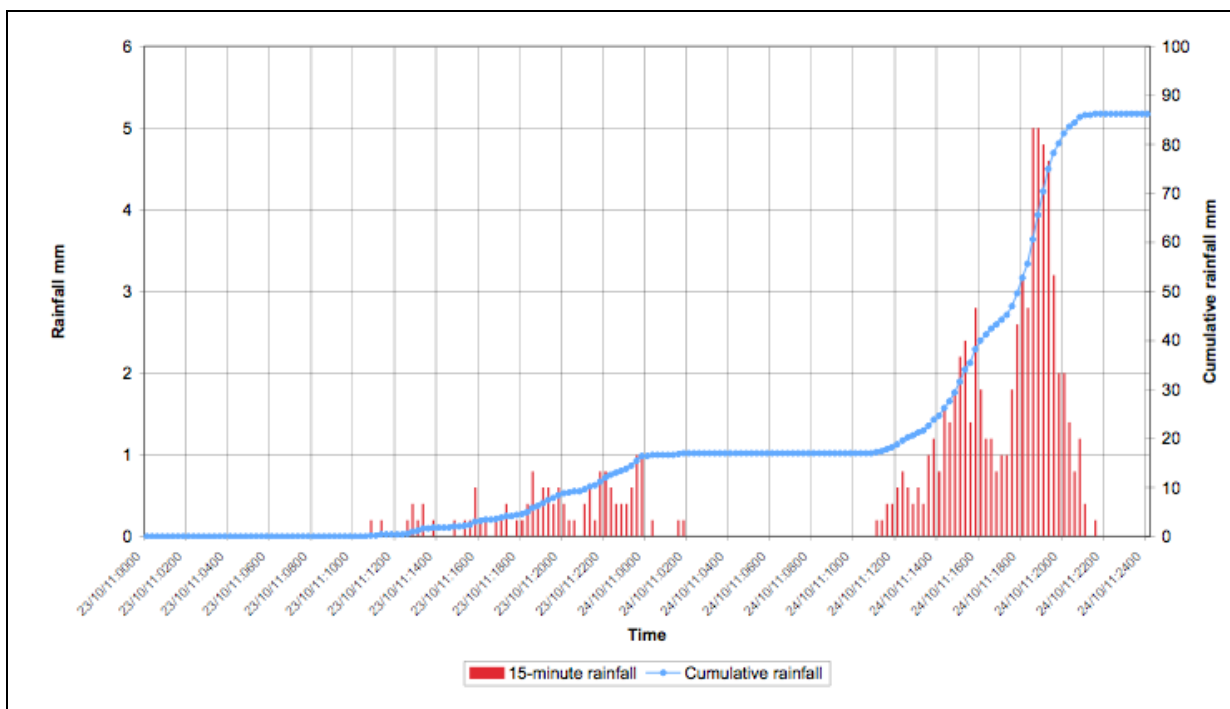


Figure C1. Hyetograph for Ballymun – north Dublin City

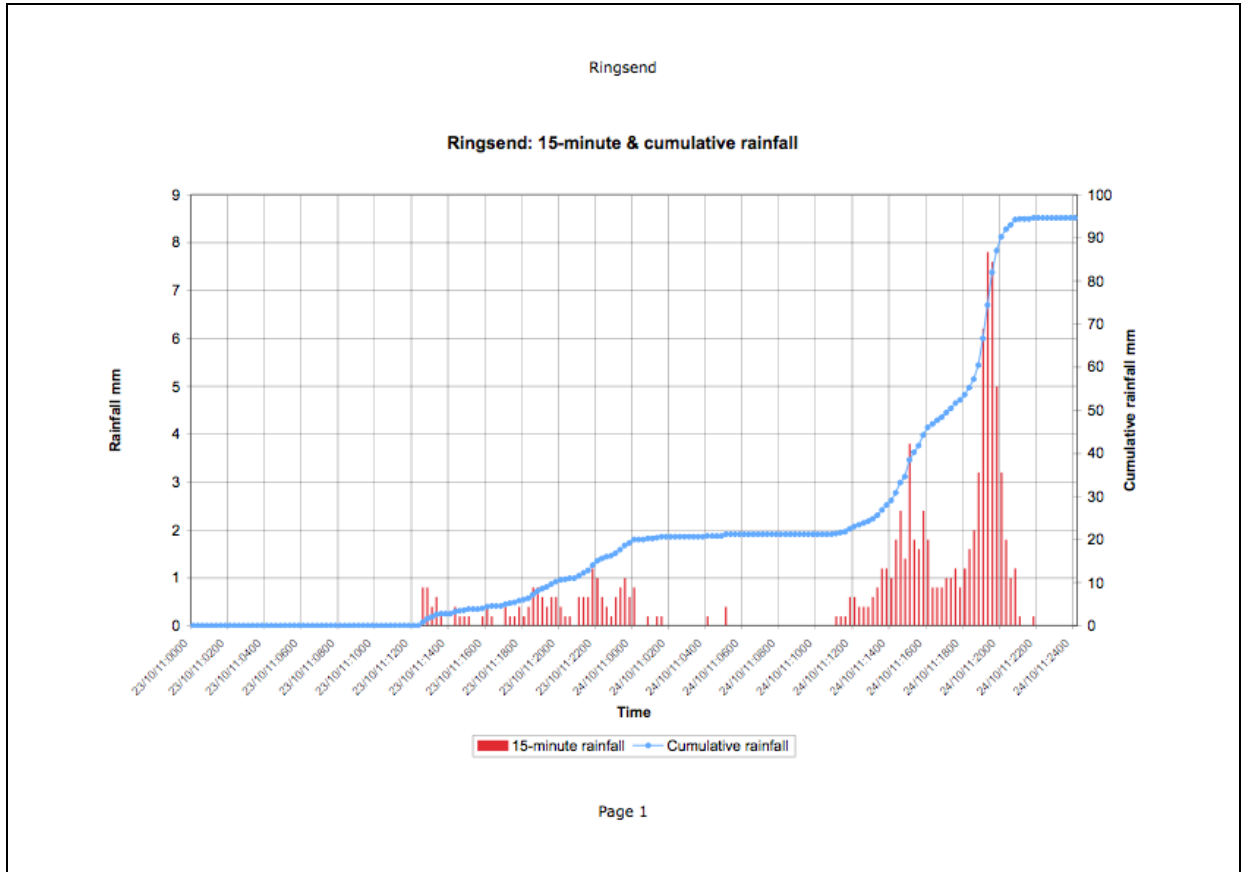


Figure C2. Hyetograph for Ringsend – East Central

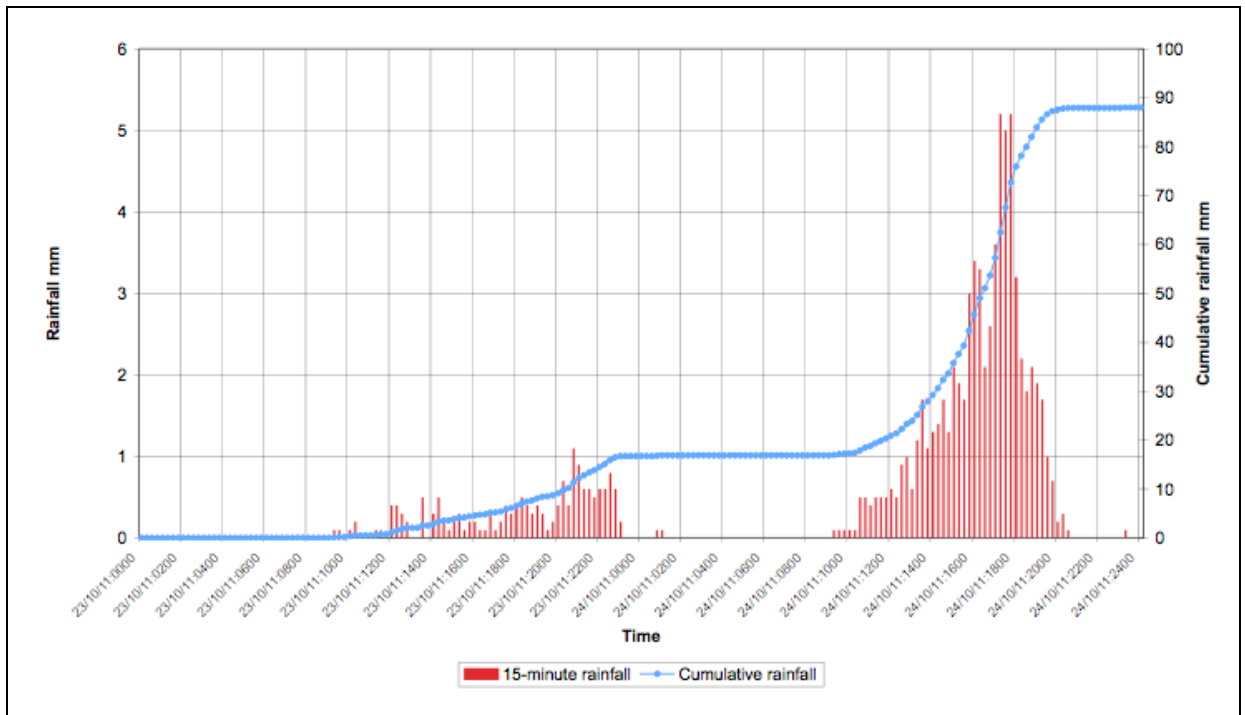
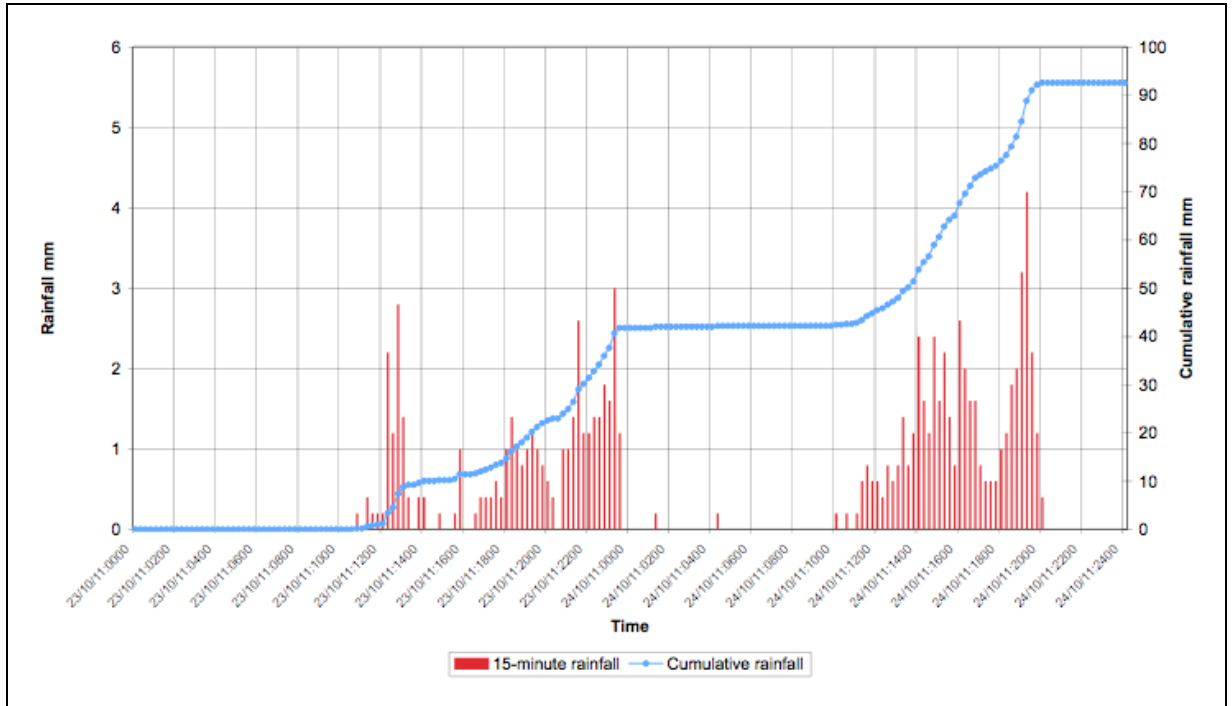
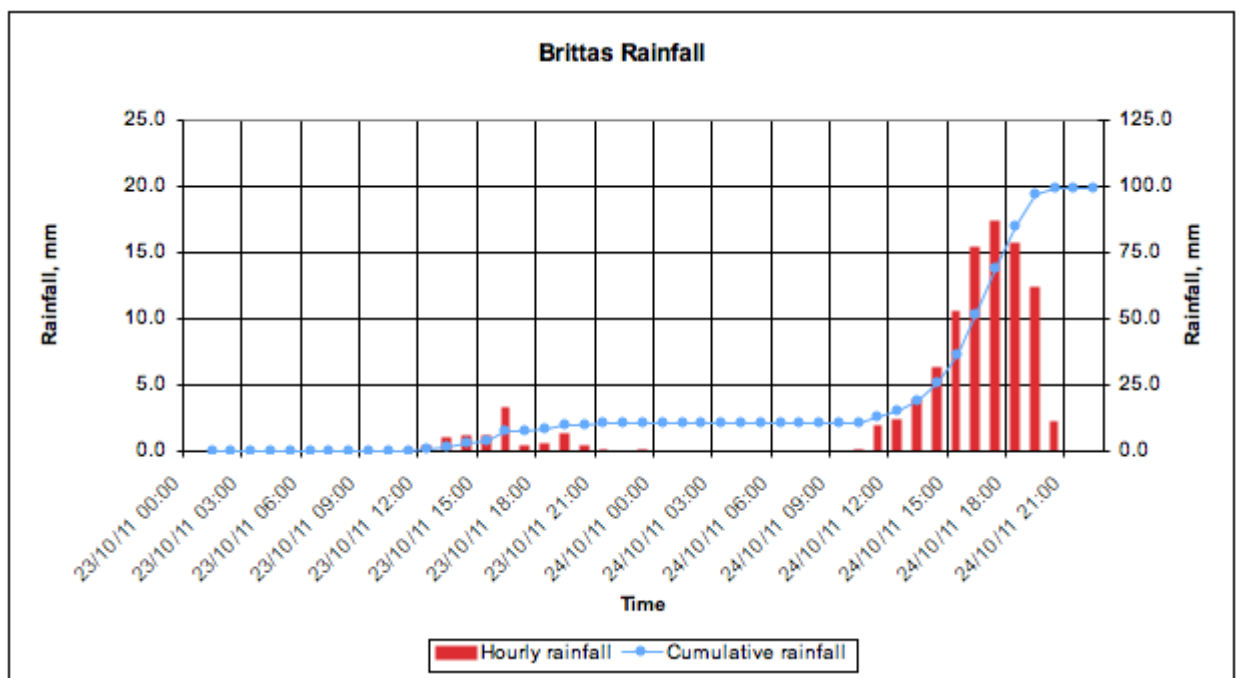


Figure C3. Hyetograph for Phoenix Park – central / west Dublin City



**Figure C4. Hyetograph for Roundwood – outside SE of city**

Data from a number of telemetry raingauges operated by South Dublin County Council (SDCC) to the south-west of Dublin are available, but these are only available for 1-hour clock intervals. The hyetograph for Brittas shown in Figure C5 is representative of this area.



**Figure C5. Hyetograph for Brittas – SW Dublin**

## Appendix D Probability of the event at each raingauge

The table below is a repeat of Table 2.2 from Section 2.5, and provides the basis of the analysis used to estimate the rainfall event probability.

### Maximum rainfall by duration for 24<sup>th</sup> October 2011

Raingauge	Duration				
	15 min	30 min	1 hr	2 hrs	3 hrs
Roundwood	4.4	7.8	12.0	17.0	20.4
Ballymore	3.2	6.0	10.4	18.4	24.6
Bohenabreena	5.2	10.0	18.0	15.0	25.0
Ringsend	8.2	16.0	26.8	37.2	42.0
UCD Horticulture	6.0	10.8	15.0	19.8	25.0
Ballymun	5.2	10.2	19.6	31.2	38.0
Grange	8.2	15.0	25.6	34.4	39.2
Civic Offices	7.4	14.4	25.6	38.6	45.6
Phoenix Park	5.5	10.4	19.3	30.6	40.7
Dun Laoghaire Harbour	10.9	19.7	29.7	35.6	39.0

The values in the Table above can be directly compared to the depth-duration frequency (DDF) reference data (Reference 4). In Tables D1 to D5 a representative reference 2km grid square has been selected for each of the five Dublin City Council Operational Areas. For each area, the tables give the DDF design rainfall quantity for a range of return periods and durations: the final row of each table gives the recorded maximum depth for the 24<sup>th</sup> October event at a representative tipping bucket raingauge (TBR) within that Operational Area. Where a measured rainfall exceeds any DDF value, this has been highlighted in orange: the return period (or annual chance event) value which those measurements exceed has also been highlighted. This provides a rapid assessment of the probability range of rainfall occurring within the different operational areas. DDF index values were exceeded for durations of 1-hour and longer, with most of the probability levels lying between the 1 in 20 and 1 in 50 annual chance events but in places up to 1 in 100 (20 year to 50-year and up to 100 year return periods).

**Table D1: North Central Operational Area**

Return Period	Duration					
	15 min	30 min	1 hour	2 hours	3 hours	4 hours
10 years	11.9	15.1	19.2	24.3	27.9	30.8
20 years	14.5	18.2	22.9	28.8	33.0	36.3
50 years	18.6	23.1	28.8	35.8	40.7	44.6
100 years	22.3	27.5	34.1	42.1	47.7	52.1
<b>Ballymun</b>	5.2	10.2	19.6	31.2	38.0	42.2

**Table D2: North West Operational Area**

Return Period	Duration					
	15 min	30 min	1 hour	2 hours	3 hours	4 hours
10 years	12.6	16.0	20.3	25.7	29.5	22.6
20 years	15.6	19.6	24.6	31.0	35.4	39.0
50 years	20.3	25.3	31.5	39.2	44.6	48.9
100 years	24.7	30.6	37.8	46.8	52.9	57.8
<b>Phoenix Park</b>	5.5	10.4	19.3	30.6	40.7	48.0

**Table D3: Central Operational Area**

Return Period	Duration					
	15 min	30 min	1 hour	2 hours	3 hours	4 hours
10 years	12.4	15.9	20.2	25.5	29.3	32.3
20 years	15.5	19.4	24.4	30.7	35.1	38.7
50 years	20.2	25.1	31.3	38.9	44.3	48.5
100 years	24.6	30.4	37.5	46.4	52.6	57.4
<b>Civic Offices</b>	7.4	14.4	25.6	38.6	45.6	50.2

**Table D4: South Central Operational Area**

Return Period	Duration					
	15 min	30 min	1 hour	2 hours	3 hours	4 hours
10 years	13.0	16.5	20.9	26.6	30.5	33.7
20 years	16.2	20.4	25.7	32.3	37.0	40.7
50 years	21.5	26.7	33.3	41.5	47.2	51.7
100 years	26.4	32.7	40.4	49.9	56.5	61.7
<b>Johnstown*</b>	-	-	21.2	36.4	50.2	60.6

\* Note: Johnstown is a SDCC raingauge about 1km west of the city boundary, providing hourly data only.

**Table D5: South East Operational Area**

Return Period	Duration					
	15 min	30 min	1 hour	2 hours	3 hours	4 hours
10 years	13.1	16.6	21.0	26.6	30.6	33.7
20 years	16.2	20.3	25.6	32.2	36.8	40.4
50 years	21.2	26.4	32.8	40.9	46.5	50.9
100 years	25.9	32.0	39.5	48.9	55.3	60.4
<b>Ringsend</b>	8.2	16.0	26.8	37.2	42.0	46.0

## Appendix E Flood Risk Mitigation Measures

This information included in this appendix summarises a wide range of measures utilized to respond to flood risk, structured in the following tables:

Table E1: Generic Flood Risk Management Measures

Table E2: Community Flood Resilience Measures

Table E3: Site Specific Measures – Focus on Surface Water and Pluvial Flooding

Table E4: Site Specific Measures – Focus on River Flooding

Table E1: Generic Flood Risk Management Measures

Generic Measure	Scope of Application	Key Advantages	Risks	Relative Cost	Maintenance Level	Responsibility for Implementation
<b>Planning and Building Control</b>	Future developments, changes/alterations to existing development.	Relatively inexpensive and simple to implement. Potentially highly effective in reducing future flood risks.	Benefits may not be fully realised for some years.	Low	Low	Local Authorities
<b>Flood Warning and Enhancement of Flood Emergency Management</b>	Applicable to all stakeholders: Local Authorities, emergency services, other services (transportation, water and waste water treatment facilities, other utilities), commercial businesses, communities.	Improved emergency response to extreme rainfall events. Reduced impact on road network, local transport and associated services. Effective management of resources (staff and equipment). Effective communication.	Requires significant community education and engagement to ensure full take up of warning services and appropriate response.	Moderate	Required resources for hardware and software management, for related training and community awareness campaigns.	Local Authorities in partnership with Met Éireann and Office of Public Works.
<b>Development Policy and Urban Land-use Management</b>	Future developments, changes/alterations to existing development, future infrastructure, future development plans.	Improved sustainability and reduced flood risk to future developments. Avoids any worsening of flood risk to existing properties arising from future developments.	Benefits may not be fully realised for some years. Require political buy in.	Low	Low	Department of Environment, Heritage and Local Government
<b>Access Protection</b>	Residential and commercial properties with access at or close to street level or below street level.	In many cases can be relatively inexpensive and quick to apply.	Not suitable to all properties. Not effective against deeper flooding.	Low	Low	Owners/occupants of properties. Local Authority to support wider implementation.
<b>Enhanced Maintenance</b>	Highways gullies and drains, SuDS features, small local watercourses in open channels, culverted sections of small watercourses, sewers. Targeted high risk locations, known flooding hot spots.	Potential early win measure.	May result in an increase in existing flows in the below ground systems and exacerbate any weaknesses in these systems.	Low to Moderate	Required resources for regular upkeep.	Local Authority
<b>Green Roofs</b>	New development, existing developments with flat roofs (where structural check confirms acceptable for additional loading). More scope for large roof commercial/industrial buildings including schools, hospitals, shopping centres and other developments with	Minimises runoff through potentially useful volume of surface water storage available. Potentially significant amenity value. Potential improvements in water quality.	Expensive to retrofit. Cannot be fitted to light framed buildings despite large roof area (warehouses). Could require amendments to planning regulations to encourage take up.	Moderate	High	Owners/occupants of properties. Local authority for planning consents. Department of Environment, Heritage and Local Government for changes in regulations.
<b>Aggregated Micro-Storage</b>	Hard standing areas in built up areas - car parks, roof areas, sports facilities.	Potential to maximise benefit from many relatively small storage areas and optimise the control of this storage in real time.	May result in some areas temporarily out of service. Dependant on forecasting system and smart control.	Low to Moderate	Moderate to upkeep the smart control.	Local Authority but privately owned storage areas may be utilised with consent.
<b>Other Generic SuDS</b>	Applicable to new developments and upgrades of existing infrastructure.	Reduces run off volumes from large paved areas, enhances water quality when appropriately designed. Can be used as pathway measures alongside roads.	Structural and environmental aspects should be considered in design.	Moderate	Potentially high	Developers, National Roads Authority, Local Authority, property owners (e.g. using pervious paving for gardens)
<b>Rain Gardens</b>	Urban roads infrastructure, schools, hospitals, shopping centres and other developments with relatively large paved areas. Residential and commercial properties.	Reduces run off volumes, enhances water quality. Relatively easily and cheaply implemented. Additional amenity value. Can be installed in public and private places.	Only suitable for permeable ground conditions. Requires ongoing framework for adoption and maintenance.	Low	Potentially high	Developers, Local Authority
<b>Gully Enhancement and 'Gully Gardens'</b>	Urban roads infrastructure	Reduces run off volumes, enhances water quality. Easily and cheaply implemented.	Gully Gardens only suitable for permeable ground conditions. Requires ongoing framework for adoption and maintenance.	Low	Potentially high	Local Authority
<b>Vegetation Management</b>	Urban watercourses.	Increases capacity in conveying flood waters. Potential early win solution.	Should be treated as supplementary measure, used alone may not mitigate long term climate change effects.	Low	Moderate	Local Authority

Table E2: Community Flood Resilience Measures

Community Flood Resilience Measure	Scope of Application	Key Advantages	Risks	Relative Cost	Maintenance Level	Responsibility for Implementation
<b>Awareness Raising and Education</b>	Residential and business communities in areas historically and potentially affected by flooding.	Potential widespread benefit. May result in raising Local Authority profile and reputation. Enhances community preparedness and resilience to flooding.	May be difficult to manage expectations which might result in bad press. Requires resources and regular liaison.	Low to Moderate	Requires designated resources (community liaison officer).	Local Authority in dialogue with Community and Business Groups.
<b>Rainwater Harvesting including Leaky-Butts*</b>	Residential and commercial properties.	Effective in capturing and diverting potentially significant volumes of run off at source. Sustainable solution minimising overall water use. Easily applicable to new developments. Potential for re-use of waste plastics for manufacture.	Likely to require amendments to planning regulations and/or public engagement programme to encourage take up. Larger harvesting measures may be more difficult to retrofit.	Low to Moderate	Low to Moderate	Householders, Developers, Department of Environment, Heritage and Local Government for changes in regulations.
<b>Domestic Rain Gardens</b>	Residential properties.	Reduces run off volumes, enhances water quality. Relatively easily and cheaply implemented. Additional amenity value.	Only suitable for permeable ground conditions. Likely to require amendments to planning regulations and/or public engagement programme to encourage take up.	Low	Low	Householders, Developers, support by Local Authority.
<b>External Resistance Measures</b>	Residential and commercial properties.	Can be applied for individual property flood proofing where larger engineering works are not practical.	Dependant on effective warning system. Require installation works. Neighbouring properties may still be susceptible to flooding if adjacent property does not install or implement. Require management and maintenance plans if applied to community areas.	Moderate to High	Moderate. Require management and maintenance plans if applied to community areas.	Developers, owners/occupiers of properties, Local Authority.
<b>Internal Resilience Measures</b>	Residential and commercial properties in areas historically and/or potentially affected by flooding. Use in conjunction with resistance measures.	Limits damage and speeds up drying-reoccupation time. Provides “peace of mind” to occupiers. Can reduce internal structural damage.	Could be relatively expensive for residents if no grant/assistance programme is provided.	Moderate to High for individual occupiers unless grant assistance provided.	Moderate.	Developers, occupiers, Local Authority for financial assistance.
<b>Specific Garden flat Measures including Riser-Steps*</b>	Residential and commercial and properties occupying lower ground floor and garden flat premises. Use in conjunction with resistance and resilience measures.	Provides protection to highly vulnerable properties.	Risk that may not always be effective. Some measures require an effective warning system. Neighbouring properties may still be susceptible to flooding if adjacent property does not install or implement.	Moderate to High.	Moderate	Developers, occupiers, Local Authority for financial assistance.

Table E3: Site Specific Measures – Focus on Surface Water and Pluvial Flooding

Site Specific Measure	Scope of Application	Key Advantages	Risks	Relative Cost	Maintenance Level	Responsibility for Implementation
<b>Fringe Interception / Storage and Land Management</b>	Urban/rural fringe areas where surface runoff potentially enters urban areas.	Reduce pressure on urban drainage. Open space to implement.	May require extensive land management plan.	Moderate	Moderate	Local authority (Planning departments), Forestry, Landowners
<b>Enhance Existing Storage</b>	Existing reservoirs, attenuation ponds and wetlands.	New land intake not required.	Potentially some treatment of the run off required to avoid disturbing existing ecology. Compliance with regulatory requirements for reservoirs.	Moderate	Moderate	Local authority. Reservoir owner.
<b>SuDs storage</b>	Applicable to new developments and upgrades of existing infrastructure.	Reduces run off volumes from large paved areas, enhances water quality when appropriately designed.	Requires health and safety risks to be assessed and addressed in design.	Moderate	Potentially high.	Developers. Local Authority.
<b>GreenWaterSpace Storage*</b>	Existing green areas and urban parks systems.	Utilisation of existing green areas to minimise runoff. Potential for carbon sequestration.*	Trialling of carbon sequestration techniques.	Moderate	Moderate to potentially high.	Local Authority. Park management bodies.
<b>SuDs Infiltration</b>	Pedestrian, low volume vehicular traffic areas, car parks. Applicable to new developments or upgrades of existing infrastructure.	Reduces run off volumes from large paved areas.	Infiltration capacity depends on permeability underlying soil.	Low to moderate	Low to Moderate	Developers. National Roads Authority, Local Authority
<b>Surface Conveyance (carrying capacity) (Streets as Streams Roads as Rivers)</b>	Urban road system and drainage paths.	Allows for surface water to be routed to attenuation areas or other suitable discharge point reducing risk to residential and commercial properties.	Requires coordination with forecasting system, signage and communication with roads authorities and local communities in relation to temporary affected routes.	Moderate to High	Low to Moderate	Local Authority. Roads Authorities.
<b>Bio Swales</b>	Urban roads infrastructure, schools, hospitals, shopping centres and other developments with relatively large paved areas.	Reduces run off volumes, enhances water quality. Additional amenity value. Can be used to link GreenWaterSpace areas. Potential for carbon sequestration.*	Requires sufficient space to construct. If use for infiltration requires permeable ground conditions. Trialling of carbon sequestration techniques.	Low to Moderate	Moderate	Local Authority. Roads Authorities. Developers.
<b>Below Ground Conveyance</b>	In areas where managing surface water on the land surface is limited for various reasons.	Can take advantage if combined with other underground sewer network works.	High cost, extensive works and less sustainable method.	High	Moderate	Local Authority
<b>Separation of Foul and Surface water sewers</b>	Greenfield development and brownfield where opportunities arise. Otherwise ongoing rectification of misconnections whenever feasible.	Reduces risks of sewers overflowing, reduces pressure on waste water treatment facilities.	Potentially high cost and extensive works required unless opportunistic rectification of misconnections.	Moderate to High	Moderate	Local Authority.
<b>Temporary and Demountable Defences</b>	Community areas where traditional resistance measures are not effective. As part of Streets as Streams / Roads as Rivers flowpath designation.	Effective where traditional resistance measures are not effective.	Dependant on effective warning system (this may not be possible, particularly for pluvial flooding). Requires storage and staff available for deployment. Some measures may require engineering works. Require management and maintenance plans if applied to community areas.	Moderate to High	Moderate. Require management and maintenance plans if applied to community areas.	Local authority. Community groups (liaison).

Table E4: Site Specific Measures – Focus on River Flooding

Site Specific Measure	Scope of Application	Key Advantages	Risks	Relative Cost	Maintenance Level	Responsibility for Implementation
<b>Flow diversion - culvert or channel</b>	Areas where space is limited along the existing watercourse route and extra channel capacity is required	Water is removed from "pathways" where there are multiple "receptors" channelling flow through low risk areas.	Often difficult to find suitable diversion route in urban areas.	High	Moderate	Local Authority
<b>Increase conveyance</b>	On channel sections that create a bottleneck - often locations where water first flows out of bank.	Removal of bottleneck (can be a very short length or a longer river reach) with significant risk reduction in that location.	Can be less sustainable in terms geomorphological impacts, and may create ongoing maintenance requirements. Flood risk can be passed downstream to next bottleneck.	Moderate	Moderate	Local Authority
<b>Flood walls</b>	Along river reaches where increased capacity is required but there is no scope for increasing the channel size. Typically in flat areas.	Works do not take up significant space so are often appropriate in urban environments.	Events above the design standard can result in large flooded areas when walls are overtopped. Access to river restricted. Potentially unsustainable in longer term with climate change.	High	Low	Local Authority
<b>Flood embankments</b>	Along river reaches where increased capacity is required but there is no scope for increasing the channel size. Typically in flat areas where there is significant space on river banks, so peri-urban environments generally more suitable than urban environments.	Can protect very large areas of development within the flood plain. Scope for defence raising in future if needed.	Events above the design standard can result in large flooded areas when banks are overtopped. Access to river may be restricted. Insufficient space in many urban areas.	Moderate	Medium	Local Authority
<b>Minor works - defence raising, infilling gaps etc.</b>	Applies where there are existing assets but these have been degraded over time for various reasons. Works best where there is a clear deficiency on a defined stretch of otherwise good asset.	Makes best use of existing asset base. Planning and technical feasibility are generally less of an issue than with other capital measures.	Works can be "bitty" and awkward requiring multiple works sites. "Patch and Mend" approaches on existing assets can lead to unforeseen additional costs.	Low / Moderate	Low	Local Authority
<b>Major Flood Storage - online or offline</b>	Where the topography upstream of an "at risk" area lends itself to providing a large storage area. A large proportion of the flow in the "at risk" area must flow through the storage area.	Works are concentrated away from development areas. Opportunities for environmental enhancement.	Defence failure upstream of a developed area can have catastrophic impacts (i.e. dam break). Events above the design standard can have limited effect on reducing the flooding impact, for example, if the storage reservoir fills before the peak of the flood occurs.	High	Low	Local Authority.

## Appendix F References

1. Flooding in Cornwall 17 November 2010 in association with segmented line convection. Andrew Sibley, Weather Vol 66, No 11, November 2011.
2. Heavy Rainfall of 24th October 2011 in the greater Dublin Area. Met Éireann: [www.met.ie/news](http://www.met.ie/news).
3. Report of the Flood Policy Review Group, Office of Public Works, 2004.
4. Estimation of Point Rainfall Frequencies – Technical Note 61. D L Fitzgerald, Met Éireann, October 2007.
5. Progress Report on Extreme Event Pluvial Flooding 24<sup>th</sup> October 2011. Dublin City Council, December 2011.
6. Report on Dublin City Flood Risk and interim report on extreme pluvial flooding event affecting East Coast and Dublin City on 24<sup>th</sup> October 2011 (Report No. 338/2011), Dublin City Council, November 2011.