07 - RESULTS OF HYDROLOGICAL AND HYDRAULIC ANALYSIS OF THE HEAVILY URBANISED PODDLE CATCHMENT AND THE OCTOBER 2011 FLOOD EVENT

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Abstract

Following severe flooding in the Poddle Catchment on the 24th and 25th October 2011 the analysis of the catchment under the CFRAM Study programme was accelerated such that flood risk management options could be brought forward at the earliest opportunity for this acutely affected catchment. The hydrological analysis of this catchment has been at the forefront of testing of FSU tools and a number of other recently developed techniques. The hydrological analysis techniques include:

- Processing of rainfall data from the Met Éireann operated radar at Dublin Airport. This included the removal of clutter from the radar images and spatial and temporal adjustment against quality checked ground station (rain gauge) data
- Application of rainfall data within a Poddle catchment run-off model using MIKE NAM and URBAN run-off modelling tools to generate a simulated historic flow record in this otherwise ungauged catchment
- Comparison of design flow estimates from the FSU methods and tools against FSR methods. Calibration and validation of the design flow estimates against historic data and observations, predominantly from the October 2011 event

Data gathering in the days following the October 2011 flood event as part of the CFRAM Study flood event response included:

- Mapping of flood extents
- Recording of flood depths, wrack levels, evidence of culvert blockage and structural damage / collapse
- Event rainfall and hydrometric gauge data

Data collected as part of the flood event response was used to estimate the frequency conditions of the event both in terms of the meteorological conditions and the Poddle catchment response. This analysis formed a large part of the design flow calibration and validation and informed the need for an integrated approach to hydraulic modelling of the catchment in order to accurately capture flood performance of the combined watercourse / urban drainage network. An integrated model of the catchment was built using InfoWorks ICM such that the constraints of the drainage network in delivering the high intensity rainfall observed on the 24th October into the channel of the Poddle watercourse were accurately captured. As part of this integrated approach rainfall was input directly to the model with inputs derived from both observed gauge / radar data (for calibration) and using FSU DDF

rainfall sums (for predicted AEP events) applied using FSR summer and winter storm profiles. Achieving calibration of the model required a thorough analysis of all the data collected from the October 2011 event in order to form an understanding of the causes and flood mechanisms associated with the event including culvert blockage and wall collapse.

Simulations of the October 2011 event have been developed which included building in the event specific flood mechanisms to the model in order to accurately replicate the observed flood event including the rapid inundation of the Harold's Cross area. The hydrological and hydraulic analysis undertaken has been presented to the public through the Poddle flood maps and public consultation days with responses indicating good agreement with public observations.

1. INTRODUCTION

The Poddle catchment, located in South Dublin, is one of the most heavily urbanised catchments in Ireland with approximately 89% of the total catchment area of 12.2 km^2 considered to be urbanised (as defined under FSU WP 5.3). The catchment emanates in the Tallaght area and crosses under the M50 at Tymon Park before passing through Whitehall, Kimmage and Harold's Cross areas, though the city and then discharging to the Liffey at Wellington Quay. Much of the watercourse is canalised or culverted and the main channel could be considered an integrated spine of the urban drainage network. There are in excess of thirty significant urban drainage connection junctions and two significant overflows out of the Poddle main channel. The Poddle catchment and storm sewer network are shown in Figure 1.

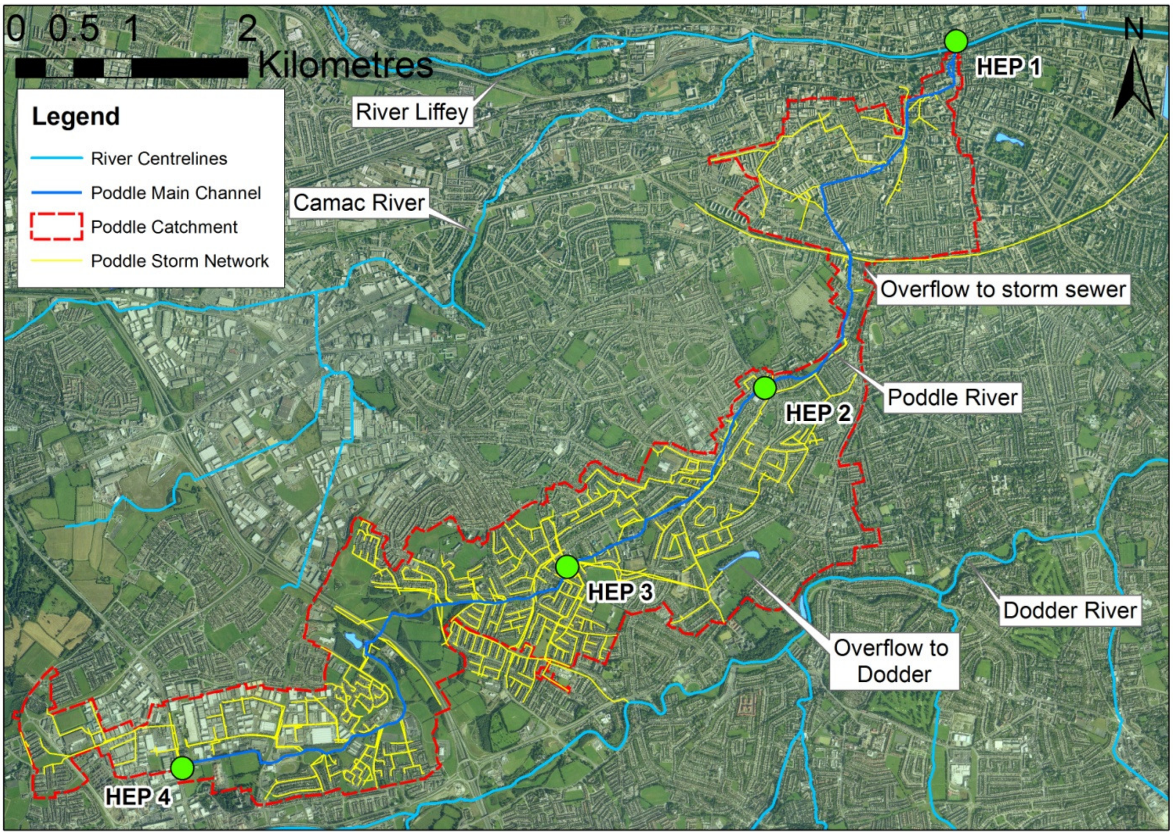

Figure 1. *Poddle Catchment Storm Drainage Network*

There are no hydrometric gaugings stations on the Poddle network although some short term flow data exists for events in 2002 from flow monitoring undertaken as part of the Greater Dublin Strategic Drainage Study and there is a fair degree of uncertainty in the recorded flows. The nearest hydrometric gauging stations are located on the adjacent Camac and Dodder Rivers. High spatial and temporal rainfall data is available at Casement approximately 4km to the west and from the Met Éireann radar at Dublin Airport approximately 9km to the north.

2. PAST FLOOD EVENTS

A review of historic records indicated over half a dozen times when the Poddle has burst its banks and caused significant damage to property but three events stand out as being particularly significant and have data available:

- August 1986 (Hurricane Charlie)
- November 2000
- October 2011

Of these three recent significant flood events the October 2011 was the most significant in terms of documented damage, including the loss of a life in the Poddle catchment. From review of the rainfall sums from the nearby Casement hourly rain gauge it is evident that the October 2011 event is different in character to the other two significant events as shown in Table 1 and Figure 2.

Storm Event	Duration (hours)	Max Hourly Rainfall Sum (mm)	Event Total (mm)	FSU DDF AEP (%)
August 1986	29	9.3	91.4	3.4%
November 2000	35	6.6	90.5	4 %
October 2011	10	18.2	82.1	1.6 %

Table 1. *Poddle Flood Event Rainfall Characteristics*

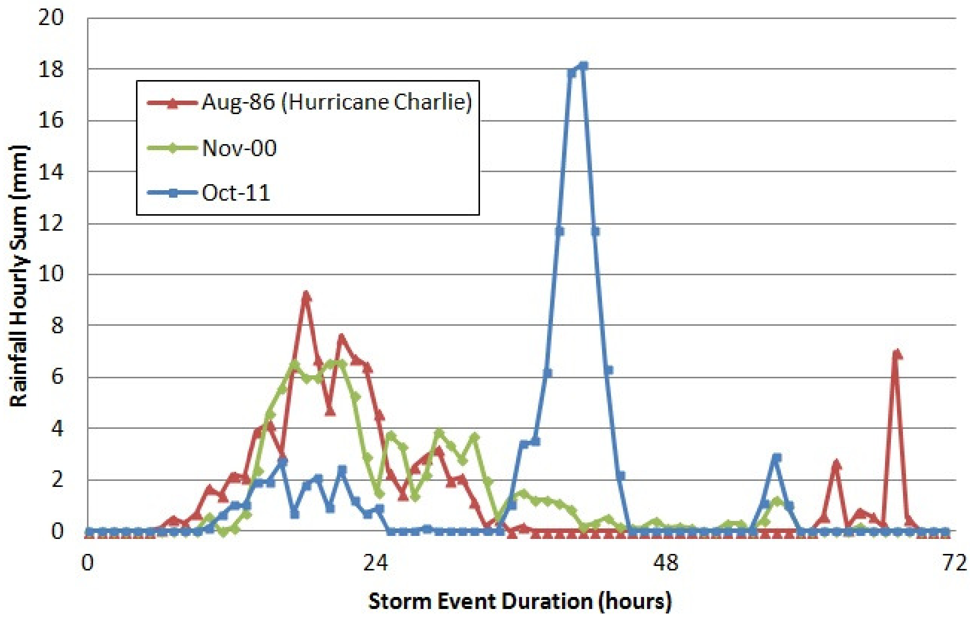

***Figure 2.** Poddle Flood Event Rainfall Hourly Sums*

The October 2011 storm event was much more intense than any of the other three identified flood events and had the third largest recorded hourly rainfall sum from 49 complete years of record at Casement, with the other two hourly sums, in the Augusts of 1997 and 2008, representing short duration high intensity summer rainfall events, neither of which is known to have caused flooding in the Poddle catchment. The three rainfall events were also considered against the FSU Depth Duration Frequency (DDF) model (FSU Work Package 1.2) to ascertain the estimated frequency / probability of the events. The rainfall event which occurred on the 24th October 2011 can be shown to be the most extreme of the three identified events with an estimated Annual Exceedance Probability (AEP) of 1 – 2%. This frequency estimate considers the event in isolation yet it was preceded by a rainfall event of 20mm over 15 hours on the 23rd October which may have contributed to the rapid catchment response to the rainfall of the following day.

3. HYDROLOGICAL ANALYSIS AND DESIGN FLOW ESTIMATION

In Ireland and the UK statistically based methods using flow data from within the subject catchment are preferred for design flow estimation and flood frequency estimation. In the case of the Poddle catchment there is no long term observed flow record available for such a statistically based approach. In the absence of flow data from within the catchment statistically based approaches are centred around catchment descriptor based estimates of flood flow and the use of appropriate gauged data from hydrologically and geographically similar donor sites to improve the estimates. The application of data from donor sites poses problems in the case of the Poddle catchment due to the limited amount of long term flow data from similarly small and heavily urbanised catchments in Ireland.

In the case of the Poddle catchment statistically based approaches have been supplemented with rainfall run-off based approaches whereby flows within the catchment have been simulated using rainfall data applied to lumped sum and fully integrated catchment models.

The initial approach was to use a lumped sum catchment model with high temporal resolution rainfall data inputs to produce a simulated, continuous flow trace for the catchment which could be used as the basis for statistical analysis. The Poddle catchment has a high temporal resolution (hourly) rainfall record available in close proximity to the catchment but in order to provide high resolution data across the entire Eastern study area an exercise was undertaken to extract, quality check and process the record from the rainfall radar at the Met Éireann operated rainfall radar at Dublin Airport. The processing of the radar images is based on the principle of applying varying adjustment factors (spatially and temporally) to the radar derived rainfall sums based on observations from the Met Éireann network of ground stations (both hourly and daily rain gauges). The outputs from this are gridded (1km x 1km) and catchment aggregated hourly rainfall sums covering over 95% of the Eastern Study area for the calendar years 1998 – 2009 (the period of concurrent rain gauge and radar data at the time of processing). For the period covered the radar derived record was used in place of the Casement hourly record to drive the Poddle run-off model as it is based on sums observed above the Poddle catchment as opposed to 4km to the west. A comparison of the hourly rainfall sums from the Casement rainfall gauge and the hourly rainfall sums from the adjusted radar images above the Poddle catchment for the November 2000 event are shown in Figure 3. It is evident that the maximum hourly intensity is slightly lower (5.5mm as opposed to 6.6mm) and the event total slightly less (85.4mm as opposed to 90.5mm) from the Poddle catchment aggregated radar sums compared to the Casement hourly rain gauge. The visual fit of both rainfall patterns appears to be very good but without hourly gauge information from within the Poddle catchment it is not possible to confirm if the differences in total sums are due to actual differences in rainfall sums which fell at each location during the event or due to error in the adjusted radar sums. A wider analysis of the total adjusted radar rainfall sums at hourly and daily gauge locations across the greater Dublin area found the margin of error generally to be within 2.5% but up to 10% within the Wicklow Mountains where blocking of the radar beam becomes an issue.

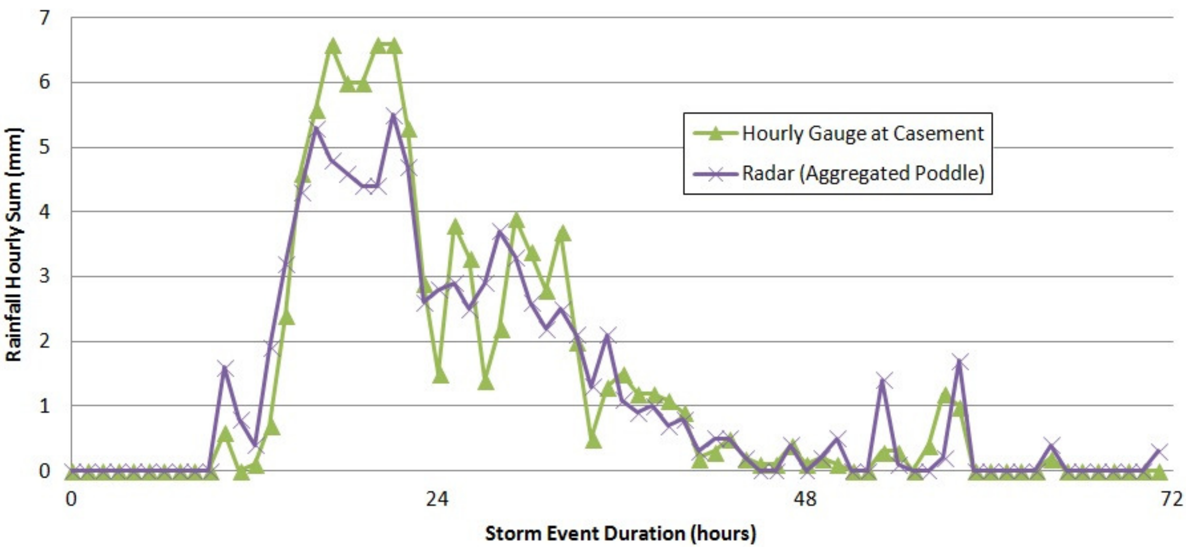

Figure 3. *Rain Gauge vs. Radar Based Hourly Sums for Nov 2000 Storm Event*

Design Flow Estimation

The hourly rainfall datasets where used to drive catchment run-off models using DHI's MIKE NAM and URBAN lumped sum catchment run-off models. The model parameters were initially estimated based on GSI and Corine land use mapping and aerial photography and then adjusted based on the calibration parameters for the adjacent model on the Camac system at the Killeen Road gauging station (09035). Hydrological Estimation Point (HEP) 3 located off Whitehall Road as shown on Figure 1 was chosen as the simulation point for generating a run-off model for the catchment to that point due to its mid catchment location and positioning just upstream of the first major overflow, below which comparison between catchment run-off and observed / modelled flow becomes more difficult.

In addition to the catchment modelling approach, statistical ungauged catchment flow estimation techniques using physical catchment descriptors were considered alongside the index flood flow derived from the simulated flow record. The methodologies which were considered were:

- IH124 'Flood Estimation for Small Catchments' - 3 parameter regression equation plus an adjustment for urbanisation based on catchment wetness, rainfall continentality factor and extent of urbanisation. Adjustment from QBAR to Q_{MED} for direct comparison with other methods.
- FSU 7 variable equation (FSU Work Package 2.3) plus an adjustment for urbanisation. No pivotal site adjustment was deemed necessary as the method with urbanisation adjustment applied was found to perform well against observed data in neighbouring, heavily urbanised gauge catchments.

The results of the rainfall run-off modelling produced a simulated continuous flow trace of nearly 50 years duration and from this record an Annual Maxima (AMAX) series was extracted and an at site flood frequency analysis performed on the record. Based on the record length this frequency analysis can be considered to have sufficient statistical robustness for prediction of design events up to a 1% AEP without pooling. These design flows are shown in table 2.

In relation to the estimates based on catchment descriptors a pooled flood frequency analysis was undertaken based on the methodology detailed in FSU Work Package 2.2 whereby AMAX years from the most hydrologically similar gauging stations are pooled together in order to develop a growth curve / growth factors for estimating extreme design flood events. The pooling group was made up of records from 26 gauging stations in order to pool enough years of data to provide statistical confidence for predicting extreme events. The vast majority of the pooled sites are located in the Eastern River Basin District. Catchment areas of the pooled sites ranged from 1km^2 to 162km^2 with a median value of 38km^2 and urban extent of the pivotal sites ranged from 0 to 68% with a median value of 6.5%.

Results of the design flood flow estimation for a range of design events from the catchment run-off modelling and the two methods outlined above at HEP 3 (5.44 km^2) are given in table 2 below. For comparison purposes the 50% AEP flow from the finalised fully integrated catchment run-off / hydraulic model (as described in Section 4) at the same point in the catchment is included within the table. In the absence of a long term gauged flow record this is considered the best estimate of Q_{MED} as it is derived from a model which captures all the major hydrological and hydraulic factors including catchment topography, the urban drainage network and driven by robust FSU DDF input data and high quality local rain gauge calibration data.

Methodology	Index Flood Flow Estimate (Q_{MED})	10% AEP Design Event	1% AEP Design Event	0.1% AEP Design Event*
Run-off Model (MIKE NAM / URBAN) & at site EV1 growth curve	2.92	6.19	10.27	-
IH124	2.02	3.63	6.71	11.97
FSU 7 variable	1.87	3.36	6.21	11.08
Integrated Catchment Run-off / Hydraulic model (max. flow FSU DDF AEP rainfall events)	3.04	4.14	6.32	8.47

**Note: The prediction of the 0.1% AEP (1000 year) event is in all cases based on extrapolation beyond the confidence limits of the available data and as such must be treated with caution.*

***Table 2 .** Comparison of Estimation Methods for Extreme Design Flood Flow Events*

The results of all of the catchment run-off and statistical catchment descriptor based methods are in contrast to the fully integrated catchment / hydraulic model outputs which have at their core the surveyed drainage system. Results of the integrated modelling suggest that traditional catchment flow estimation techniques, although allowing a large adjustment upwards to take into account the effect of urbanisation, do not fully capture the effectiveness of conventional drainage systems in conveying storm run-off for the median (50% AEP) annual maximum flood event to the main spine of the Poddle drainage system, the Poddle River. For more extreme flood flow events the results are the opposite with the integrated model showing lower growth rates than traditional techniques for small and urbanised catchments. The 1% AEP design event from the integrated modelling approach is just over 2 times the median event compared to a 1% AEP growth factor of 3.32 for FSU pooled analysis and 3.52 for a single site analysis of the MIKE NAM / URBAN catchment run-off simulated record.

The point of the Poddle at Whitehall Road which has been considered on the main channel is open and in a relatively natural state, although the immediate floodplain is heavily urbanised. The catchment does include 28% of non-urbanised area although this is largely made up of the mid catchment area around Tymon Park rather than natural upland catchment. At the upstream node (HEP 1) of the Poddle catchment in Tallaght the results of the integrated modelling are even more pronounced with even less growth in flow between the median and 1% AEP flood events. The catchment upstream of this point at less than 1km^2 is nearly entirely urbanised and largely covered by artificial and impermeable surfaces draining to the top of the Poddle watercourse through conventional drainage systems. The design of urban drainage systems as laid out in design guidance such as 'Sewers for Adoption' (UK WRc) and the 'Design Manual for Roads and Bridges' (NRA) is centred on removing water from surfaces quickly and efficiently for the vast majority of rainfall events. It does not however seek to size elements of the drainage system to remove rainfall events with extremely low frequencies of occurrence under free flow conditions as this would lead to up-scaling of the drainage design system by large factors, with associated cost and environmental implications, for events which are unlikely to happen in any given year. The typical design standards for drainage elements such as carrier pipes is to convey the 20-50% AEP design rainfall events without surcharging and more generally to prevent surface flooding for events up to the 3.33% AEP design rainfall event. It follows that that for drainage systems working to their intended design capacity that higher frequency (in extreme flood frequency terms) rainfall events will be conveyed with maximum efficiency to their outfall points at watercourses and coastlines. For the more extreme flood events considered in flood risk assessment the flows generated by the catchment are in all likelihood beyond the free flow capacity of the drainage system and some attenuation as elements of the drainage system become surcharged is likely.

The catchments which have been considered through a pooled analysis are not truly representative of the Poddle catchment due to the extremely high levels of urbanisation within this small subject catchment and a lack of data in Ireland which reflects small urban catchments. If we consider that in less urbanised catchments were the drainage systems is not the dominant conveyance system but natural watercourse networks and their floodplains are then there is not likely to be the same restricted extreme flood growth behaviour above the 20-50% AEP events.

The Poddle lumped sum catchment rainfall run-off model is largely an urban run-off model with a large portion of the catchment area modelled through the MIKE URBAN run-off module. This model uses a time / area calculation similar to the rational method with the shape of the run-off hydrograph dictated by catchment length, slope and roughness with some losses to infiltration allowed for. The model however does not allow for restricted flow paths as the extremity of events increases but rather represents a free flow of run-off across the catchment surface. As such the model does not capture the effect of flow restriction / attenuation by the drainage network itself.

4. INTEGRATED MODELLING APPROACH

The focus of the CFRAM Studies is to assess the fluvial and coastal flood risk only within the areas identified for analysis. The Poddle watercourse extents are relatively easily defined from the commencement of the natural watercourse at Tallaght through Tymon Park, to the partly culverted and canalised middle reaches to the discharge point on the Liffey at Wellington Quay. There are no defined natural tributaries and all major branches represent junctions with urban drainage systems. The pluvial and fluvial risks in the Poddle are not easily separated and they are to some degree interdependent. Following initial hydrological analysis and model conceptualisation it became clear that for a number of reasons the drainage system must be considered in tandem with the Poddle watercourse to capture the fluvial flood risk accurately:

- Estimates of extreme design flood flow inputs based on statistical techniques were higher than the channel capacities to which they were to be introduced presenting problems in accurately capturing model boundary conditions.
- Flow inputs points and sub-catchment delineation would require identification of the urban drainage network and design flow estimation at these points based on run-off or rational method analysis for each sub-catchment served.
- The effect of hydraulic constrictions in the drainage network in delivering extreme flood flows to the Poddle must be captured

Following consideration of a range of hydrological analysis and modelling options in terms of accuracy, appropriateness and efficiency an integrated catchment modelling approach was chosen using InfoWorks ICM which models the hydrological cycle from the rainfall input through to catchment discharge point through a complete hydraulic model. The model is constructed from survey of the catchment topography, drainage system and watercourse cross sections to produce a combined 2D floodplain, drainage network and 1D river model as shown in Figure 4.

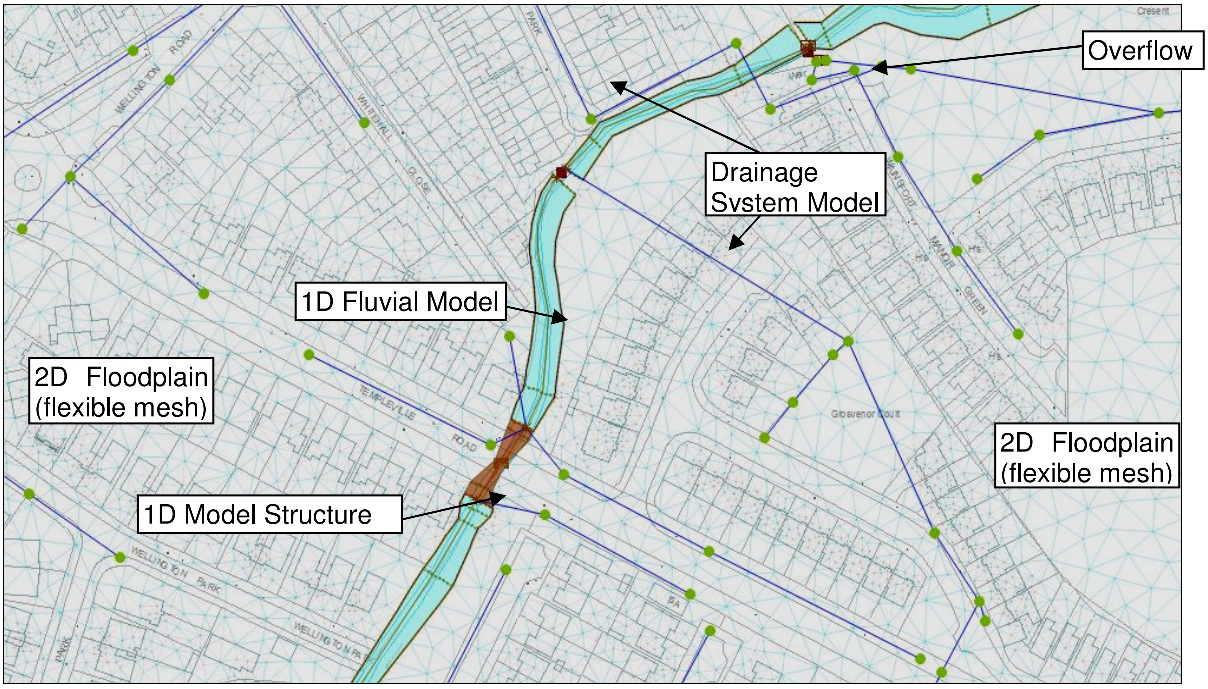

Figure 4. *ICM Model Reach Visualisation at Templeville Road / Wainsfort Manor*

The ICM model captures the effect and performance of the drainage network by modelling rainfall across each defined drainage node area based on the permeability and slope characteristics of the sub-catchment. Pipes, manholes and structures are analysed as 1D elements and interactions at the junctions between the 1D fluvial model and the 2D floodplain model are fully represented. Rainfall is applied as a time series input file and derived from the following sources:

- Calibration Events – Catchment aggregated, radar derived hourly time series or Casement hourly gauge data
- Design Events – DDF outputs from FSU Work Package 1.2 from mid catchment grid point. Sums distributed to summer and winter FSR storm profiles.

In order to minimise the total number of design runs, the full range of 1% AEP events were initially considered to ascertain the critical storm duration and rainfall profile for the Poddle catchment. The complete range of combinations of FSU rainfall depths and summer and winter rainfall profiles were introduced to the model with the most onerous flood extents found to be produced by differing rainfall events. Within the integrated catchment model the catchment was found to have two critical storm durations:

1. Upstream of M50 and city centre reaches – 2 hour summer storm profile
2. Downstream of Tymon Park to city centre (Grand Canal approx.) – 9 / 12 hour summer storm profile

The difference in the flood extents produced by the 9 and 12 hour summer rainfall events was found to be negligible. For each design AEP event two storms were modelled, 2 & 12 hour summer profiles, and the cumulative flood extents were combined to produce the draft flood risk mapping.

5. CALIBRATION TO THE OCTOBER 2011 FLOOD EVENT

A review of the rainfall data suggests that the October 2011 event had an annual exceedance probability of 1 – 2% for the observed duration and depth. A review of the rainfall data observed at Casement shows that the storm profile, for the main rainfall event occurring on the 24th October had a typical FSR winter storm profile as shown in Figure 5 below.

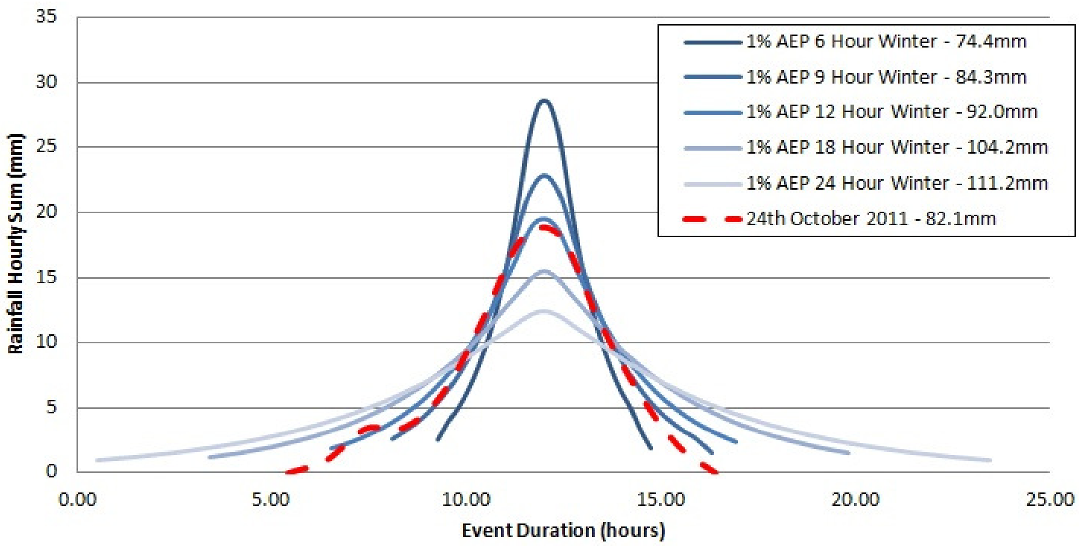

Figure 5. *Oct. 2011 rainfall compared to FSU rainfall depth / FSR winter storm profile*

Despite the peaks providing a good visual match to the 1% AEP 12 hour design winter storm, approximately 10mm less fell during the peak rainfall event on the 24th October. This 10mm however is largely accounted for in the rising and receding limb of the rainfall event rather than at the peaks and in considering the overall frequency of the event it is worth considering the 20mm which fell within 24 hours of the commencement of the main peak event on the 24th. Both the observed rainfall data from the Casement gauge and the 1% AEP design event with 12 hour winter profile were routed through the model and found to be in good agreement with the mapped flood extents from the October 2011 event, with the exception of the Harold's Cross area where the extreme flooding was as a result of a combination of the extreme flows, culvert blockage and wall collapse.

The capturing of the flood extents and mechanism within the Harold's Cross area are considered crucial in providing validation of the model due to the severity of the flooding in the area and also bearing in mind the loss of life. In light of this, further modelling was undertaken to consider various culvert blockage scenarios in order to capture the flood mechanism which occurred on the evening of 24th October 2011. The critical mechanism for the flooding at Harold's Cross was quickly identified as the blockage of the trash screen on the culvert opening just upstream of St. Clares Avenue on the main channel of the Poddle watercourse. Following blockage two walls which were containing the build-up of flood waters in the Gandon Close area collapsed leading to the rapid inundation of the Harold's Cross area directly downstream. Flood event data was collected in the days following the event including accounts given by local people who witnessed the flood event, surveyed flood extents, flood depths and wrack levels etc. From the data collected it was not possible to ascertain the percentage of trash screen blockage for modelling although the maximum flood water level in the Gandon Close area was surveyed adjacent to both wall collapses along with the remaining sections of the structures. These flood containing walls were represented within the ICM model based on a maximum water level rule whereby the sections of wall would collapse subject to the maximum surveyed flood level adjacent to each structure being reached. Model simulation representing total culvert blockage at Gandon Close and the wall collapse rules was undertaken using the observed hourly rainfall data from the Casement gauge.

Flood extent mapping produced from the October 2011 validation model was presented to the public during the public consultation days for the Poddle catchment alongside the standard no blockage scenario in order to give confidence to the public that the October 2011 event could be replicated within the model.

6. CONCLUSIONS

Traditional hydrological analysis techniques which are based on analysis of gauged data are limited in small heavily urbanised catchments due to the scarcity of relevant data, particularly within Ireland. At the Poddle catchment scale which is close to full urban saturation the ability of the drainage system to convey run-off to the main channel is integral to the consideration of fluvial flood risk despite being traditionally considered within the realms of a pluvial assessment. Integrated catchment modelling from rainfall input to catchment outfall indicates that in the Poddle catchment:

- The drainage system is more effective at conveying run-off to the main channel of the watercourse for the index flood (50% AEP, 1 in 2 year event) than a range of traditional statistically based estimation techniques would suggest
- For low probability / extreme flood events hydraulic constrictions in the drainage network may be a significant factor in the consideration of main channel flow. The application of growth factors based on limited small urbanised catchments may not be appropriate and could lead to an overestimation of the more extreme flood events.

In order to better understand the extreme flood frequency behaviour in small, heavily urbanised catchments such as the Poddle it would be beneficial to analyse a larger pool of data, either through the introduction of additional gauging stations in Ireland or through the use of appropriate data from farther afield.

In the Harold's Cross area of the Poddle catchment the most important factor in bringing public confidence to the process of flood risk assessment was the accurate representation of the recent extreme flood event. Had this event, which was dominated by culvert blockage, occurred following public consultation and the uncertainty surrounding this flood mechanism not been communicated to the public, it could have potentially lead to a loss of public confidence in the process. In light of this where culvert blockage is a potential flood mechanism and the risk and consequences of the flood mechanism are significant then it is important that this is communicated to the public and stakeholders.

7. ABBREVIATIONS

AMAX	-	Annual Maxima flood flow series
FSR	-	Flood Studies Report
FSU	-	Flood Studies Update
GSI	-	Geological Survey of Ireland
HEP	-	Hydrological Estimation Point
IH124	-	Institute of Hydrology Report No. 124
MIKE NAM	-	Catchment run-off model developed by DHI
MIKE URBAN	-	Urban catchment run-off model developed by DHI
Q_{MED}	-	Index Flood (defined as the median flow of an AMAX series)

8. ACKNOWLEDGEMENTS

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supplying supplementary data and advising on the complexities of the Poddle drainage system, the October 2011 event and on calibration and validation of the model.

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