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# An Evaluation of Urban Flood Estimation Methodologies in Ireland

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#### Abstract

This paper summarises the findings of a study to evaluate the use in Ireland of the different flood estimation methodologies that can be applied to urban or urbanising catchments. The study, undertaken as part of the Office of Public Works' (OPW) Flood Studies Update programme, comprised both quantitative (posted questionnaires) and qualitative research (focus groups) targeting a range of organisations involved with planning and design issues pertaining to urban flooding. A total of 291 questionnaires was circulated. Of these, 100 were returned, equating to a response rate of 34%. Results indicate that formulae and methods for determining runoff rates in urban and urbanising catchments are being applied very generally without due consideration being given to the statistical foundation underlying the methods. The resulting inconsistencies in estimated runoff rates highlight the need for National Guidance for flow estimation in urban and urbanising catchments in Ireland.

Key words: Urban, greenfield, floods, peak flows, estimation, survey, quantitative, qualitative.

#### Introduction

Fuelled by the "Celtic Tiger", Ireland has recently seen an upsurge in the development of residential, commercial and industrial properties which has resulted in a rapid increase in the areas of impervious surfaces. As a result, a greater proportion of incident rainfall on these catchments appears as direct runoff and this, combined with the sewers, gulleys and culverting of natural streams that accompany development, results in a more rapid conveyance of stormwater through the drainage network. Failures of the existing drainage network in these areas have become more frequent, requiring both significant improvements of the existing infrastructure and also completely new systems.

In light of this increasing urbanisation, together with the influences of climate change and changing land use on the natural hydrology of catchments, over-reliance on the 1975 Flood Studies Report (FSR) (NERC 1975), the FSR Supplementary Reports and Institute of Hydrology methodologies, currently used in Ireland, is not recommended. The Flood Estimation Handbook, which superseded the FSR in the UK and Northern Ireland, did not study catchments in the Republic of Ireland and thus, does not apply there. Recognising the deficit in accurate methodologies and the need to utilise the additional years of hydrometric data that has become available since 1969 and the advances in computer and digital technologies, the Irish Office of Public Works (OPW) initiated a research project to update the FSR, termed the Flood Studies Update (FSU). This paper presents a component of this update that focused on identifying and evaluating current urban flooding issues in the Republic. The main objective of the study was to establish the problem issues with current design practice as they apply to practitioners on a day-to-day basis. Particular reference was made to:

• reviewing the methods of flood estimation in urbanised catchments currently in use in Ireland;

• assessing the deficiencies inherent in these methods.

## Background

The current approach to stormwater management in Ireland promotes sustainable development by restricting the peak outflow from new developments to the predevelopment greenfield peak flows (Doyle et al 2003). In practice, this approach involves determining runoff rates for specified design storms from urban portions of development areas using deterministic or fixed percentage runoff formulae and controlling or attenuating the difference between these and the greenfield runoff before these flood flows are allowed entry to drainage networks or water courses. The rational type methods used for urban catchments are generally based on assigning a fixed percentage runoff from each type of surface. While simple rational type formulae do not properly account for variations in rainfall intensity, flow velocity or temporal storage in a sewer system, they generate acceptable results for small catchments. Methods of estimating runoff rates from catchments to be urbanised (small greenfield) are governed by individual Local Authorities but generally follow those outlined in the FSR, the FSR Supplementary Reports and reports published by the Institute of Hydrology. It is commonly recommended that the 3-Variable equation presented in the Institute of Hydrology (IoH) Report No. 124 (Marshall and Bayliss 1994) be used for developments up to 24ha and the 3-paramater equation contained in the FSR Supplementary Report (FSSR) No. 6 (Institute of Hydrology 1978) be used for developments in excess of 24ha. The 3-Variable equation in the FSSR No. 6 evolved following analysis of the FSR methodologies which showed that floods on small catchments were less well predicted than on larger ones. The IoH Report No. 124 and the FSSR No. 6 3-Variable equations are expressed in terms of catchment descriptors as follows:

IoH Report No. 124 Eqn.:

$$\overline{Q} = 0.00108 \text{ AREA}^{0.89} \text{ SAAR}^{1.17} \text{ SOIL}^{2.17}$$
(1)

FSSR No. 6 3-Variable Eqn.:

 $\overline{\mathbf{Q}} = 0.00066 \,\mathrm{AREA}^{0.92} \,\mathrm{SAAR}^{1.22} \,\mathrm{SOIL}^{2.0}$  (2)

where  $\overline{Q}$  is the mean annual flood, AREA is the catchment area, SAAR is the standard annual average rainfall and SOIL is a number depending on soil class.

It is important that inconsistencies in the generalised application of these (and other) statistical formulations are not overlooked. Peak flows for specified return periods are determined by multiplying  $\overline{Q}$  values (as determined by equations 1 and 2) by dimensionless regional growth curve constants derived in the FSR. These constants are based on average responses to rainfall for 1700 record years from 112 gauged sites across Ireland. The concept of a unique growth factor for a specified design storm that is applicable to all areas of the country is open to question and Bruen (2005) has illustrated

that these factors for catchments on the east coast of Ireland are lower than those in the FSR methodology and result in underestimation of peak flow values.

The FSSR No. 6 3-Variable equation is based on a regression analysis of 53 small catchments (less than 20km<sup>2</sup>) of the FSR data set and the IoH Report No. 124 equation is based on regression studies of 87 catchments of areas less than 25km<sup>2</sup>, 71 of which were completely rural (rural fraction of less that 0.025). While catchment areas and average annual rainfall values (SAAR) were reasonably well distributed over the catchment sample, SOIL values were not. Of the 53 catchments on which the FSSR No. 6 equation is based, 41 have soil classes 4 and 5. Consequently, the equation is likely to perform well for high runoff soils (SOIL indices greater that 0.45 and representing soil classes 4 and 5) but less well for soil classes 1, 2 and 3. Similarly, analysis of the SOIL parameter for the IoH Report No. 124 equation indicates that only 16 of the 71 rural catchments were represented by soil classes 1, 2 and 3 but 39 of the catchments were characterised by very high runoff, soil class 5 (Cawley and Cunnane 2003). It was further shown that for the 17 catchments of the sample having areas of less than 5km<sup>2</sup>, soil classes 1 and 2 are not represented at all, soil classes 3 and 4 are represented in 4 catchments and soil class 5 has 9 catchments. Consequently, as with the case of the FSSR No. 6 3-Variable equation, the IoH equation is significantly biased.

In Ireland, the scale of catchments for urban development is often less than  $1 \text{km}^2$ , significantly less than the catchment sizes on which the FSSR No. 6 and IoH Report No. 124 equations are based and this calls into question the 'one size fits all' approach often applied to the analysis of urban catchments in Ireland. This difference, combined with the fact that significant areas of Ireland are represented by soil classes 1, 2 and 3 (low to medium runoff) which are not well represented in either the FSSR No. 6 or IoH equations, raises further uncertainties in the predicted flows. The inaccuracy in flood flow prediction by these equations for Ireland is generally based on poor resolution FSR mapping. Predicted peak flows are very sensitive to SOIL parameters. This sensitivity was demonstrated by Cawley and Cunnane (2003) who, by adding three catchments with soil classes of 1, 2 and 3 respectively to the catchment sample on which the IoH Report No. 124 equation is based, showed that equation (1) would become:

 $\overline{Q} = 0.001 \text{AREA}^{0.89} \text{SAAR}^{1.15} \text{SOIL}^{1.88}$  (3)

Climate change predictions of increased intensity and frequency of winter rainfall can also be expected to impact on urban flood issues into the future (Dublin Drainage Consultancy 2005). Currently, the majority of rainstorms that pass over Ireland are frontal, but it is expected that more convective type rainfall will occur in the future. Higher intensity storms will further stress drainage networks and this combined with the "locking" of outfalls that could potentially occur, will in some cases, surcharge sewer systems. These factors, combined with changes in catchment land use, have the potential to exacerbate current urban flooding problems and highlight the need for a more radical and holistic approach to urban runoff control in Ireland.

### Methodology

Both quantitative and qualitative research methods were employed in the study described below. The quantitative element of the study consisted of circulating a self-completion postal questionnaire to target sectors in all 26 counties of the Irish Republic covering a range of organisations, agencies and institutions involved with planning and design issues pertaining to urban drainage and urban flooding. The questionnaire focussed on the following issues:

- (1) Peak flow estimation in greenfield catchments;
- (2) Peak flow estimation in urban catchments;
- (3) An assessment of data available for flow estimation;
- (4) Guidelines for peak flow estimation in either greenfield or urban catchments.

A total of 291 questionnaires were circulated and of these, 100 were returned, representing a response rate of 34%. A total of 83 of the 100 respondents completed the questionnaire in full, the remaining 17 stating that their organisations were not involved in urban catchment flood analysis or drainage system design. The majority of the questionnaires (82 in total) were returned from engineering consultancies and public bodies (Local Authorities, County Councils, City Corporations etc.) indicating that these organisations lead in the design, planning and implementation of all aspects that relate to urban flooding. Questionnaires tended to be completed by senior staff members in these organisations. Results suggest that only minor inputs to urban flooding issues are made by engineering contractors, architects and planners, partially explaining the low response rate from these sectors. The breakdown of complete and incomplete survey responses for target sectors is summarised in Table 1.

The qualitative work in this study comprised four focus group meetings in major conurbations in Ireland. Focus group participants were recruited from the questionnaire respondents from the main target sectors. A focus group topic guide was developed through consultation with the Technical Steering Group of the FSU and, in the interest of independent and unbiased reporting, external consultants were appointed to facilitate the focus groups.

### **Results and Discussion**

### **Experience with Peak Flow Estimation**

The majority of survey respondents had experience in calculating or using peak flow runoffs from either greenfield or urban catchments. While some respondents were familiar with only urban or greenfield methodologies, Figure 1 indicates that approximately 61% and 53% of respondents have experience with methodologies for both greenfield and urban catchments respectively.



Figure 1

### Equations/Methods Used for Peak Flow Estimation from Greenfield Sites

Respondents expanded on this part of the questionnaire by stating the methods with which they were most familiar for calculating peak flows from greenfield sites. A list of commonly used methods was provided in the questionnaire. The responses for this question are shown in Figure 2.



Figure 2

Survey responses contained two hundred citations of the equations/methods that were listed in the questionnaire. As illustrated in Figure 2, the IoH Report No. 124 equation and the rational method are the most commonly used flow estimation methods. Figure 2 also shows the wide variety of other estimation methods used which reflects the non-uniformity of approach to flow estimation from greenfield sites. The variety of estimation methods available is encapsulated in the following comment of one of the attendees of a focus group:

"Our main problem with the methodologies is that there's so many of them. If there was a unified methodology for the whole country, it would be easier"

Respondents to the questionnaire were asked to identify the main difficulties/limitations that were experienced when using these methods. A total of 48 of the 83 respondents (58%) who returned questionnaires provided information for this section of the survey. The most common responses were grouped and are summarised in Figure 3. These responses tended to be general and rather sweeping in their nature. It is clear that respondents are aware that uncertainties exist in the application of the various peak flow estimation methods to urban catchments but evidence of a deeper understanding of where these uncertainties may originate is not so apparent. As an example, the IoH Report No. 124 equation is commonly used across Irish catchments and a perceived difficulty with the method lies in extracting catchment descriptors from poor resolution FSR mapping. While this is without doubt the case, a greater uncertainty when using this equation may well result from the regression study on which it is based and particularly the range of soil classes in the catchment sample (refer to Background), a point not raised by any respondents.



Figure 3

Two main issues are reflected in Figure 3. The first of these, identified by over 31% of respondents was the inconsistency in the values of the peak flow determined from the various methods and how these varied over catchments of different sizes. It was suggested that some of the commonly applied methods overestimate design flows, imposing extra costs on developers for attenuation structures. The manner in which the behaviour of ground conditions is oversimplified by the assumptions inherent in many of the methodologies was also perceived as a problem. This lack of confidence in the various approaches is reflected in the following comment that was made at a focus group:

"The quality of the result is related to the relevance of the formulae used and the catchment size"

The second main issue, identified by almost 23% of respondents was the accuracy, resolution and validity of the data on which the methodologies are based. Some of the required variables, (SOIL, SAAR, runoff coefficients, concentration times) are not site specific and can vary widely. Furthermore, interpolation, where required, of hydrological parameters is subjective and open to question. In addition, respondents identified that SOIL parameters do not account for site topography or slope. Issues relating to data quality, particularly the SOIL parameter, are reinforced by the following comments that were made in focus group meetings:

"....the resolution of the maps is so poor. In many cases, all you get is something the size of a postage stamp and the methodology is very sensitive to soil around the

catchment"

"Soils can vary over a catchment, even if you have a map. The hydrologist should understand if he/she has impervious clay or a free-draining material and be able to have some guidance on how to classify that"

The issue of poor quality data, particularly relating to SOIL, was probed at focus group meetings. The idea of imposing on developers the requirement for site specific infiltration/percolation tests where planning permissions are being sought was discussed. It was generally agreed that this would be a positive initiative that would facilitate a more accurate assessment of site specific hydrological characteristics and "should be part of" all developments. It was also considered that "it would be very good to get site specific data" and could provide "very useful information .... for the country".

## Equations/Methods Used for Flow Estimation from Urban Sites

Respondents also stated the methods for calculating peak flows from urban catchments with which they were most familiar. Again, a list of commonly used methods was provided in the questionnaire and from these, 123 citations of these methods were received. These are summarised in Figure 4.



Figure 4

Figure 4 shows that rational type formulae represented by the rational and modified rational methods and the Wallingford Procedure are the most commonly used formulae for peak flow estimation in urban catchments. Respondents also have familiarity with the rainfall-runoff methods in the FSR and FSSR No. 5 and FSSR No. 16 where 7.3%, 4.9%

and 5.7% of respondents respectively stated they had either direct experience with these methods or had experience using flows calculated from these methods. The Transport and Road Research Laboratory Method (TRRL) was familiar to 7% of respondents with the 'other' grouping comprising respondents who mentioned having experience with methods such as HEC-1 (hydrological Engineering Centre 1998), TR-20 (USDA 1982) and TR-55 (USDA 1986). HEC- 1 refers to a flood hydrograph software package produced in the Hydrologic Engineering Centre of the United States Army Corp of Engineers. TR-20 and TR-55 refer to Technical Releases from the Natural Resources Conservation Service in the United States Department of Agriculture in which simplified procedures applicable to urbanising watersheds are presented to calculate runoff volumes, peak flows and hydrographs.

The perceived difficulties and limitations in applying these methods and equations to urban catchments are presented in Figure 5.





As with greenfield catchments, confidence in the results obtained from the various methods is of most concern to respondents. The problem of poor confidence is inherent in the differences in calculated flows that can result from the various methods, the dependency of the methods on poor quality and poor resolution information inputs that are uncertain and on various assumptions that are made. This inconsistency is reflected in the following focus group comment:

"...different engineers trying to calculate flow for the same catchment would arrive at different results."

Difficulties in estimating routing coefficients, runoff coefficients, entry times and

delineating catchment areas were identified by 24% of respondents as limitations of the urban catchment methodologies. Difficulties of this type for methods that require catchment descriptors are that "you don't have a stream frequency or an S1085 value that you can use. It's basically a small stream going through the site. It doesn't appear on mapping either."

# Availability of Data

It was generally recognised in the questionnaire responses and focus group comments that accurate flow estimation from greenfield and urban catchments was reliant on good quality data. However, only 41% of respondents were satisfied with the quality and availability of this data.

Respondents expanded on the reasons for their dissatisfaction with the currently available data. While many reasons were mentioned, the main factors are represented in the three groupings in Figure 6. This shows that an overall lack of, or access to, various data for accurate flow estimation is the most significant source of dissatisfaction, with over 40% of respondents identifying this as a problem. However, the accuracy and the resolution of the data that is available is also a significant problem and is reflected in the 37% of respondents who mentioned that existing data is more readily applied to large catchments. In this regard, it was specifically noted that the "data available is not specific to a particular region" and that "values read from FSR maps are too general and are not site specific". Characteristics specific to some Irish catchments were also raised by one focus group participant who recognised the "problems with karst and the indeterminate nature of underground flow as well as runoff". Regarding these conditions it was noted that "they're characteristic of Irish catchments, but we often have to rely on English data (for their analysis)". A single respondent also noted that there is "no site specific rainfall data available". The absence of national guidance also features with approximately 22% of respondents citing this as a problem.



Figure 6

### **Availability of Guidance**

While many sources provided information, the primary references used by practitioners for flood estimation in Ireland were the Flood Studies Report and Local Authority Guidelines. The diversity of the reference sources accessed by respondents serves to highlight the perceived inadequacy (Figure 7) of current guidance for peak flow estimation and as shown in Figure 8 where limitations of this guidance are presented in four groupings, the absence of a national policy document continues to be problematic.



Figure 7



Figure 8

Issues relating to inconsistencies and lack of confidence in peak flow values determined from various methodologies continue to permeate through the identified deficiencies and limitations with the available guidance as shown, and the need to update some of the commonly used methodologies (FSR methodologies, IoH Report No. 124 equation and the TRRL methods) with respect to Irish catchments was identified by over 37% of respondents.

## Conclusions

- (1) A wide range of methodologies for peak flow estimation from small greenfield and urban catchments are applied in Ireland in a general way without due consideration to the underlying statistical foundations on which they are based.
- (2) The large number of methods that can be applied to a given catchment results in significant variations in peak flow estimation.
- (3) Uncertainties in estimating peak flows are often compounded by the use of poor quality data, particularly SOIL parameters based on poor resolution FSR mapping.
- (4) The uncertainty in design peak flow estimation could be reduced by the provision of a national policy document or handbook that would provide guidance on methodologies that are applicable for a range of catchment conditions, for a variety of catchment sizes and represent both the geographical and geological variations in Irish catchments.

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Figure 9 Respondents' experience with greenfield and urban peak flow estimation

Figure 10 Familiarity of respondents with equations/methods for flow estimation from greenfield catchments

Figure 11 Difficulties/limitations when calculating flows from greenfield catchments

Figure 12 Familiarity with equations/methods for flow estimation from urban catchments

Figure 13 Difficulties/limitations when calculating flows from urban catchments

Figure 14 Reasons for dissatisfaction with available data for peak flow estimation

Figure 15 Adequacy/inadequacy of current guidelines for peak flow estimation

Figure 16 Limitations with peak flow calculation guidelines

Target Sector	Questionnaires circulated	Questionnaires returned	Incomplete returns	Total responses	Response rate (%)
Contractor /	31	7	4	11	35.5
Builder /					
Developers					
Consultant	104	36	5	41	39.4
Public (Councils,	135	36	5	41	30.4
LA, Academic,					
State)					
Insurance	14	1	2	3	21.4
Architects	7	3	1	4	57.1
/Planners/Urban					
designers					
Total	291	83	17	100	34.4

Table 1 Breakdown of responses to questionnaires