THE FLOOD STUDIES REPORT UNGAUGED CATCHMENT METHOD UNDERESTIMATES FOR CATCHMENTS AROUND DUBLIN

Michael Bruen[1], Fasil Gebre[2], Tim Joyce[3] & Padraig Doyle[4]
1 UCD Dublin, Centre for Water Resources Research
2 UCD Dublin, Urban Institute and Centre for Water Resources Research
3 Office of Public Works, Design Section
4 Dublin City Council, Drainage Division

INTRODUCTION.

This study was commissioned by Dublin City Council. The brief was to investigate the suitability for the Dublin region of the Flood Studies Report (FSR) method for estimating design flows using catchment characteristics, i.e. based on estimates of the mean of the annual maximum series (QBAR).

METHODOLOGY

Methods for estimating design flows for ungauged catchments are described in the Flood Studies Report (NERC, 1974) (FSR) and subsequent modifications. In applying the Flood Studies Report's "QBAR" method to a particular ungauged catchment, first an estimate of QBAR is calculated using an empirical formula based on catchment characteristics. Then, the FSR calculates the flood discharge for any return period using a table of coefficients ("growth factors") for a range of return periods. This is equivalent to specifying an empirical frequency distribution.

One way of checking methods for ungauged catchments is to apply them to gauged catchments, for which sufficient data is available for an alternative, more direct, estimate of design flows. Using recorded Annual Maxima Series for 22 specific gauge sites in the study region, this investigation checked both of the FSR steps separately, i.e.

(i) **Growth Factors:** The appropriateness of the FSR growth factors for Ireland was studied by fitting the EV1 distribution to the recorded data and comparing estimates of flows of various return periods with those given by the FSR method.

(a) QBAR is estimated directly from the Annual Maximum series for the study catchments.
(b) The data is plotted using Gringorten plotting positions.
(c) The EV1 distribution is fitted to the data using the Maximum Likelihood Method, as used in the FSR (vol. 1, p.145).
(d) The FSR growth factors are applied to the calculated mean of the annual maximum series data.
(e) The results of all the above are compared to indicate whether the FSR growth factors are supported by the data.

In this analysis, the growth factors are multiplied by a QBAR determined from the data. Thus the influence of any errors in the catchment characteristics regression equation for QBAR is removed from this part of the analysis.

(ii) **Regression Equation:** The regression equation for "QBAR" was studied with specific focus on the Mid-Eastern/Dublin side of Ireland. This is done by estimating the appropriate catchment characteristics for each of the study catchments and using the values to estimate the mean of the AM series. This estimate is then compared with the mean value calculated from the data, viz. section 6.

DATA

Annual maximum series data were sought from stations which have a long record and, ideally for which a reliable high flow rating curve exists. At least 20 years of record for each station would be ideal, but to reject all stations with shorter records would have restricted the number of stations used in the analysis. The shortest record used was 13 years and the longest 62 years. From the register of gauges in Ireland, maintained by the EPA, a list of potentially suitable stations was compiled and the data was acquired free of charge from the OPW and EPA. Table 1 lists the Stations considered and the number of years of record available at each.

Table 1 : Stations considered

Station Id no.	Station Name	River name	Area km^2	years record	Comments
06012	Clarebane	Fane	167	45	
06013	Charleville Weir	Dee	307	27	V-weir since 7/75
06014	Tallanstown Weir	Glyde	270	26	V-weir since 10/75
06021	Mansfield town	Glyde	321	47	
06025	Burley	Dee	176	27	
07002	Killyon	Deel	285	22	Post CDS 4/79
07005	Trim	Boyne	1282	25	Post CDS 8/75
07006	Fyanstown	Moynalty	179	15	Post CDS 10/83
07009	Navan Weir	Boyne	1610	26	Post CDS & V-wier10/76
07010	Liscartan	Blackwater(Kells)	717	15	Post CDS '82 – '86
07012	Slane Castle	Boyne	2408	62	CDS effect to '79
07023	Athboy	Athboy	98	4	Not used
08004	Owen's bridge	Ward	40.2	4	Not used
08007	Ashbourne	Broadmeadow	1734	17	
08008	Broadmeadow	Broadmeadow	110	22	
08009	Balheary	Ward	62	10	Not used
08011	Duleek d/s	Nanny	181	22	
08012	Ballyboghil	Stream	22.1	13	
09001	Leixlip	Ryewater	215	45	V-weir 8/80
09002	Lucan	Griffeen	41.2	25	
09009	Willbrook Road	Owendoher	22.4	20	
09010	Waldron's Bridge	Dodder	95.2	13	
09011	Frankfort	Slang	6.5	15	
09019	Drumcondra	Tolka	141.3	5	Not used
09037	Botanic Gardens	Tolka	137.8	5	Not used
10021	Common's Road	Shanganagh	30.9	24	
10022	Carrickmines	Cabinteely	10.4	18	
11001	Boleany	Owenavarragh	148	29	v-weir 5/72

Note: CDS denotes Catchment Drainage Scheme.

A total of 600 years of Annual Maxima were used from 22 stations with an average of 26 years per station. From these records, data from before significant arterial drainage works in the catchment were discarded. However, within the Dublin area it is virtually impossible to find a catchment in which significant development has not taken place.

ANALYSIS

Growth Factors

Estimates of flows of various return periods (derived from the Annual Maxima series at each station) were compared with estimates derived by the FSR methodology. Some sample visual comparisons are shown in Figures 1 to 7 which show the annual maximum data, plotted according to the Gringorten plotting position, the FSR flow frequency curve (dotted red), and the EV1 (Gumbel) frequency curve fitted to the data by the maximum likelihood method. For some locations, the plotted data points show a break in slope and where this occurs an additional curve is shown which is fitted to the larger annual maxima (dashed blue). In some cases, Lucan (Figure 6) and Boleany, the largest floods plotted above the general trend. There are two possible explanations. First, if a very extreme flood with a high return period occurs in a short record, all the plotting position formulae will underestimate its return period and it will plot above its "correct" position. Secondly, such floods generally exceed the limits of validity of the station rating equations and where this extrapolation leads to an overestimate of the discharge then it too would plot above the line. Therefore, it would be useful if these rating equations were extended /validated for higher flows.

Table 2 summarises the comparisons. The last column in this Table gives the ratio of the 100 year flood estimated from the fitted EV1 distribution to QBAR estimated from the AM data. A value of 1.96 would be expected if the FSR growth curve applied. Provisionally, they can be categorised into three separate groups:

(1) Where the FSR growth curve overestimates the higher return period flows compared with the data. The two stations in this category are Burley, Liscarton.

(2) Where the EV1 and growth curve give comparable results, e.g. the Fane, Dee and Glyde etc.

(3) The remaining stations, where the FSR growth curve underestimates the higher return period flows, compared to the AM data, e.g. Boyne, Broadmeadow, Ryewater and all rivers close to Dublin.

The FSR underestimation for the Boyne stations may be due to improved channel conveyance and thus increased flood discharge peaks following arterial drainage works from 1970 to 1976. There is a pattern of the FSR growth curve fitting well or, in some cases, overestimating for rural catchments and underestimating for catchments closer to Dublin. This may, at least in part, be due to (i) the higher slopes in catchments near Dublin and/or (ii) urbanisation that has occurred in these catchments since the time of the Flood Studies report.

Table 2 Summary of comparisons

Station Id no.	Station name	River name	Area km^2	Result	Q_{100}/ QBAR
06025	Burley	Dee	176	FSR > EV1	1.62
07010	Liscartan	Blackwater(Kells)	717	FSR > EV1	1.48
06012	Clarebane	Fane	167	Comparable	1.96
06013	Charleville Weir	Dee	307	Comparable	1.93
06014	Tallanstown Weir	Glyde	270	Comparable	2.07
06021	Mansfield town	Glyde	321	Comparable	1.82
07005	Trim	Boyne	1282	Comparable	1.94
07006	Fyanstown	Moynalty	179	Comparable	1.82
11001	Boleany	Owenavarragh	148	Comparable	1.96
07002	Killyon	Deel	285	FSR < EV1	2.09
08011	Duleek d/s	Nanny	181	FSR < EV1	2.08
10021	Common's Road	Shanganagh	30.9	FSR < EV1	2.19
07009	Navan Weir	Boyne	1610	FSR < EV1	2.25
07012	Slane Castle	Boyne	2408	FSR < EV1	2.33
08007	Ashbourne	Broadmeadow	1734	FSR < EV1	2.55
08008	Broadmeadow	Broadmeadow	110	FSR < EV1	2.59
08012	Ballyboghil	Stream	22.1	FSR < EV1	2.94
09001	Leixlip	Ryewater	215	FSR < EV1	2.34
09002	Lucan	Griffeen	41.2	FSR < EV1	2.95
09009	Willbrook Road	Owendoher	22.4	FSR < EV1	2.6
09010	Waldron's Bridge	Dodder	95.2	FSR < EV1	2.65
09011	Frankfort	Slang	6.5	FSR < EV1	2.63
10022	Carrickmines	Cabinteely	10.4	FSR < EV1	2.35

Differences between the FSR growth curve and EV1 flow estimates are to be expected, especially in cases involving relatively short AM series. However, in the majority of cases the FSR is lower than the EV1 and this suggests a pattern of the growth curve underestimating especially for catchments near Dublin. This is a concern.

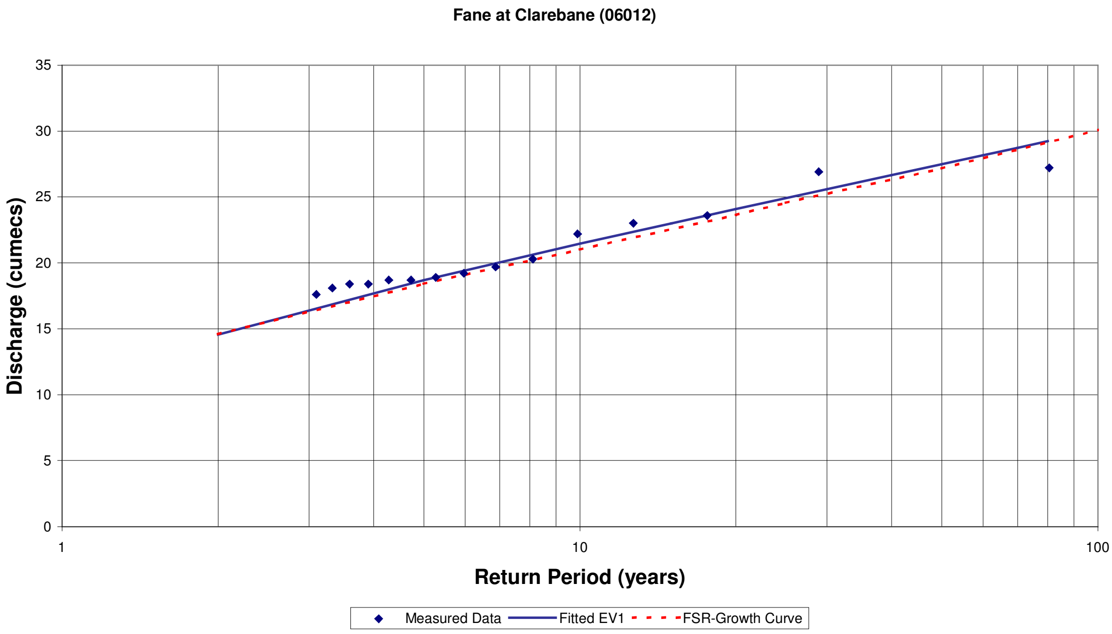

Figure 1 . Comparison of flow return period estimation methods for Fane at Clarebane (06012)

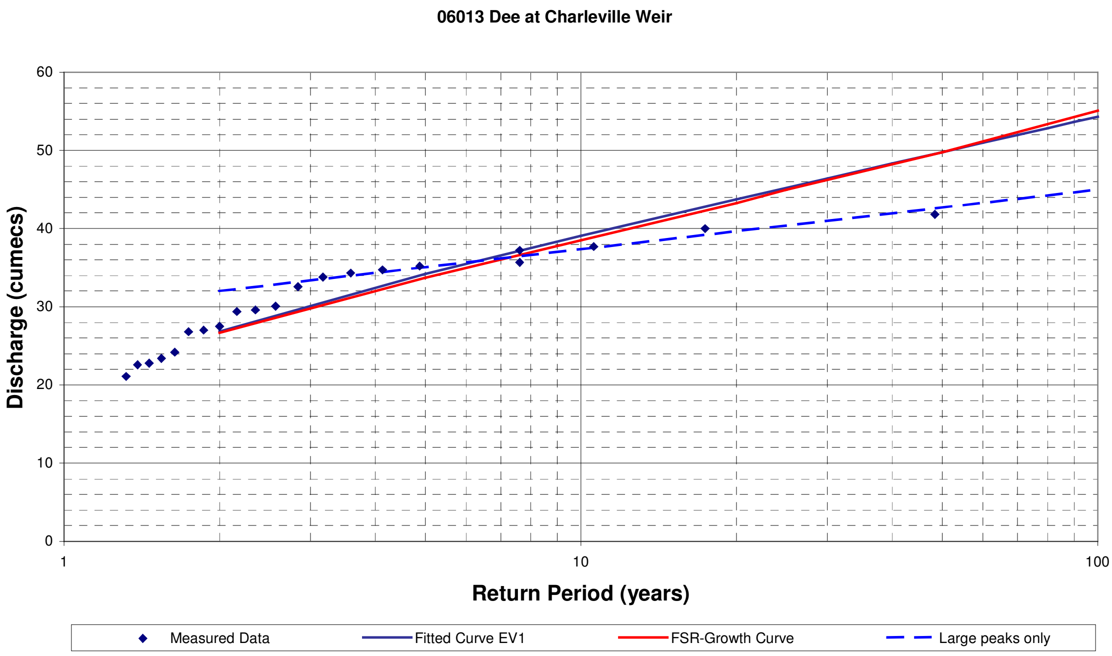

Figure 2. Comparison of flow return period estimation methods for Dee at Charleville Weir

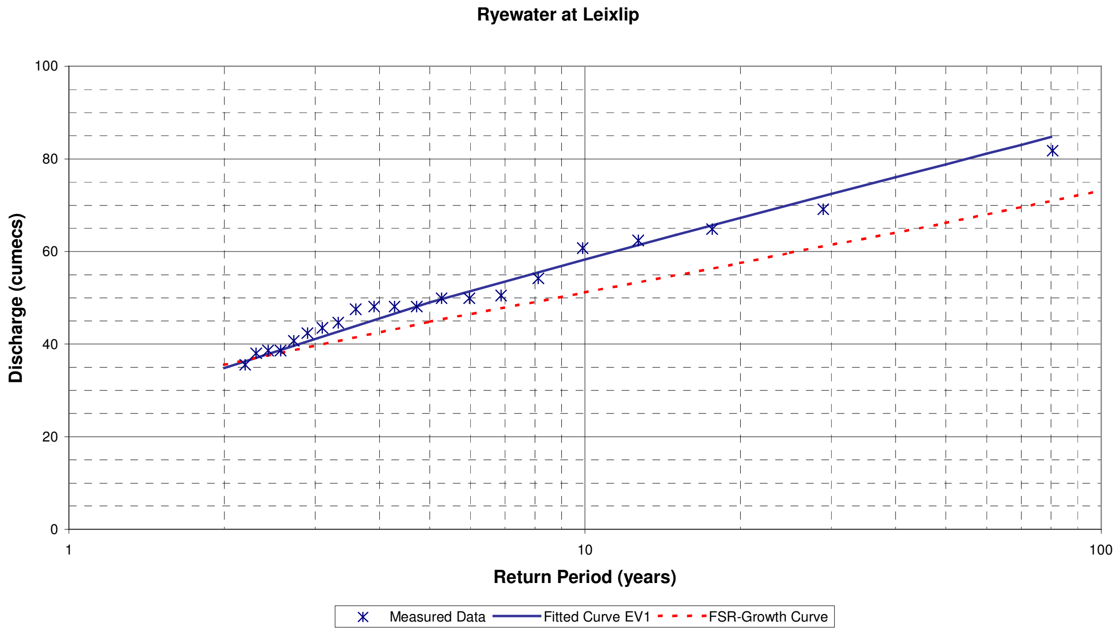

Figure 3. Comparison of flow return period estimation methods for Ryewater at Leixlip

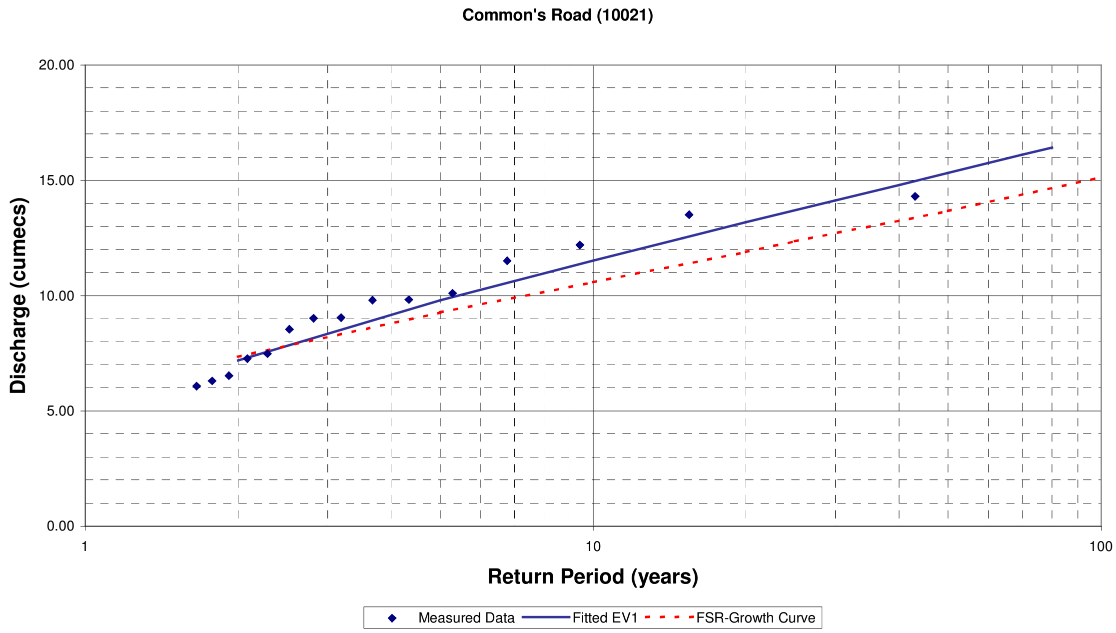

Figure 4. Comparison of flow return period estimation methods for Common's Road

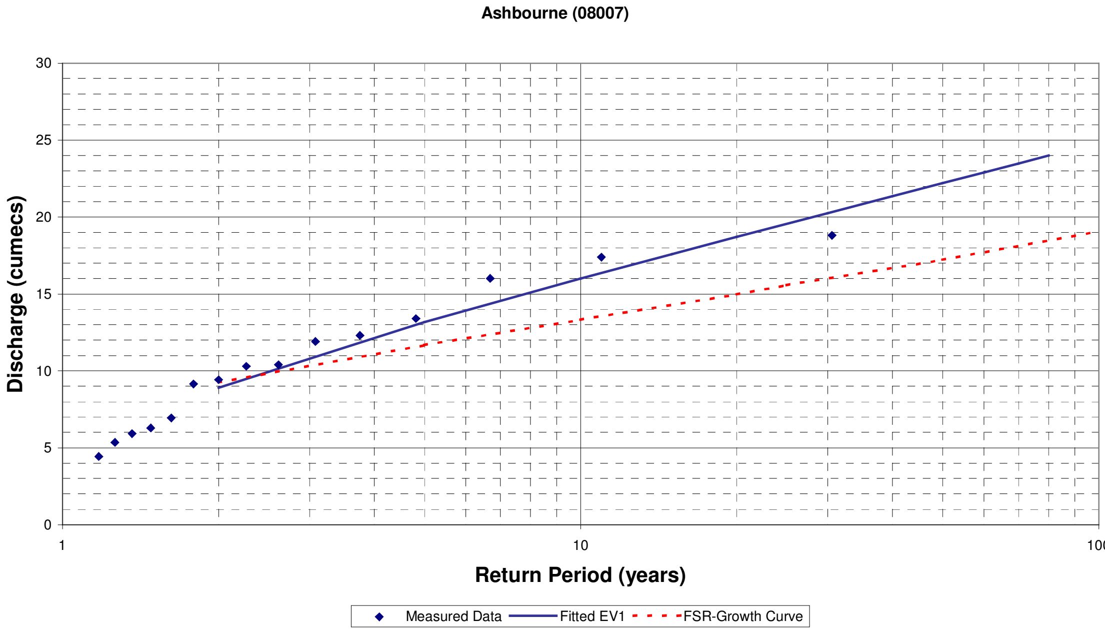

Figure 5. Comparison of flow return period estimation methods for Ashbourne

Figure 6. Comparison of flow return period estimation methods for Griffeen at Lucan

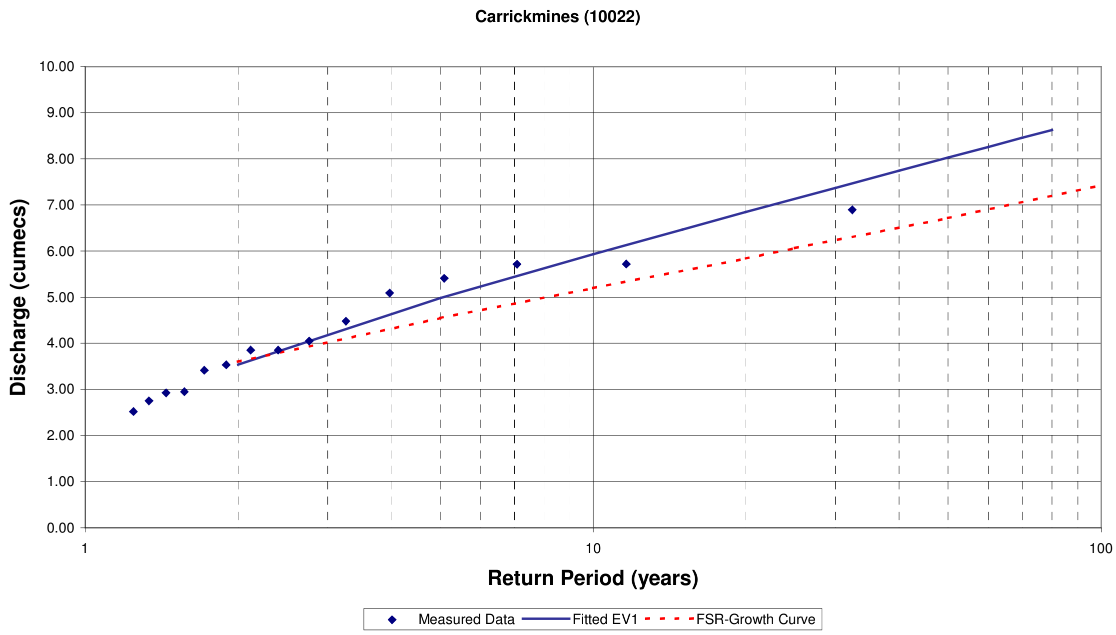

Figure 7. Comparison of flow return period estimation methods for Carrickmines

DUBLIN REGION ONLY

Eight stations within or near the Dublin area were selected for detailed analysis. These were Leixlip, Lucan, Commons, Frankfort, Broadmeadow, Carrickmines, Willbrook and Waldron's Bridge. The 8 curves obtained by fitting the EV1 distribution individually to the stations in the Dublin area, are shown in Figure 8. It is clear that (i) these all lie above the FSR curved (dotted red line) and (ii) although 4 of them do lie very close together, all 8 curves do not conform exactly to a single representative, EV1-based, growth curve. Nevertheless, a first estimate of a new growth curve for Dublin might start in the vicinity of the Frankfort, Broadmeadow, Willbrook and Waldron's Br. group of lines, as the others curves are scattered almost equally above and below this.

The two parameters of the EV1 distribution fitted to the AM data are shown in Table 3 and plotted in Figure 8, which shows a strong linear relationship.

Table 3. Estimated parameters of the EV1 distribution for gauges around Dublin

Gauge	u	alpha
Lucan	4.68	3.48
Commons	6.34	2.30
Frankfort	2.72	1.54
Broadmeadow	32.32	17.03
Carrickmines	3.08	1.27
Willbrock	10.05	5.34
Waldron's bridge	51.02	28.18
Rye	30.30	12.44

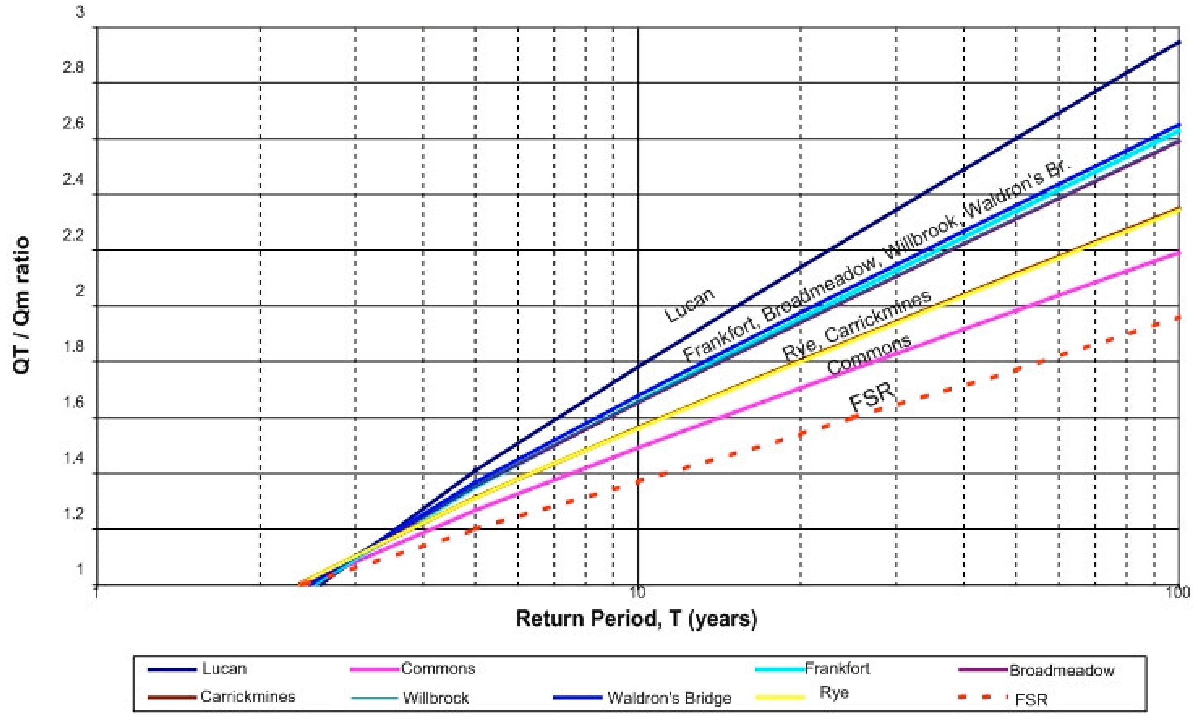

Figure 8. Growth curves suggested by AM data for some gauges around Dublin

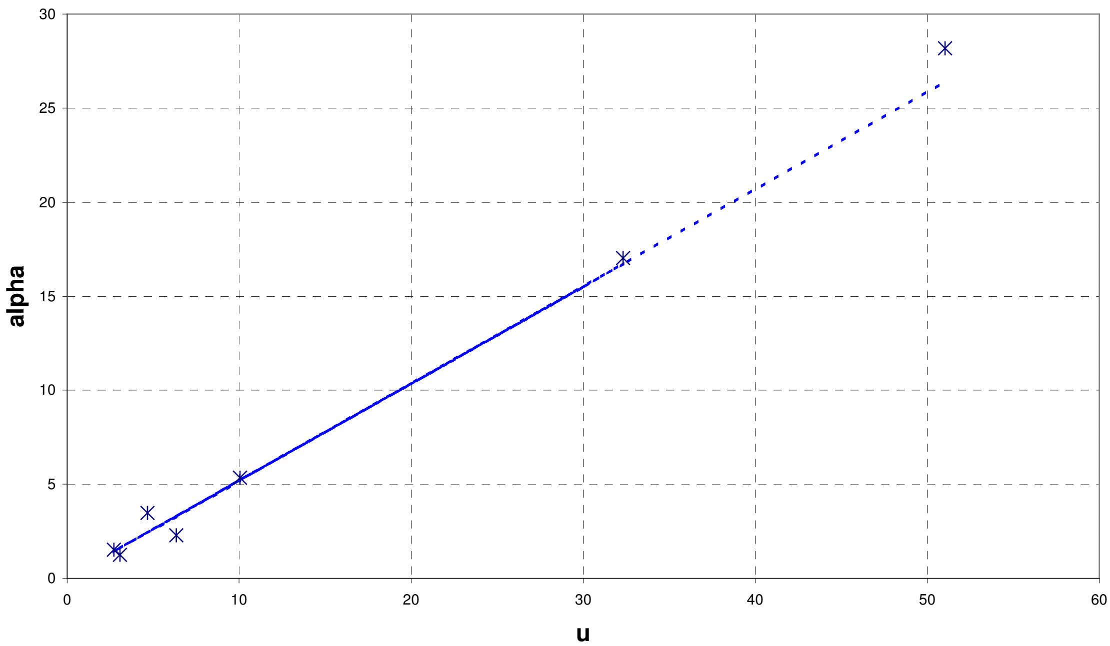

Figure 9. Relationship between EV1 parameters for Dublin stations

The EV1, (Gumbel) probability distribution can be written as:

$$p(Q \leq q) = \exp\left(-\exp\left[-\frac{q-u}{\alpha}\right]\right) \qquad \text{(Eqn.1)}$$

where, u is the location and α the scale parameter of the EV1 distribution.

A linear regression with the estimated u and α for the Dublin area (Table 3) suggests the relationship..

$$\alpha = 0.52\, u \qquad \text{(Eqn. 2)}$$

The moment equations for estimating the EV1 parameters from data moments are..

$$q_m = u + 0.5772\, \alpha \qquad \text{(Eqn. 3)}$$

Substituting equation 2 into equation 3 gives

$$u = 0.77\, q_m \qquad \text{(Eqn. 4)}$$

$$\alpha = 0.4\, q_m \qquad \text{(Eqn. 5)}$$

This suggests the following procedure for estimating the flood of any return period for the Dublin area. Estimate the mean of the annual maximum series, QBAR, from measured data if possible, otherwise from an equation linking it to catchment characteristics, such as in the FSR (as updated by Institute of Hydrology Report no. 124, Marshall & Bayliss , 1994).

Use equation 4 and 5 to estimate the parameters u and α, for the EV1 distribution.

Use the EV1 distribution equation to estimate the required Q_T, i.e.

$$Q_T = u - \alpha \ln\left(-\ln\left[1 - \frac{1}{T}\right]\right) \qquad \text{(Eqn. 6)}$$

or,

$$Q_T = q_m \left\{0.77 - 0.4 \ln\left(-\ln\left[1 - \frac{1}{T}\right]\right)\right\} \qquad \text{(Eqn. 7)}$$

Equation 7, in effect, defines a growth curve as, for any QBAR, it defines a relationship between Q_T and T. This suggested new curve is shown superimposed on the individual gauging station curves in **Figure 10.**

The corresponding multipliers are listed in **Table 4**. For return periods over 10 years, these factors are from 20% to over 30% higher than the corresponding FSR factors, with greater relative differences for the higher return periods. Note that, in **Figure 10**, the suggested curve lies on the group of four curves identified earlier as a visually good starting point for a new growth curve.

Table 4. Suggested Growth curve multipliers

T (years)	Multiplier (QT/QBAR)
2	0.92
10	1.67
20	1.96
50	2.33
100	2.61

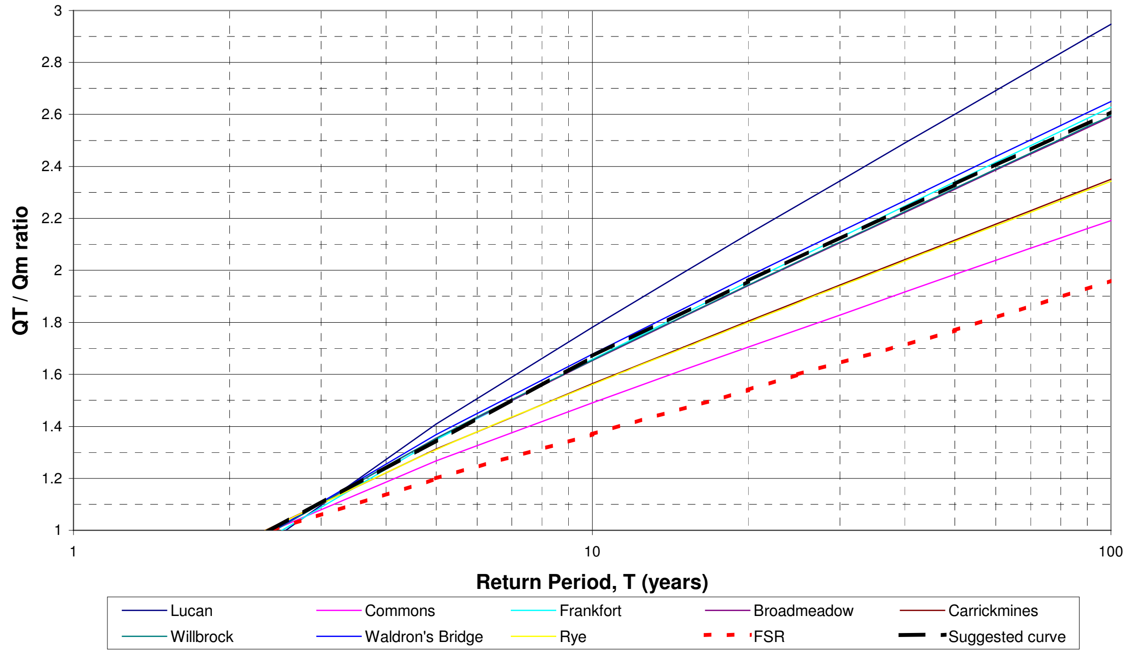

Figure 10. Suggested interim growth curve for Dublin area

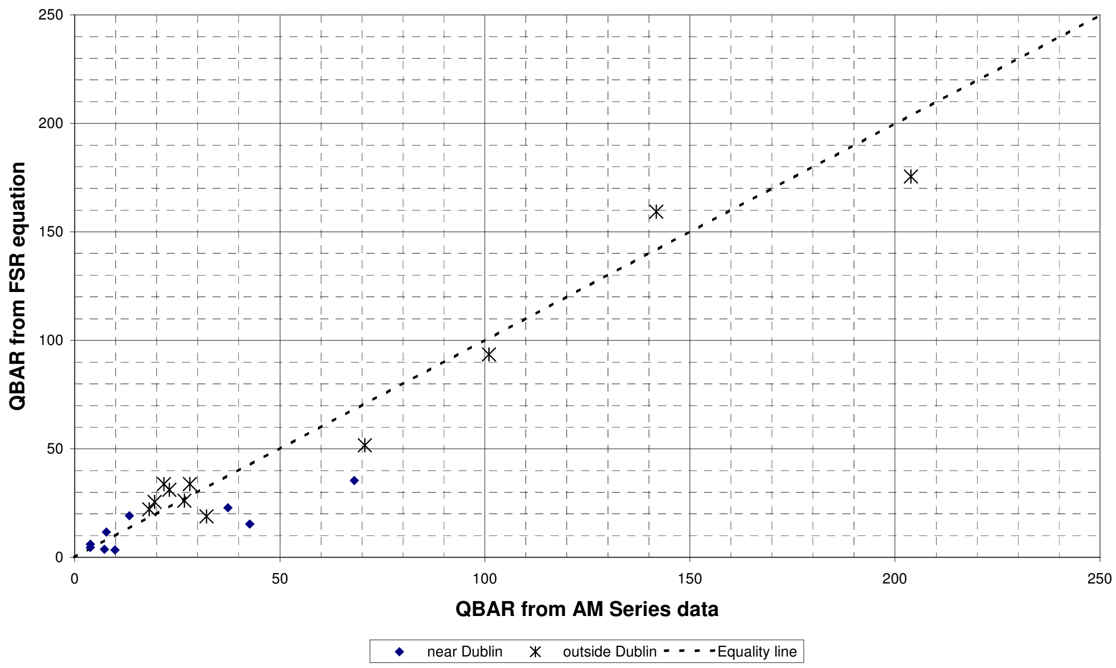

Figure 11. Comparison of QBAR estimates from FSR and AM data

NOTES

1. Equation 2 is based on a limited amount of annual maximum series information for a number of gauges in or close to Dublin. It should only be regarded as a temporary expediency, pending equations/relationships derived from a more comprehensive flood and data study.

2. The Flood Studies Report equations for estimating QBAR are of very limited use for very small urban catchments as they were derived for larger, predominantly rural catchments. For very small urban areas, say less than 5 km^2, methods of the "Rational" type, based on rainfall

statistics and a runoff coefficient may be more appropriate. Alternatively, equations derived especially for smaller, more urban catchments (e.g. Institute of Hydrology Report no.124, Marshall & Bayliss, 1994) should be considered. In any case, there still are relatively large uncertainty bands associated with these estimates.

Table 5. Comparison of QBAR values estimated from FSR and from data

River	Site	Area (km^2)	QBAR FSR	QBAR data	% difference
Nanny	Duleek	212	19.0	32.1	-41
Broadmeadow	Broadmeadow	110	15.3	42.7	-64
Ryewater	Leixlip	213	22.9	37.4	-39
Glyde	Tallanstown	267	31.1	23.1	35
Glyde	Mansfieldstown	325	33.8	21.8	55
Dee	Burley	184	22.2	18.2	22
Dee	Charleville	316	33.9	28.1	21
Fyanstown	Moynalty	185	26.1	26.8	-3
Blackwater	Liscartan	709	51.6	70.7	-27
Deal	Killyon	269	25.6	19.5	31
Boyne	Trim	1302	93.6	101.0	-7
Boyne	Navan	2011	159.2	141.8	12
Boyne	Slane	2407	175.5	203.8	-14
Broadmeadow	Asbourne	41	3.5	9.9	-65
Dodder	Waldron's Brig	89	35.4	68.2	-48
Griffeen	Lucan	43	3.7	7.2	-48
Owendoher	Willbrook Rd	28	19.1	13.3	44
Slang	Frankfort	9	4.5	3.8	18
Shanganagh	Common's Rd	39	11.6	7.7	51
Cabinteely	Carrickmines	16	6.0	3.8	58

TEST OF THE FSR QBAR EQUATION

The appropriate catchment characteristics for the study catchments were estimated from readily available maps and were used to estimate the mean of the annual maximum series, using the FSR equation for "QBAR". These were then compared with the mean of the measured annual maximum data, **Figure 11** and **Table 5**. All the AM data was used to estimate this mean and suspected outliers were not removed. For 10 stations the estimate from the Flood Studies Report "QBAR" equation was less than the mean calculated from the measured data. This underestimate ranges from just above -3% to over –65%. In 4 cases in the Dublin area the FSR estimate was higher, by up to 60%, than the QBAR calculated from the data (Willbrook, Frankfort, Common's Road and Carrickmines). However, in 5 other Dublin cases (Waldron's Bridge, Lucan, Ashbourne, Leixlip and Broadmeadow) the FSR estimate under-predicts the data estimate by similar percentages. Overall, no strong pattern can be deduced with confidence.

However, note that the FSR over-prediction is for the smaller catchments closer to the city, while the under-prediction is for the larger catchments at the periphery of the city. However, there is insufficient data to draw reliable conclusions from this pattern. A high degree of variability in the estimate of "QBAR" is to be expected and is acknowledged in the FSR. For instance 95% of the estimates are expected to lie between +117% (more than double) and – 54% of the value predicted by the QBAR equation. (FSR, p342) A later report by the Institute of Hydrology (Marshall & Bayliss (1994)) also shows a high degree of scatter, of approximately an order of magnitude, between measured and estimated "QBAR", e.g. Figure 7.1 of that report. While the QBAR equation should, in any case, be used only when no measured data is available and only for catchments with characteristics within the range of those used to derive the equation, its use in rapidly urbanising catchments near to Dublin, with relatively high degrees of urbanisation, is questionable.

COMBINATION OF GROWTH CURVE AND QBAR EFFECTS.

There are strong indications that the FSR growth curve underestimates peak discharges in the Dublin area. There are also indications of a high variability in the accuracy of estimates of QBAR from the FSR regression equation. Analysis of the combined effect of both influences was outside the scope of this study, but it should be noted that in some cases these influences will tend to combine and reinforce each other's impact and in other cases, may tend to cancel or reduce each other's impact.

CONCLUSIONS

1. The Flood Studies Method growth curve method, applied to a known QBAR, is likely to lead to an underestimation of the flood flows for high return periods in the Mid-Eastern side of Ireland, and especially in the Dublin area.

2. Comparison of QBAR estimated from the FSR regression equation with measured data shows a large range of differences for most catchments tested in the Mid-Eastern part of Ireland. There are similar numbers of over and underestimates. There are some catchments in the Dublin area for which the FSR equation seems to overestimate. While there is insufficient data to draw firm conclusions from this, the large variability in estimating QBAR from the FSR regression equation indicates the need for further study if this variability is to be reduced.

3. In the light of these findings, it is considered imperative that the question of design flood estimation, particularly in the Dublin area, be urgently addressed. It is of critical importance to enhance the flow data sets being collected by OPW, EPA and Local Authorities, so that long term high quality data sets are available for this type of analysis. In particular, the rating curves for many sites do not extend to include some of the higher flows and this should be addressed by direct measurement and hydraulic modelling.

LIMITATIONS

The data used in this report are subject to various caveats and warnings which are explained by the primary data providers, the OPW and EPA. In particular it is very difficult to establish rating curves for very high flows and many of the high flows in this analysis exceeded the range of flow gauging used in developing the rating curve. The potential impact of this on this study may be significant. In conversations with the skilled hydrometric personnel who collect and process the data, a sense can be obtained of which rating curves are well founded and reliable and which are not. In certain cases some specific feature of a gauging site may be the most likely explanation for some of the data "outliers". Specific reasons for individual outliers, are left for further investigation. Thus, the data is used here on the basis that it is the best estimate of the flows concerned available at the present time. For any station, where an annual maximum value was missing from the record, that year was ignored in the analysis. This is justified on the basis that each year is assumed independent of other years. However, if the years with missing values were correlated with high or low flow periods this would distort the analysis. What is important here is not the specific result or its magnitude for any individual station, but rather the result that ***all*** of the near-Dublin stations examined showed the FSR to underestimate to some degree. It is thus the number of stations contributing to the conclusions which gives them their weight.

ACKNOWLEDGEMENTS

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