Application of the UK Flood Estimation Handbook pooling group approach to the Munster Blackwater River

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Synopsis

The paper describes a practical means of applying the concepts of the UK Flood Estimation Handbook statistical pooling group approach to a subject catchment in Ireland using flood and catchment data from Ireland only. The application of the procedure is described for the Munster Blackwater River at the town of Fermoy. The results are compared to those of more conventional approaches.

Introduction

The town of Fermoy lies on the banks of the Munster Blackwater River in the south west of Ireland. Severe flooding causing significant damage has been experienced on a number of occasions during the last 100-years: most notably in 1916, 1946 and 1980. Recent decades have also experienced their share of out-of-bank events, perpetuating the very real worries of the community concerning the flood risk posed by the river. There has therefore been a need to assess possible alleviation or management measures to help limit the flood risk.

Previously, a preliminary flood study was carried out by University College Cork (UCC, 2000) to assess the risk and to develop outline measures to alleviate the problem. In 2002, a consortium consisting of Babtie Group, T J O'Connor, DHV and PM Group was commissioned by the Office of Public Works (OPW) to carry out a feasibility study to assess flood risk in the town and develop a flood alleviation scheme[1].

The first stage was to estimate appropriate design flood flows which could then be fed into a numeric hydraulic model of the river so that design water levels could be obtained. Since the mid 1970s the usual approach to design flow estimation in Ireland has been the application of the Flood Studies Report methods (NERC,1975). However, since 2000 new developments in UK flood estimation techniques have become available via the Flood Estimation Handbook (Institute of Hydrology, 1999). The principal new features of the FEH procedures are: a fundamentally new methodology for the estimation of design rainfall depths; a new statistical method for flood frequency estimation based on the "pooling" of hydrologically similar gauged catchments; and the FSR catchment characteristics obtained from maps are replaced by catchment descriptors derived from digitally held spatial data. As such the FEH approaches and guidance have largely superseded those of the FSR in the UK. It should however be noted that the structure of the FSR rainfall-runoff model has not been changed by FEH, though parameter value estimation has been revised in line with the FEH catchment descriptors. The FEH procedures have been adopted by most of the principal interested UK bodies (including the Environment Agency, the NI Department for Environment Food and Rural Development, the Institute of Civil Engineers, and the Department of Environment Food and Rural Affairs) as recommended standard methods for flood estimation.

Although the Institute of Hydrology were not charged with developing the FEH for application within Ireland, some of the new ideas do offer potentially useful means of tackling flood estimation in Ireland. The overall purpose of this paper is to describe how the concept of FEH statistical pooling group approach was applied to the Blackwater River at Fermoy using only Irish data, and to compare these findings to those of other conventional approaches.

[1] In parallel a separate study was also undertaken by Ove Arup for the town of Mallow (27km upstream of Fermoy; also on the Blackwater River). Feedback and findings from the Mallow study were viewed as providing valuable additional information and were incorporated into the Fermoy study, where appropriate.

Catchment Description

The River Blackwater rises in County Kerry in the Mullaghareirk Mountains and initially flows in a southern direction to Rathmore and then in an easterly direction, joining the Irish Sea at Youghal. The river passes through a number of towns along its route, the largest of which are Mallow, Fermoy and Youghal, (Figure 1). Fermoy is located approximately 50km upstream of the mouth of the river and is not tidally affected. The catchment area to Fermoy is approximately 1760 km^2, whilst to Mallow approximately 1178 km^2.

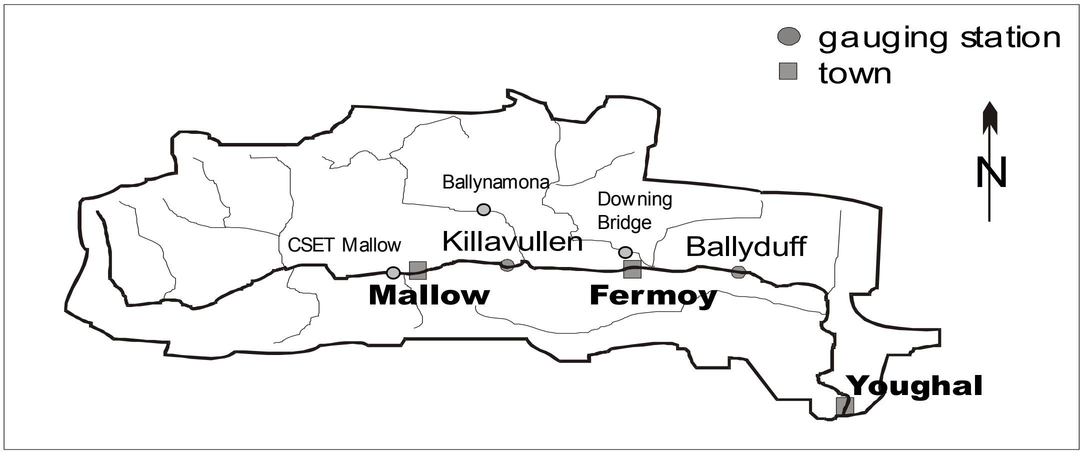

Figure 1 – Catchment map

Downstream of Mallow, the valley is broad and relatively flat and is surrounded by upland areas. To the north there are the ranges of Knockmealdown, Kilworth, Galtee, Ballyhoura and Mullaghareirk and to the south is the Boggeragh range.

The catchment is entirely rural – dominated by pasture and rough grazing with lesser extents of cultivated land and some forest cover principally in the west. No significant urban areas exist that are likely to affect the flood flow characteristics of the river. For such a large catchment it is also important to note a complete lack of large and medium sized water bodies (lakes or reservoirs), which could influence downstream flood flows.

The upper and lower parts of the catchment are characterised by different soils types. In the upper western half of the catchment the soils are dominated by the low permeability soils of WRAP classes 4 and 5. Whilst the lower eastern half of the catchment is more dominated by WRAP class 2, together with an area in the lower river valley of WRAP class 5.

The climate is dominated by the prevailing south westerly air flow. This generally leads to moist, mild conditions with most of the precipitation falling as rain during the winter period. Significant snowfalls are rare and are not, in general, linked to the floods on the Blackwater. The last major flood in Ireland with a significant snowmelt component occurred in March 1947.

Hydrometric data

Figure 1 shows those flow gauges that were potentially directly useful to the Fermoy study, and Table 1 provides associated information. For the town of Fermoy, though, no river flow station existed until the last couple of years when automatic level recorders were installed.

Table 1- Flow gauges in the Blackwater catchment

Station name	Station no.	River	NGR	Catchment area (km^2)	Period of continuous recording	Comment on high flow estimates
CSET Mallow	18006	Blackwater	W525973	1058	1977- present	Limited reliability*
Killavullen	18003	Blackwater	W647997	1258	1955 – present	Reasonable
Ballyduff	18002	Blackwater	W964991	2338	1955 – present	Reasonable
Ballynamona	18004	Awbeg	R656075	324	1955 – present	Reasonable
Downing Bridge	18005	Fushion	R823018	363	1955 – present	Unreliable

* The characteristics of the location do not lend themselves to high flow measurement however during the course of the Mallow study numeric hydraulic modelling was used to improve the high flow rating.

The Killavullen and Ballyduff stations are the closest stations on the Blackwater to Fermoy and potentially offer the best historical data; these are described in more detail below.

Killavullen Gauging Station:

It is an open channel gauging station with a channel control at low levels and a channel and bridge control at higher levels. The station is known to be bypassed on the left bank during the largest events, with water extending as far as 200m from the river, and bypassing flows in some locations with sufficient energy to cause severe damage to the road. The highest flow recorded by current meter gaugings is about 250 m^3s^{-1} (approximately bankfull). However much of the annual maximum series have peak levels higher than this, and the maximum on record (2 November 1980) reached a level approximately 2m higher than this bankfull level. Consequently instead of accepting flood flow estimates based on simple extrapolation of the rating relationship, an out-of-bank rating relationship was derived using a hydraulic model of the river in the vicinity of the gauging station (Babtie Group, 2003). Adopting the revised rating curve lowered the flow estimate of the November 1980 event from 612 m^3s^{-1} to 525 m^3s^{-1}. The flow was lowered rather than increased, as would normally be the case when floodplain flows are included, because at Killavullen the arches of the bridge exert an increasing effect upon in-channel flows as the water level approaches their soffits.

Ballyduff Gauging Station:

An open channel station with a channel control at all levels. The rating relationship is based on current meter gaugings up to a flow of 304 m^3/s. By extrapolating the station's rating curve, the highest recorded flood level equates to an estimated flow of 479 m^3/s. The spot gaugings are consistent and the gauge has never been known to be bypassed: consequently a reasonable degree of confidence is given to the high flow extrapolation of the rating curve. Between Fermoy and Ballyduff there is an extensive floodplain on the left bank that provides much more flood storage than is typical of the floodplains upstream of Fermoy. The presence of such a large floodplain between Fermoy and Ballyduff was judged likely to alter the flood flow characteristics of the watercourse.

Methodology

The methods used to derive and refine the design flood estimates at Fermoy site were:

1. Single site analysis of gauged data
2. Flood Studies Report (FSR) statistical approach for ungauged catchments with data transfer from local gauges
3. Pooling group statistical approach based on the concepts of the UK Flood Estimation Handbook (FEH)
4. Refinement of the flood frequency analysis using historic information

It was considered at the outset that these different methods would, to some degree, complement each other and lead to a higher degree of confidence in the estimated design flows.

The FSR rainfall-runoff method offers an alternative means of estimating design flows in many circumstances. However it is not recommended for use on catchments greater then 1,000km^2. Since the Fermoy catchment has an area of 1,762km^2 this method was not considered further.

i) Single site analysis of gauged data

The statistical analysis of the annual maximum series at the Killavullen and Ballyduff gauging stations may provide a valuable check on the performance of other methods of flood estimation, and can be used to cautiously assist in the determination of appropriate growth curves for the Blackwater at Fermoy. The FEH suggests that single site analysis is likely to offer the best estimate of flows up to a return period of 0.5N, where N = number of years in record, therefore, the 45-year records at these stations should provide robust estimates of flow up to almost the 25-year event.

The generalised extreme value distribution (GEV) and the generalised logistic distribution (GL) were fitted to the gauged data. The GL distribution is recommended by the FEH as giving the best fit to the analysis of data in the UK. Though not mandatory, the selection of another distribution may be considered though it advises that supporting evidence within the data or hydrological understanding is needed.

Although single site analysis was undertaken as part of the preliminary study carried out by UCC, the analysis undertaken in the present study (see Figure 2 and Table 2) supersedes that produced previously for the following reasons:

1. Additional years of data are now available
2. Corrections to the Killavullen stage data (related to datum changes) have been made for the period 1962 – 1970
3. The high flow section of the rating equation for the Killavullen gauge has been revised
4. A revised best estimate of the Killavullen November 1980 peak flow was derived based on surrounding level and flow evidence

These revisions to the Killavullen record are fully described in Babtie Group (2003).

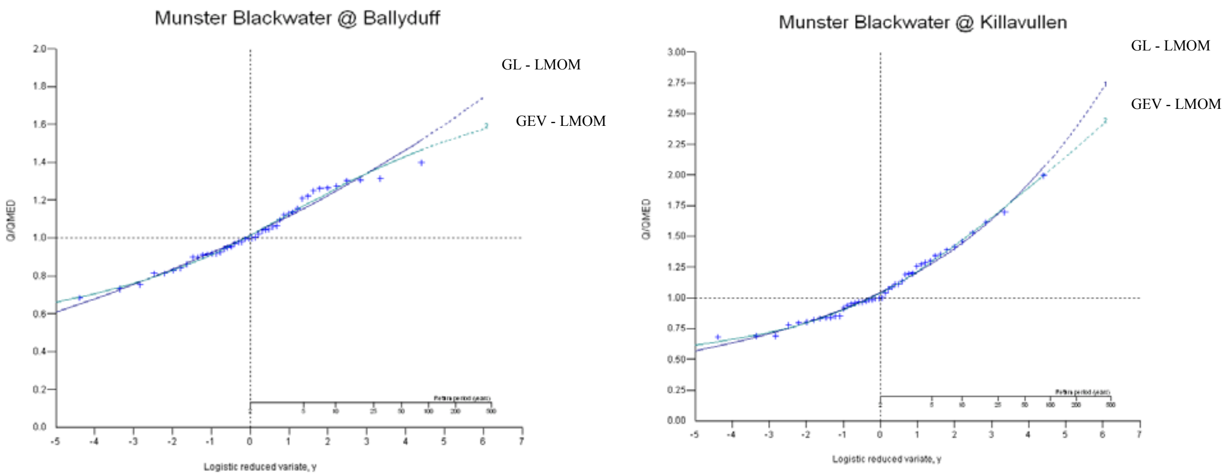

Figure 2 - Results of the single site analysis for Ballyduff and Killavullen (GL-LMOM = Generalised Logistic distribution fitted by L-moments; GEV-LMOM = Generalised Extreme Value distribution fitted by L-moments).

Table 2 – Estimated design flows based on single site analysis of annual maximum series for Ballyduff and Killavullen. (GEV = Generalised Extreme Value distribution, GL = Generalised Logistic distribution)

Return period (years)	Ballyduff flow (m^3/s)		Killavullen flow (m^3/s)	
	GEV*	GL	GEV*	GL
2	274	276	348	348
5	342	338	401	397
10	388	381	432	427
50	490	497	488	497
100	535	557	507	529

* Favoured distribution

ii) Flood Studies Report (FSR) statistical approach for ungauged catchments with data transfer from local gauges

The all Ireland regional growth curve is used to transform the index flood (QBAR) into rarer flood magnitudes. As such this approach treats all the rivers of Ireland as having the same flood growth curve. It is now generally accepted that parameters such as catchment size, topography, geology, and soil can affect the steepness of the growth curve relationship. As these parameters differ sufficiently amongst Irish catchments this suggests that one growth curve for the country may be a somewhat simplistic view.

The FSR six parameter QBAR equation, with an Ireland regional multiplier of 0.0172, was used to estimate the index flood. This value was then adjusted with reference to the performance of the equation on a nearby similar gauged catchment; according to the methodology described in the Flood Studies Supplementary Report 13 (Institute of Hydrology, 1983). The catchment characteristics for Fermoy and the nearby gauging stations are given in Appendix 1.

The Killavullen gauge was used in the data transfer process. Ballyduff was not thought appropriate as a donor due to the influence of the, previously identified, extensive floodplain between Fermoy and Ballyduff. The associated flood storage was expected to have a significant influence on the flood flow characteristics at Ballyduff; this conjecture has been strongly supported by the shape of the Ballyduff single site analysis flood frequency curve (see Figure 2).

iii) Pooling group statistical approach based on the concepts of the UK Flood Estimation Handbook (FEH)

The FEH statistical method (Institute of Hydrology, 1999) is the recommended approach for flow estimation on large catchments in the United Kingdom. Although the Republic of Ireland was not included in the FEH research, the underlying pooling group principal of deriving the flood growth curve for the subject site from a group of hydrologically similar catchment holds. However, the flat nature of the FSR Ireland regional growth curve suggests that some form of regional factor may have a significant influence. A possible candidate for this regional response may be linked to regional rainfall growth factors rather than catchment hydrological characteristics (Morris, 2003). It was therefore considered that the best application would be to use only Irish flood data in the procedure. An alternative approach, though less favoured, would have been to accept flood data from across the British Isles (Ireland and Britain) based on the assumption that Irish and British hydrological conditions are similar.

The FEH statistical method, like the FSR statistical method, uses an index flood and growth factors to produce floods of various frequencies. The index flood used is the median annual maximum flood (QMED). The advantage of using QMED is that it is a more robust index as it is not affected by the magnitude of any extreme floods in the record. Additionally the accuracy of flow estimates tends to decrease for the higher floods and this increasing uncertainty attached to the larger flow estimates affects the estimate of QBAR but does not affect the median (QMED). The second stage of the procedure is to use flood peak statistics from hydrologically similar catchments (selected via a “pooling” process based on the catchment size, wetness and soil properties) to estimate the growth factor between QMED and the flood of the required return period. The advantage of the FEH pooling method is that the growth factors are determined from a group of stations whose catchments are similar to that of the subject site. FSR growth factors on the other hand were determined from a regional group that may have little in common with the subject site, or each other, apart from their geographical location.

A FEH digital dataset of catchment descriptors was developed for the UK in conjunction with the development of the FEH procedures. It is possible to abstract catchment information down to a catchment size of 0.5 km^2 anywhere on the UK mainland without recourse to paper maps; these catchment descriptors effectively replaced the need for the manually derived catchment characteristics of the FSR. New equations based on multiple regression analysis of the catchment descriptors were derived to estimate the index flood. FEH guidance is quite clear: a catchment descriptor’s estimate of QMED at an ungauged site should be adjusted by a data transfer from a hydrologically similar catchment (preferably on the same water course) in a similar fashion to that advocated in FSSR 13, where possible.

The FEH software (WINFAP-FEH) also provided a database of UK flood data and gauging station catchment descriptors available for the semi-automated pooling process. For a full description of the pooling group procedure the reader is referred to chapters 6, 7, 16 and 17 of FEH Volume 3. However the basic principal is that hydrologically similar gauged catchments are selected based on the similarity of three catchment descriptors representing three physical characteristics viz: size (AREA), wetness (SAAR), and soil properties (BFIHOST) - where AREA = catchment area, SAAR = standard average annual rainfall for catchment, and BFIHOST = baseflow index determined from the UK hydrology of soil types classification. The following similarity distance measure is used to judge the similarity of the subject catchment to each of the gauged catchments with available data.

$$Dist_{ij} = \sqrt{ \tfrac{1}{2} \left(\frac{\ln AREA_i - \ln AREA_j}{\sigma(\ln AREA)} \right)^2 + \left(\frac{\ln SAAR_i - \ln SAAR_j}{\sigma(\ln SAAR)} \right)^2 + \left(\frac{BFI_i - BFI_j}{\sigma(BFI)} \right)^2 }$$

where

AREA= catchment drainage area (km^2)

SAAR= standard average annual rainfall 1961-1990 (mm)
BFI= base flow index, BFIHOST derived from the HOST soils data.
σ = standard deviation,

The division by the standard deviation terms in the equation are to standardise the parameters since they have different size and range of variables. Institute of Hydrology research showed that too much emphasis was given to the size of catchment, so the ½ term was added by the Institute of Hydrology to reduce its importance.

The catchments with greatest similarity are selected until the number of station years in the pooling group is 5 times the return period of interest. This was found by the Institute of Hydrology to be the optimum size for the pooling group.

Next, the stations in the pooled group are reviewed using station and catchment information. Those judged, on hydrological grounds, to not be representative of the subject catchment can be either removed or given a lower ranking. Finally the flood peak data are themselves examined and checks made for discordant sites[2] and group heterogeneity[3], which highlights stations within the group that have an unusual distribution of annual maximum values compared to the other sites in the group and may require further consideration.

A growth curve is then fitted to the pooled data. All stations in the pooling group influence the final curve to some extent, though greater weighting is given to the longer-record stations and to those catchments judged to be more similar to the subject catchment. Application of this FEH approach to a site in Ireland is not immediately possible as FEH catchment descriptors are not available and flood data from Ireland are not included. Means of supplying equivalents, therefore, needed to be sought.

Estimation of QMED:
QBAR was calculated using the FSR statistical approach and then converted to QMED using the Irish growth curve factor of 0.95 (a value checked against the growth rate for Killavullen). Then a data transfer from the Killavullen gauge was used to estimate the final Fermoy QMED according to the methodology described in the Flood Studies Supplementary Report 13 (equivalent to the FEH data transfer by donor catchment).

In the pooling process, equivalent or surrogate catchment descriptors, based on the FSR catchment characteristics given in FSR Volume IV, were used and the pooling process relatively simply undertaken outside of the FEH software. Gauging stations from both the Republic of Ireland and Northern Ireland were considered. Stations with FSR quality grades A to D were accepted; grades E and Z were rejected. Any stations with a LAKE value greater than 0.2 were removed since the Fermoy catchment has no lakes or reservoirs and the presence of these features in candidate catchments for pooling were judged to potentially make these catchments hydrologically dissimilar.

Values for AREA and SAAR (1941-1970) are provided for the majority of Irish gauges in Volume IV of the FSR. Values for BFIHOST are not available for Ireland, instead the SOIL value was used as a substitute[4]. The standard deviations of the parameters were calculated for the Irish dataset: σ(lnAREA)=1.03, σ(lnSAAR)=0.21, σ(SOIL)=0.075.

The initial pooling group was further refined by considering the accuracy of gauges at high flows, and the estimated similarity in floodplain storage effects. In addition, consideration was given to watercourses within the pooling group that have benefited from Arterial Drainage Schemes. It was felt that the flooding regimes

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[2] A statistical test for discordancy is supplied in the FEH software. It is used to detect whether the distribution of annual maxima at an individual station is strongly different from the group average.

[3] A statistical test for group heterogeneity is supplied in the FEH software. It is used to assess whether the distribution of flood growth is broadly similar at all the sites in the group.

[4] SOIL is closely related to the standard percentage runoff parameter SPR, for example FSSR5 (Institute of Hydrology, 1979) gives SPR = 104.4*SOIL. Conceptually BFI can, to a first order estimate, be estimated as 1 – 0.01SPR. Based on more detailed work in FSSR16 (Institute of Hydrology, 1985) BFI was given as 1.08-0.015*SPR, whilst BFIHOST is given as 0.987-0.013*SPRHOST in the FEH Volume 3. Within the pooling process SOIL, 1-SOIL, and 0.987-0.013*(104.4*SOIL) were all used as surrogates for BFIHOST. The resultant pooling group rankings were similar and the SOIL parameter was accepted as a reasonable surrogate for BFIHOST.

may have been significantly changed by these schemes and, therefore, it was necessary to test the sensitivity of the analysis to the inclusion and exclusion of pre and post drainage work data. The catchments affected by arterial drainage are:

- Maine at Shanes Viaduct - Drainage works 1958-63
- Blackwater at Maydown Bridge - Drainage works 1986-95
- Maigue at Croom - Drainage works 1973-86
- Boyne at Slane Castle - Drainage works 1969-86

The sensitivity analysis was undertaken in three stages. First, the pooling group growth curve was derived using all the data, then all post drainage work data was removed from the four gauges and, finally, a similar analysis used only the post drainage works data from these four gauges. This analysis showed that that for this particular pooling group the 100-year growth rate was insensitive to whether the pre or post arterial drainage data were included. Changes in the 100-year growth rate were of the order of 2%.

Furthermore, stations in close proximity to other pooled stations on the same watercourse were assessed for duplication of data, and the weaker station(s) for the pooling process removed, where necessary.

Having established the hydrologically similar catchments, their updated annual maximum data (obtained from OPW) was processed within the FEH software to produce the final flood frequency curves.

iv) Refinement of the flood frequency analysis using historic information

Several severe floods occurred in the 20th century prior to the commencement of records at the gauging stations in the Blackwater catchment. This information is valuable in assessing the frequency of occurrence of floods above a certain threshold.

Maximum flood level information (principally for the town of Fermoy) was sought from a variety of sources to attempt to identify the worst floods experienced. If all the major floods above the threshold can be identified then it offers a means of extending back the flood series (albeit the very highest components) beyond the period of record of any local gauging station (Bayliss & Reed, 2001). The ranked severity of the Fermoy floods could then be used to better understand the rarity of recent events and help potentially refine the flood frequency analysis of the earlier discussed methods. Flood level information was taken from flooding reports, recorded level data, newspaper reports and photographs. The Gringorten plotting position was used to assess the return period of specific events from their ranking.

Results

Results of the single site analysis for the Ballyduff and Killavullen gauges have been presented in Figure 2. Although the Generalised Logistic distribution may be the FEH favoured distribution, its unbounded-above nature prevents a good fit to the Ballyduff data, which is thought to be influenced by the extensive floodplain between Fermoy and the gauging station. The GEV distribution is better disposed, though not perfectly, to fitting the data. Both distributions visually appear to fit the Killavullen data well. The GEV distribution was favoured due to the apparently better fit and because the authors are unaware of a comparative performance assessment of the GL and GEV distributions on the Irish data set that suggests the GL should be favoured.

The predicted flood growth curves, with respect to the QMED index flood, of the various methods undertaken are compared in Figure 3. The Fermoy pooling group and the Killavullen growth rates are almost identical, whilst the Irish FSR growth curve (adjusted so that the 2-year event is the index flow) is slightly higher. The Ballyduff curve is markedly different, almost certainly reflecting the influence of the large active floodplain downstream of Fermoy. The gauges included in the final pooling group are given in Appendix 2.

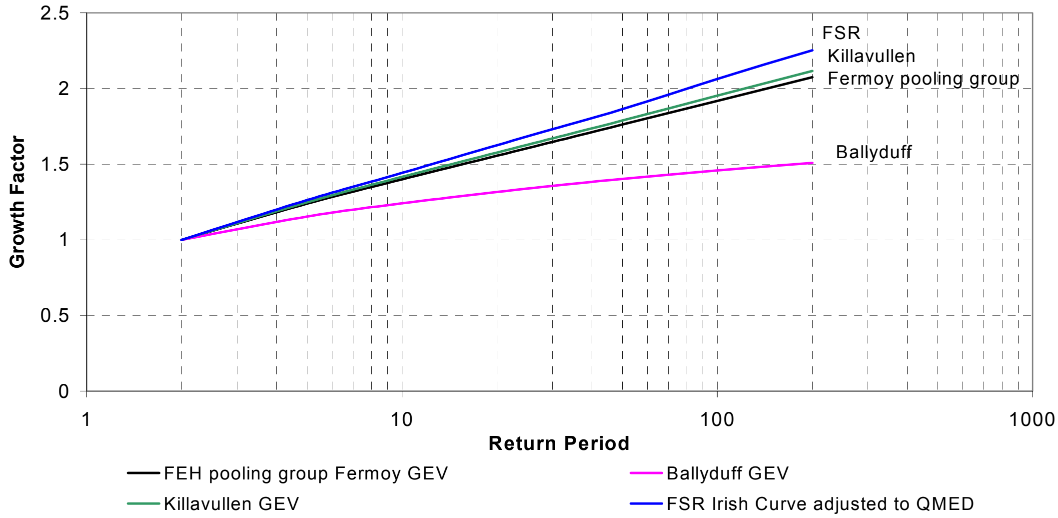

Figure 3 - Comparison of flood growth curves

Figure 4 shows the predicted flows at a number of stations on the Blackwater. The flows for Killavullen and Ballyduff and the Fermoy pooling group are all calculated using the GEV distribution. The two methods of predicting flows at Fermoy are also shown, i.e. the FEH pooling group analysis and the FSR approach in which the regional Irish growth curve is used.

With the flows for the gauging stations plotted on the same figure it is possible to speculate how the river system behaves along its course. Ballyduff, the furthest point downstream, has a greater flow predicted than Killavullen up to about a 30-year event based on the single site analyses. For rarer events the higher flows are estimated at the upstream site of Killavullen. As indicated before, the likely explanation is that the floodplain between Fermoy and Ballyduff stores and attenuates these flows, which suggests that the flood growth behaviour at Ballyduff is inappropriate to be applied to the Fermoy situation.

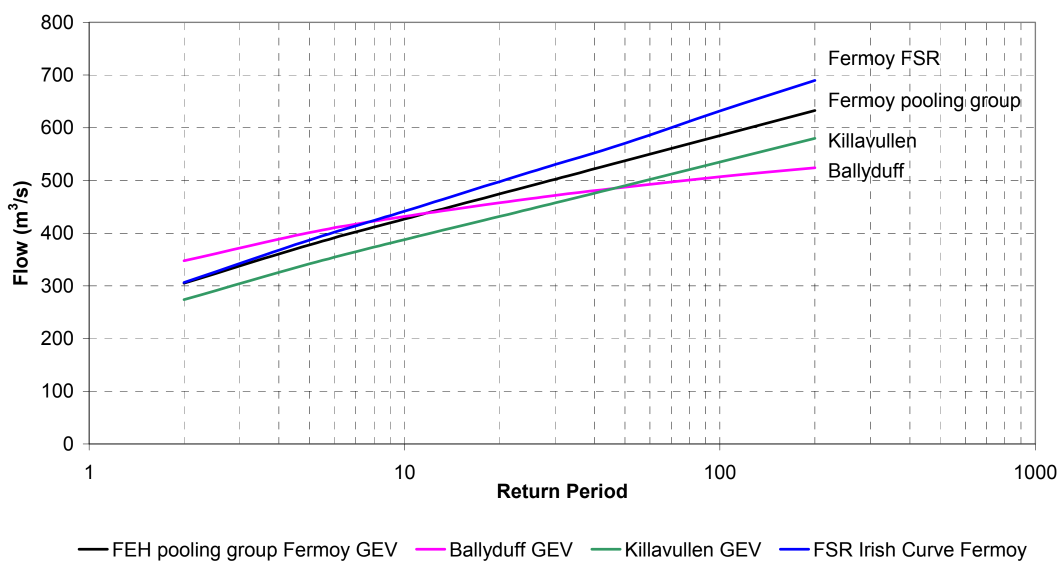

Figure 4 - Comparison of flood frequency curves

Findings of the historic review of flooding in Fermoy

The bridge in Fermoy is believed to have been built in 1865 and the weir in 1916[5]. River modelling of the current situation has indicated that the bridge does not exert a significant influence on flow levels while the weir drowns for flows in excess of 480 m^3s^{-1} and the control then passes to the downstream channel. It therefore appears that neither of these man-made structures significantly affects the levels of the most extreme floods.

The severity of a number of events in Fermoy has been recorded with level measurements taken at different locations throughout the town. These data were collated by Jack O'Keefe of Cork County Council and John McCarthy of Murphy McCarthy Consulting Engineers, Cork and was reproduced in the UCC report (2000). These records suggested that the worst event during the 20th century occurred on 8 December 1916 and the second worst on 2 November 1980.

In addition to the automated sub-daily monitoring at Killavullen, manually read daily level records were also available from the OPW for the period 1940 to 1955. These records identify that there were substantial events in 1946 and 1948. A local Fermoy flooding report (reference unknown) identified the 12 Aug 1946 event as 18 inches lower than the 1916 event in Fermoy. This report included photographs of the event in the town. From this direct evidence this flood has been ranked between the 1916 and 1980 events.

Historic daily rainfall records, provided by MET ÉIREANN, were examined, in an attempt to better understand the relative magnitudes of the 1948 and 1946 events. High rainfall totals were evident for the 11th of August 1946 with a notable maximum of 115.1mm recorded in the Cork area. With the event being in August, one may speculate that it was characterised by intense rainfall and runoff from what was likely to have been a relatively dry catchment. The 1948 event was, on the other hand, in December with the main peak of the event occurring on 5th but the maximum daily rainfall totals were recorded on 1st. Anecdotal evidence from Mallow (Sullivan, 1986) suggests that there was an initial flood event on the 2 December and therefore the rainfall required for the main event could have been relatively small, since it would have been falling on a saturated catchment. Unfortunately a definitive ranking of these events cannot be achieved from this rainfall data alone.

Further evidence has been considered from the town of Mallow where level measurements have been recorded (Sullivan, 1986: Sullivan, 1988). These measurements suggest that the largest recorded event occurred in 1853 and that the 1948 event was marginally greater than that experienced in 1916; probably within measurement accuracy achievable at the time. The 68 years from 1916 back to 1853 provides additional time for natural changes to occur to the channel and its flowing floodplain such as increased vegetation; this reduces confidence in the 1853 event so its estimate should be treated with caution.

Since level data have been taken at different locations within and around Fermoy for the various flood events, it has not been possible to construct a definitive level-frequency relationship for Fermoy. The Gringorten plotting position could, however, be used to estimate the return period of the flood events experienced at Fermoy based on their rank. However, ranking the magnitude of the flood events in Fermoy is not simple. This study has only identified from direct flood observations in the town two 20th century floods greater in magnitude than the 1980 event. Yet it is believed that, in the last 150 years, another two major floods may have occurred, (in 1853 and 1948**)** but no direct level information from the town was identified during the course of the study. Therefore, two sets of return period calculations were undertaken. The first is based on only the direct flood information gained from the town (i.e. the records from 1916 to present). The second is to assume that the in-direct evidence on the 1948 and 1853 events is valid. Tables 3 and 4 show the respective rankings:

The historic review ranks the 1980 event in Fermoy as 3rd largest in the 88 years record of direct flood evidence (Table 3) and 5th largest in 151 years (Table 4) when the indirect evidence is accepted. Following the methodology advocated by Bayliss and Reed (2001), the Gringorten plotting position for both sets of rankings estimated the 1980 event to have a return period of 45 +/- 10 years. Corresponding historical analysis at Mallow undertaken by Ove Arup (2003) gives a similar return period to the 1980 event.

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[5] The 8 December 1916 flood event is therefore almost certain to have occurred after the weir had been built. It is also worth noting that the one spot height available from the 1916 flood comes from a location downstream of the bridge and weir.

Table 3 - Ranking of floods in Fermoy based only on direct flood evidence in Fermoy

Fermoy Rank	Date
1	1916
2	1946
3	1980

Table 4 - Ranking of floods in Fermoy including indirect evidence of flooding from outside of Fermoy

Fermoy Rank	Date
1	1853
2	1948
3	1916
4	1946
5	1980

The Killavullen 1980 "best estimate" value of 525 m^3/s [+/- 70 m^3/s (Babtie Group, 2003)] has a return period of approximately 80 years based on the single site flood frequency analysis of the site. Although not conclusive, the historic evidence may point toward a lower return period for the 1980 event at Killavullen than the "best estimate" value obtained from the revised rating curve (which attempts to account for the bypassing flows). However the robustness of the single site curve for return periods beyond 0.5N (where N is the number of years in the record, which for Killavullen is 46 years) is likely to be poor. For example if the Hydrometric Stations at Killavullen and Ballyduff had not been installed then the investigation would conclude that the 1980 flood was about a 45-Year event (based on the historic evidence). If, also, information on the historic events was not uncovered then there would be a flood table containing just one entry, namely, the 1980 event and it would be concluded that the 1980 flood was greater than a 100-year event. The lesson that may be drawn is that ignoring historic information just because there is a flood record can lead to a significant misunderstanding of the return period of a recent significant flood.

It is not possible to quantify the whether the Killavullen 1980 estimate is slightly high, but the use of 525 m^3/s might be slightly conservative. Had a lower range value of 460 m^3s^{-1} for the 1980 event been used then this would have reduced the single site growth factors by up to 5% for return periods up to 100 years. The impact of adopting the lower 1980 flow on the pooling group analysis is much less. Consequently, and given the inherent uncertainties in the estimation of the return periods of extreme events the mismatch in the return period of the 1980 event was not considered too worrying.

Discussion

Conceptually, following the FEH pooling group approach offers a powerful tool to the hydrologist, allowing in this case the estimation of the flood frequency relationship of an ungauged site from the flood characteristics of those gauged catchments that are most hydrologically similar. This removes the reliance on growth factors determined from a regional group that may have little in common with the subject site, or each other, apart from their geographical location. The pooling group method is also flexible enough to assess the sensitivity of the end result to catchment factors that may be thought to have a possible influence: for example Arterial Drainage Scheme affected catchments. Consequently the pooling group analysis is favoured over that of the older FSR regional growth curve approach.

The single site analysis at Killavullen lends weight to the pooling group analysis, though it is emphasised that the single site curve at the higher return periods is unlikely to be particularly robust. However, in this particular case the difference between the pooling group and the FSR flood frequency curves is not substantial. Experience from the UK (Cargill and Price, 2001) indicates that much larger differences are possible.

It may also be speculated that the growth rates of all Irish catchments are quite similar, and hence the relative similarity in the steepness of the pooling group and FSR regional growth curves is to be expected. This study has not set out to investigate this specifically, but it is interesting to note the range of growth curves in the Fermoy pooling group alone is quite large (Figure 5). More applications of the FEH pooling group approach in Ireland may provide evidence of larger discrepancies between the two approaches.

It should be stressed that the study has borrowed the UK FEH pooling group approach, whose form and nature has in part been based on the characteristics of UK data, and not on data from Ireland. For further application in Ireland it is advised that more research and development would be beneficial, to ensure that the techniques are optimised to the specific characteristics and responses of the Irish catchments and their flood datasets.

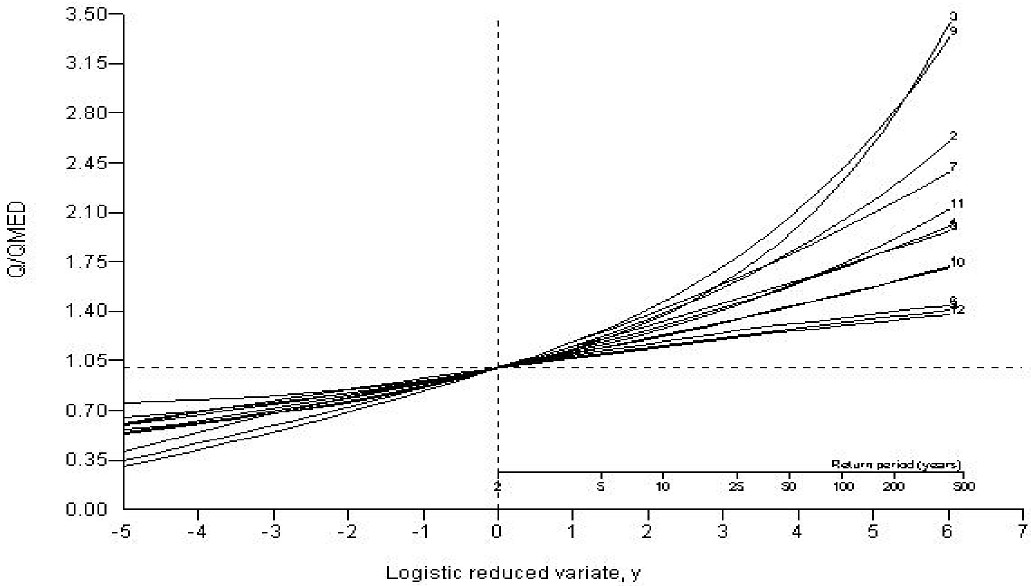

Figure 5 – Single site growth curves of the pooled catchments used in the Fermoy pooling group analysis.

Conclusions

A means of applying the FEH pooling group approach within Ireland has been developed using data exclusively from Ireland. Initial selection of hydrologically similar catchments is made in terms of three catchment characteristics: size (AREA), wetness (SAAR), and soil properties (SOIL); SOIL was used as a surrogate for the FEH catchment descriptor BFIHOST.

The approach has been applied to the ungauged subject site of the Blackwater at Fermoy, along with the more conventional FSR and 'single site' statistical methods. The results from the pooling group analysis were preferred on the basis that it removes the reliance on growth factors determined from a regional group that may have little in common with the subject site, or each other, apart from their geographical location. Supporting evidence for the pooling group growth curves was obtained from the single site analysis at Killavullen (a relatively nearby gauge on the same river).

The FSR regional growth curve approach suggests a slightly steeper growth curve than that of the favoured pooling group. The study offers no view as to whether this relative similarity to the regional growth factor should be considered typical or not. Examination of the growth curves of the individual members of the Fermoy pooling group indicates that, even within a group of catchments that are considered hydrologically similar, a large range of growth factors can exist. This may suggest the potential for pooling group growth curves to be significantly different in some cases to that of the FSR regional growth curve.

Information from reviews of historical flooding in Fermoy, and also from the upstream town of Mallow, provided valuable supplementary information that helped refine the estimates of the Fermoy flood frequency relationship.

For further application of the pooling group approach in Ireland it is advised that more research and development would be beneficial to ensure that the techniques are optimised to the specific characteristics of the Irish catchments and their flood datasets.

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Appendix 1 FSR catchment characteristics for the Blackwater catchments

Location	AREA (km^2)	STMFRQ (junctions\ km^2)	S1085 (m/km)	SOIL	RSMD	LAKE
Killavullen	1258	1.05	2.02	0.440	42.7	0
Fermoy	1762	0.77	1.35	0.418	42.7	0
Ballyduff	2338	0.95	1.22	0.400	42.7	0

Appendix 2 Final pooling group for the Blackwater at Fermoy catchment

Station No	River	Location	AREA	SAAR	SOIL	Dist
18003	BLACKWATER	KILLAVULLEN	1258	1240	0.439	0.395
* NI gauge	MOURNE	DRUMNABUOY HOUSE	1839	1261	0.392	0.420
* NI gauge	MAINE	SHANES VIADUCT	705	1187	0.406	0.651
16009	SUIR	CAHIR PARK	1602	1100	0.37	0.765
* NI gauge	BLACKWATER	MAYDOWN BRIDGE	971	1032	0.435	0.857
23002	FEALE	LISTOWEL	646	1281	0.473	1.053
201009	OWENKILLEN	CROSH	441	1332	0.357	1.347
24001	MAIGUE	CROOM	774	985	0.354	1.390
15001	KINGS RIVER	ANNAMULT BRIDGE	443	985	0.386	1.402
14006	BARROW	PASS BRIDGE	1096	906	0.383	1.454
15006	NORE	BROWNSBARN	2388	957	0.341	1.503
20001	BANDON	BANDON BRIDGE	406	1483	0.380	1.513
07012	BOYNE	SLANE CASTLE	2408	925	0.292	2.009
* NI gauge	BALLINDERRY	BALLINDERRY BRIDGE	426	1133	0.251	2.446
* NI gauge – Northern Ireland gauge taken from WINFAP-FEH						