THE HYDROLOGICAL ANALYSIS FOR THE FINGAL EAST MEATH FLOOD RISK ASSESSMENT AND MANAGEMENT STUDY

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ABSTRACT
This paper describes the hydrological analysis undertaken for the Fingal East Meath Flood Risk Assessment and Management Study (FEM FRAMS). The objective of the FEM FRAMS is to develop an economically, socially and environmentally appropriate long term Flood Risk Management Plan for the Fingal and East Meath study area, which would also meet the requirements of the EU Flood Directive.

The FEM FRAM study area is approximately 772sq km in plan area consisting of 24 rivers and streams, 3 estuaries and the study area coastline. Only two of the rivers have operational hydrometric stations, while others are either ungauged or their gauging stations were discontinued or removed. Some limited hydrometric data is available at the discontinued stations, although the EPA has identified concerns with the quality of some of the extreme flow estimates.
The rivers and streams in the study area have been further sub-divided into 270 sub-catchments, to allow reconciliation between the hydraulic models and the hydrological analysis at key locations, and to ensure adequate resolution for the production of robust flood mapping. The purpose of hydrological analysis is to estimate design inflows, for a range of annual exceedence probabilities (AEPs), for these sub-catchments. These design inflows will be used in the river hydraulic models developed using ISIS for approximately 400km of the high and medium priority watercourses (HPWs and MPWs) in the study area.

The hydrological study was based on an analysis of available hydrometric and meteorological data in the vicinity of the study area and at neighbouring catchments in accordance with the Flood Studies Report, the UK Flood Estimation Handbook and the ongoing Office of Public Works (OPW) Flood Studies Update, together with recommendations on the effects of future climate change in Ireland. A combination of rainfall based unit hydrographs analysis and L-moments based statistical analysis together with the hydraulic modelling approach is used to estimate the design inflows at the sub-catchments.

The flatness of the terrain intersected by many rivers and streams and the availability of low level of data make FEM FRAMS different from other similar studies. This has been overcome by adopting a combined rainfall-runoff and statistical based approach, augmenting the data from the neighbouring catchments and by integrating the hydrology with the hydraulic modelling.
Key words: *FEM FRAMS, L-moments, sub-catchments, HPWs, MPWs, OPW*

INTRODUCTION
The Fingal and East Meath area has suffered significant flooding over the last 23 years: the events of August 1986 (Hurricane Charlie), November 2000 and November 2002 all resulted in considerable flood damage in the area. Fingal County Council (FCC), along with project partners Meath County Council (MCC) and the Office of Public Works (OPW), have recognised the high levels of existing flood risk in Fingal and East Meath. This risk, combined with the significant development pressure associated with Ireland's fastest growing area and predicted climate change is likely to increase the flood risk in the future. In 2008, to address these issues, FCC, MCC and the OPW commissioned Halcrow Barry (HB) to produce a catchment-based flood risk assessment and management study, namely, the Fingal East Meath Flood Risk Assessment and Management Study (FEM FRAMS). The FEM FRAM study is one of the four principal flood risk management studies currently underway in Ireland.

Flood risk in Ireland has historically been addressed through the use of structural or engineered solutions to existing problems, such as the implementation of flood relief schemes to protect areas already at risk. In line with internationally changing perspectives, the Irish Government adopted a new policy in 2004 that shifted the emphasis in addressing flood risk towards pro-active management of flood risk. It focuses on avoiding or minimising future increases in flood risk through integrated flood risk management and development planning to safeguard people, property and the environment; and increased use of non-structural and flood impact mitigation measures. Flood Risk Assessment and Management Studies (FRAMSs) and Flood Risk Management Plans (FRMPs) are at the core of this national policy. These studies have been developed to meet the requirements of the EU Floods Directive on the assessment and management of flood risks (the Floods Directive).

STUDY OBJECTIVES

The main objectives of the Fingal East Meath FRAMS are to assess and map the spatial extent and degree of flood hazard and risk in the catchment; examine future pressures that could increase the flood risks; carry out a Strategic Environmental Assessment (SEA); identify viable structural and non-structural measures and options for managing the flood risks in the study area; and to develop an economically, socially and environmentally appropriate long-term **F**lood **R**isk **M**anagement **P**lan. This FRMP sets out the measures and policies, including guidance on appropriate future development, that should be pursued by the local authorities, the OPW and other stakeholders to achieve the most cost effective and sustainable management of flood risk within the study area.

The main objective of the hydrological analysis of FEM FRAMS is to estimate design flood flows within the modelled watercourses at the sub-catchment level, with a level of accuracy that ensures the development of flood inundation maps that are fit–for-purpose and based on the best available data, and thereby, a robust and integrated Flood Risk Management Plan (FRMP).

The paper is based on the findings of the hydrological analysis carried out to date for the FEM FRAM study. It also outlines the further analysis being carried out as part of the study.

THE STUDY CATCHMENT

The FEM FRAM study area is comprised of the Irish Hydrometric Area 08 and some of Area 09 and is approximately 772sq km in plan area. It is bounded by the River Boyne catchment (HA 07) to the north and west, the Tolka and Santry River catchments (HA 09) to the south, and by the Irish Sea to the east.
The topography of the study area is generally low undulating land intersected by 24 watercourses and 3 estuaries. Of them, the Mornington River is the subject of a separate detailed flood alleviation scheme and the results and recommendations from that study will be incorporated into the FEM FRAMS. Thus the present study involves 23 rivers and streams in the study area. All watercourses in the study area outflow to the Irish Sea between Mornington Point in the north and Portmarnock Point in the south of the study area.

The urban areas and the areas zoned for future development with a history of flooding or likely to be at risk from future flooding are designated as the Areas of Potential Significant Risk (APSRs). The watercourses causing flooding within the APSRs are defined as the High Priority Watercourses (HPWs). The additional areas where these flood risks are considered to be moderate are defined as the Areas of Potential Moderate Risks (APMRs). The watercourses causing flooding within the APMRs are defined as the Medium Priority Watercourses (MPWs). Figure-1 shows the catchment boundaries of the rivers and streams in the FEM FRAMS area.

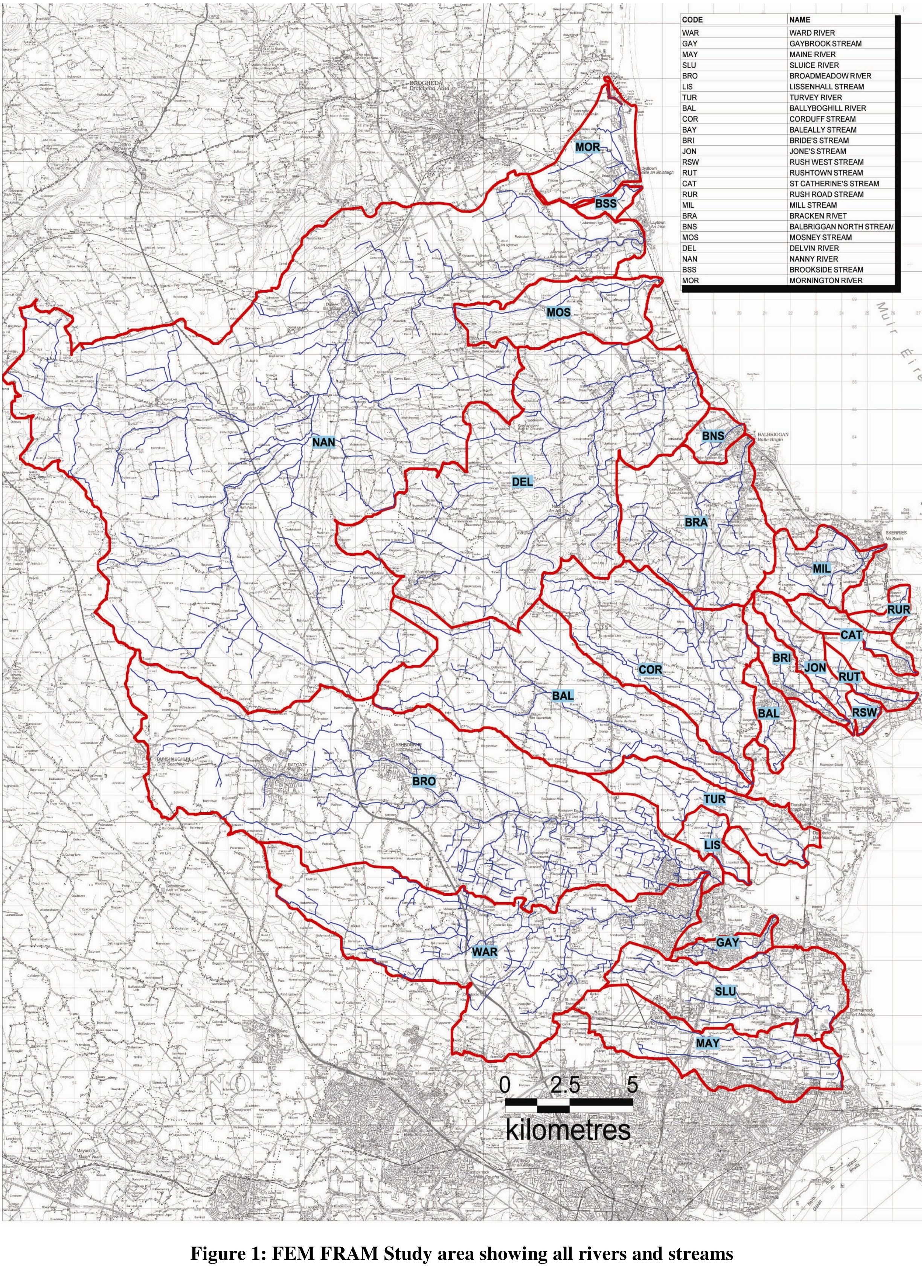


Figure 1: FEM FRAM Study area showing all rivers and streams

DATA AVAILABILITY AND QUALITY

The data used in the hydrological analysis is hydro-meteorological, historical flood data, land use data, soil data and topographical data including channel and structure survey data, 2m and 5m LiDAR data (provided by the OPW) and 20m hydrologically corrected DTM (available from the EPA). A brief description of hydro-meteorological data used in the hydrological study is presented in the subsequent paragraphs.

Hydrometric data

Hydrometric data of altogether 12 stations in the study (HA 08) were available, out of which two stations are operated by the OPW (termed here after as 'the OPW stations') and ten stations by the local authorities assisted by the EPA (termed hereafter as 'EPA stations'). The two OPW stations, namely, Stn 08008-Broadmeadow (Broadmeadow River) and Stn 08011-Duleek (Nanny River) are still in operation and for which hydrometric data was available from the OPW. On the other hand, all ten EPA stations, namely, 08002-Naul (Delvin River), 08003-Fieldstown (Broadmeadow River), 08004-Owen's Bridge (Ward River), 08005-Kinsaley Hall (Sluice River), 08006-Hole in the Wall (Mayne River), 08007-Ashbourne (Broadmeadow River), 08009-Balheary (Ward River), 08010-Garristown (Garristown Stream), 08012-Ballyboghill (Ballyboghill River) and 08014-Skerries (Mill Stream) were closed between 1995 and 2001. One of the EPA stations, namely Stn 08007-Ashbourne is the administrative area of Meath County Council. The remaining nine EPA stations, which were previously in the administrative area of Dublin County Council, were subsequently in the administrative area of Fingal County Council (FCC) when FCC was established in 1994. According to FCC (2008), these gauging stations have not been in operation for some years due to a variety of reasons, mainly due to uncertainty as to who is responsible for these stations.

A detailed rating review was carried out for nine out of twelve stations, the data for which was provided by the OPW and the EPA. However, the data of Stn 08003-Fieldstown was not used for further analysis, as its quality of high water levels is suspicious due to the obstruction by the downstream bridge. The Stn 08003 was included in review of stations by OPW FSU consultant and the rating quality of this station was designated as 'B'.

No rating review was carried for thee stations, namely, Stns 08004, 08006 and 08014. According to FCC (2008), Stn 08014 has an access problem whereas the location of Stn 08004 is now a reservoir. The zero datum of Stn 08006 changed 8 times and the rating curve changed 7 times for the 10 years of data. These three stations were not included in the OPW review of gauging stations (HydroLogic, 2006), and hence their rating quality was also not known. Therefore, the hydrometric data of these three stations was not used for further analysis.

To augment the relatively low level of data available in the study area, hydrometric data from the neighbouring gauging stations (namely, from HA 07 and HA 09) was collected from the EPA and the OPW. The list of 16 gauging stations (eight from HA 08, six from HA 07 and two from HA 09) selected for further hydrological analysis is presented in Table 1.

Table 1: List of hydrometric data used for statistical analysis

Station Number	Data Provider	Station Name	River Name	Data Start	Data End	N (yrs)	Catchment Area, km2	Qmed, m3/s	Specific Qmed, m3/s	Quality of Rating (Hydro-Logic)
Hydrometric Stations in the study area (HA 08)										
08002	EPA	Naul	Delvin	1977	2002	24	37.0	4.40	0.27	A1
08005	EPA	Kinsaley Hall	Sluice	1977	2000	23	10.1	3.17	0.53	A2
08007	EPA	Ashbourne	Broadmeadow	1977	1996	21	34.0	8.16	0.54	B
08008	OPW	Broadmeadow	Broadmeadow	1978	2007	28	110.0	21.06	0.56	A2
08009	EPA	Balheary	Ward	1980	1995	15	62.0	4.97	0.21	A1
08010	EPA	Garristown S.W.	Stream	1983	1996	13	1.13	0.62	0.56	C
08011	OPW	Duleek	Nanny	1980	2007	28	181.0	48.38	0.88	B
08012	EPA	Ballyboghill	Ballyboghill	1980	1998	17	22.1	6.83	0.63	B
Hydrometric Stations in the neighbouring catchment (HA 07)										
07002	OPW	Killyon	Deel	1953	2005	47	285.0	18.3	0.24	A2
07005	OPW	Trim	Boyne	1975	2006	31	1282.0	99.0	0.40	A1
07006	OPW	Fyanstown	Moynalty	1986	2005	20	176.0	27.5	0.51	A2 & B
07009	OPW	Navan weir	Boyne	1953	2006	52	1610.0	99.6	0.34	A1
07010	OPW	Liscartan	Blackwater (Kells)	1953	2006	48	717.0	55.3	0.35	A1 & A2
07012	OPW	Slane Castle	Boyne	1940	2006	67	2408.0	191.0	0.48	A1
Hydrometric Stations in the neighbouring catchment (HA 09)										
09001	OPW	Leixlip	Ryewater	1956	2006	50	215.0	35.5	0.57	A1
09002	EPA	Lucan	Griffeen	1978	2000	23	35.0	5.4	0.35	A1

Rainfall data

The rainfall analysis undertaken for the FEM FRAMS used rainfall data from eight stations from the study area, which have nine years or longer of data. These included Stn 532 - Dublin Airport, Stn. 632 - Lusk, Stn. 1032 - Duleek, Stn. 1332 - Malahide, Stn. 1632 - Bellewstown, Stn. 2332 - Bellewstown (Collierstown), Stn. 2432 - Ratoath and Stn. 2532 - Dunshaughlin. To augment the data for rainfall analysis, further rainfall data from four neighbouring catchments was also used, which included Stn. 3723 – Casement, Stn. 931 – Kells, Stn. 2931 - Warrenstown, and Stn. 2638 – Ardee.

HYDROLOGICAL ANALYSES, RESULTS AND DISCUSSIONS

Rainfall analysis

The rainfall data was analysed both individually and in a group following the procedures of both the *FSR Volume II – Meteorological Analysis* and the *FEH-Rainfall Analysis*. The results of the study were compared with those of the Depth Duration Frequency (DDF) curves of FSU.

The results of the analysis showed that the 2, 5 and 100-year return period 48-hour rolling duration rainfall values obtained from the regional analysis of 12 stations are close to the median values of the 12 stations obtained from FSU-DDF curve for the corresponding return periods. However, station-based comparisons of the 2 and 5-year return period 48-hour rolling duration rainfall showed variation of the results from the FSU-DDF curve in some of the stations, especially for the stations having shorter (and most recent) data sets. These differences could have arisen due to the fact that the FSU DDF study utilised daily rainfall records with a minimum period of 20 years up to 2004 (refer: TN 61 by Fitzgerald, 2007), whereas the present study utilised daily rainfall records with a minimum period of 9 years, including records up to 2007

Based on the greater regional and temporal scope of datasets used, the FSU-DDF curves will be broadly adopted for estimating the design floods in the watercourses of the study area. However, the results of the individual rainfall data analysis suggested that the FSU-DDF curve underestimates the rainfall values at stations with rainfall records less than 20 years, particularly at Bellewstown, at Ratoath and at Dunshaughlin. Therefore, the FSU-DDF curve values will be scaled, in accordance with the results of the present study, at the sub-catchments in the vicinity of these stations.

Rating review

The rating curve review assessed the existing OPW and EPA ratings and extended these to high flow using local hydraulic computer models (in ISIS 1D) and following the guidance in the "Extension of Rating Curves at Gauging Stations – Best Practice Guidance Manual, R & D Manual W06-061/M (2003)" produced by the UK Environment Agency. As the main purpose of the rating review was to define the upper range of the stage-discharge relationship, the low flow ratings were adopted from those obtained from the EPA and the OPW and high flow rating from the ISIS based stage-discharge relationships. For the stations having more than one rating equation, the latest rating was used.

The present study has modified the existing OPW high flow rating at both Stn 08008-Broadmeadow and Stn-08011 Duleek (Nanny River). At Stn. 08008, the OPW rating produced Q_{med} value 39.1m^3/s and corresponding specific Q_{med} (i.e., $Q_{med}/A^{0.77}$) as 1.05m^3/s. This is much higher than the specific Q_{med} of Stn 08007-Ashbourne (0.54m^3/s) further upstream on the same river. However, the HB proposed rating produced the revised Q_{med} as 21.06 m^3/s and the corresponding specific Q_{med} value as 0.564m^3/s, which is quite close to that of Stn. 08007 and also to those of other stations in the study area.

On the other hand, HB proposed high flow rating produced larger values of Annual Maximum Series (AMS) at Stn. 08011-Duleek than those from OPW high flow rating. The OPW Q_{med} value was 33.6m^3/s and the corresponding specific Q_{med} was 0.61m^3/s whereas the modified Q_{med} is 48.38m^3/s and the corresponding specific Q_{med} is 0.884m^3/s. This increase in the Q_{med} value is considered to be from the extensive over-bank flows in the Nanny River, which was not included in the extrapolated rating curve of the OPW developed from in-bank flow measurements.

The EPA rating based Q_{med} value at Station 08009-Balheary (Ward River) was 5.77m^3/s and the corresponding specific Q_{med} was 0.24m^3/s. The modified Q_{med} and specific Q_{med} at this station are 4.97m^3/s and 0.207m^3/s respectively. This specific Q_{med} is much smaller than that of the adjacent Stn. 08008-Broadmeadow and also than the HA 08 median value of 0.564m^3/s. All AMS values at Stn 08009 are less than 7m^3/s except the 1993 value, which is 15m^3/s. One of the reasons for this small value of specific Q_{med} and of the AMSs is that this station might have failed to record water levels at extreme flood events (e.g the 26th August 1986 event). The revised Q_{med} and the specific Q_{med} at the gauges of HA-08 is presented in Table 1.

L-moment ratio diagram

The similarity (homogeneity) of the data for a regional pooling group method is measured on the basis of geographical proximity and catchment similarity. The study area (HA 08) is surrounded by the Irish Sea to the east and by HA 07 and HA 09 to the north, west and south. Hydrometric data from the catchments beyond HA 07 and HA 09 was not included, as these catchments are not considered as directly representative of the study area, due to their inland location. Their use is also prohibitive due to the absence of a corrected national data set. Therefore, catchment similarity tests were not carried out for the present study.

The L-moment ratio diagram was prepared following the FEH and Hosking *et al* (1997) methodology, for individual AMS data as well as for the group of stations (See Figure 2).

In accordance with the FEH V3 6.5 check for pooling group discordancy, a visual review was undertaken of L-moment ratio similarity. The L-moment ratio diagram (Figure 2) demonstrated that the most discordant L-moment ratio were Stns 08009, 07005, 07006 and 07010. L-moment ratios of these four AMSs were considered unrepresentative of the group cluster, and were also excluded from the pooling group method of regional analysis. It is noted that the AMS of Stn 08009-Balheary, which has a much lower value of specific Q_{med} in comparison to the other stations in the study area lies away from the group cluster on the L-moment ratio diagram. Therefore, only 12 AMSs (total number of flood values being 393) were considered for pooling group analysis. Figure 2 also shows that the GEV distribution is appropriate for the pool group analysis.

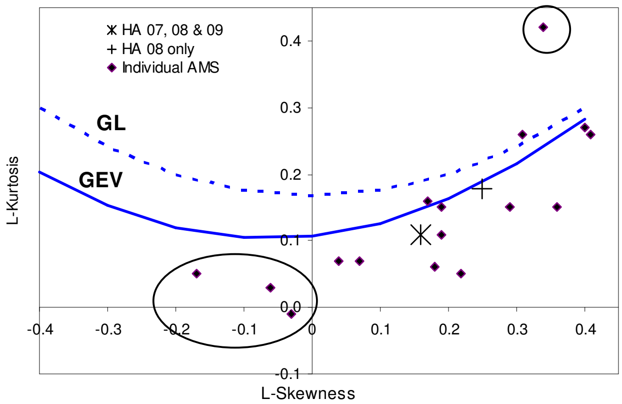


Figure 2: L-moment ratio diagram (circled AMSs were excluded from pooled group)

Study growth curve

Bruen *et al* (2005) suggest that the FSR method significantly under predicts extreme flows in the Dublin and Mid Eastern Region. The Greater Dublin Strategic Drainage Study (GDSDS) recommends a modified growth curve for the Greater Dublin area. To address the uncertainty in the FSR growth curve, a statistical analysis was carried out to prepare a study growth curve, using AMSs of the pooling group (seven from HA 08, three from HA 07 and two from HA 09). The study growth curve was compared with those of FSR and GDSDS in Table 2 and Figure 3.

Table2: Study growth factor compared with GDSDS and FSR (all indexed to Q_{med})

Return Period	2	5	10	25	50	100	200	1000
AEP	50%	20%	10%	4%	2%	1%	0.5%	0.1%
FEM FRAMS	**1.00**	**1.52**	**1.89**	**2.38**	**2.76**	**3.16**	**3.57**	**4.60**
GDSDS	1.00	1.47	1.85	2.23	2.53	2.83	3.15	
FSR (Ireland)	1.00	1.26	1.44	1.68	1.86	2.06	2.25	2.74

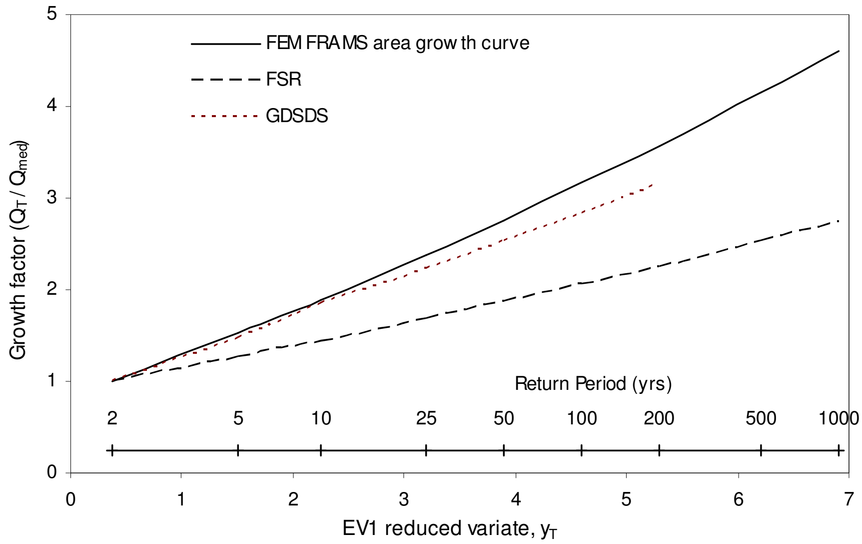
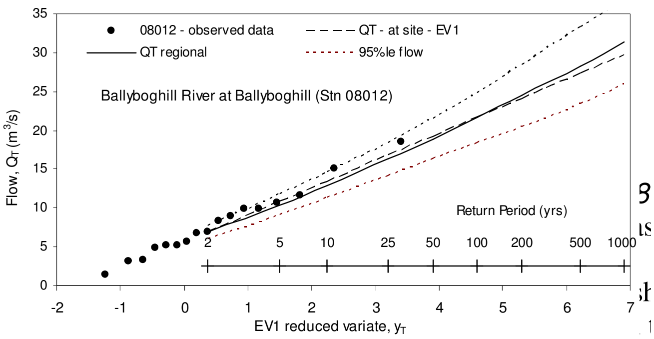


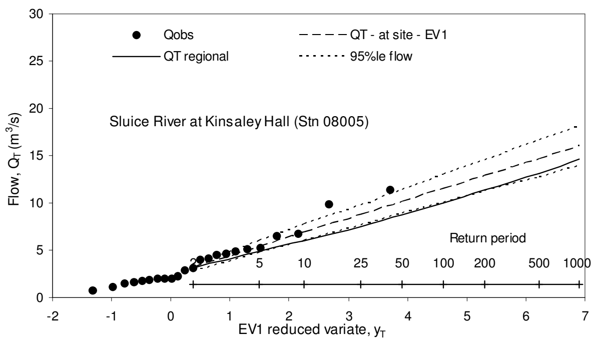
Figure 3: Study growth curve compared with those of GDSDS and FSR

Table 2 and Figure 3 show that the study growth factor for 1% AEP (i.e. 100 year return period) is 3.16, in comparison to 2.83 from the GDSDS and 2.06 from the FSR (both indexed to Q_{med}). The study growth curve is higher than those of both the FSR and the GDSDS.

Design flood at hydrometric stations

Flood frequency curves from the study growth curve and at-site growth curve are plotted together with the AMS values against EV1 reduced variate (and return period). Figure 4 shows such plot for two stations, namely, Stn 08012 and Stn 08005.





recorded AMS value in the year 2000). The Sluice catchment area contains more significant urbanization than most of the other catchments in the study area. The regional growth curve for the predominantly rural study area may not be representative of the gauge (refer Section 9.2.2 of FEH Vol. 3 discussion on modifying regional growths for ungauged urban catchments). Therefore, instead of modifying the regional growth curve at this catchment, it is recommended to use the at-site growth curve so as to incorporate the effects of urbanization in the catchment itself.

The 95%le confidence intervals for the quantile estimates are calculated using the standard error. The standing error (*se*) of the quantile estimates is calculated using the methodology proposed for the FSU.

Inflows at sub-catchments using integration of hydrology and hydraulic model

The 23 rivers and streams in the study area have been further sub-divided into 270 sub-catchments. There are three types of sub-catchments: (i) upstream catchments (ii) mid-catchments with dominant tributaries and (iii) mid-catchment without dominant tributary. MSL and S1085 are derived from the longest stream contained within the sub-catchment boundary as defined by the 1:50,000 mapping. The approach used the consistent logical rule in defining FSSR 16 MSL and S1085 parameters for all types of catchments. For some flat catchments, if the calculate slope is flatter than 0.019%, the minimum slope of 0.019% is used, which avoids use of very low value of S1085.

Other data such as the soil factor and urban factor were extracted from the corresponding maps and the rainfall parameters (M5-2day, M5-25day, SAAR, Jenkinson's ratio etc) were extracted from the GIS layers (FSU) provided by the OPW.

The design inflows at sub-catchment level are calculated using the FSSR 16 and Institute of Hydrology Report No. 124 (for catchment area less than 25km^2) Unit Hydrograph (UH) method. To facilitate this, a tool has been developed in the ISIS model, which is capable of producing hydrographs of various AEPs using FSSR16/IOH UH method. This tool uses the ISIS FSSR 16 boundary unit as a data file, which was prepared for all 270 catchments for the range of AEPs using GIS automation aided by manual checking. The design inflow at a sub-catchment node can be calculated directly by importing the relevant ISIS FSSR 16 unit into the hydraulic model.

The total (routed) inflow at the gauging station produced by all the upstream sub-catchments will be reconciled with the design flood estimated from statistical method using iterative hydraulic model simulations. The reconciliation is carried out for the peak flows of 50% AEP (two year RP) and 1% AEP (100-year RP) by adjusting the global scaling factor in the ISIS FSSR 16 tool. The scaling factors used for reconciliation of the 50% AEP and 1% AEP will be interpolated / extrapolated for the other AEPs as necessary. The results of the reconciliation will be presented in the hydraulic report.

SUMMARY AND CONCLUSIONS

The hydrological analysis undertaken for the FEM FRAM study is concerned with the estimation of extreme flows, which will form the basis for subsequent flood level and mapping stages of the study. A detailed review of the high flow ratings at the study area gauges was undertaken to increase confidence in the out of bank flow estimates at these stations and thus increase confidence in the flow estimates.

A study area growth curve was derived using the FEH pooled group methodology, involving seven AMS from the study area and five from neighbouring catchments. The design flood estimates at the hydrometric stations are based on the Q_{med} value and the study area growth curve. The confidence interval of the quantile estimates is calculated using the method of standard error (*se*) calculation suggested for Irish AMS under FSU.

To distribute these design flows along the river reach, the HPWs and MPWs reach of the rivers and streams have been further sub-divided into a total of 270 sub-catchments. Design inflows at these sub-catchments are calculated using the catchment characteristics, FSU-based rainfall inputs and applying the FSSR 16 / IOH 124 unit hydrograph method. The total routed inflows from the upstream sub-catchments at the gauging stations will be reconciled with the statistical method estimated design floods at the gauges using iterative simulations in the river hydraulic models. The combination of hydrology and hydraulic modelling is considered to further refine the flow estimates at sub-catchment levels.

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Disclaimer

The findings of the hydrological analysis presented in this paper are based on draft hydrology report, which are subject to client review and may be changed.

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