05 – THE FLOOD STUDIES UPDATE FOR IRELAND – THE NEW FSU METHODOLOGIES AND WEB PORTAL AND FUTURE DIRECTIONS

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Abstract
The Flood Studies Update web-based applications Portal (FSU Web Portal) was launched in June 2014. The Portal is a key output of the Flood Studies Update (FSU) Research Programme that was initiated, managed and funded by the Office of Public Works (OPW) and is a substantial update of the Flood Studies Report (NERC, 1975) which provided methodologies for flood estimation in Ireland and the United Kingdom. The rainfall and flood estimation methodologies that derive from the FSU Research Programme are now implemented in the FSU Web Portal (http://www.opw.ie/en/fsu/).

The Portal facilitates the estimation of design flood flows, rainfall depths and other hydrological variables at approximately 134,000 river locations/nodes in Ireland using a series of algorithms and river location/node-specific parameters. It also provides users with a map-based search tool to find their location of interest and guides them through each step of a calculation process resulting in the derivation of final design rainfall or flow estimates.

The Portal is intended to be used by the OPW, Local Authorities, Third Level Institutions and Private Sector Practitioners and will be continually applied and referred to by professionals working in the area of flood risk assessment and management in Ireland. It is expected to be used mostly for commercial purposes in the design of engineered structures and other flood risk management activities but also by Third Level Institutions and other training organisations for educational and research purposes.

Some of the main features of the Portal include a Site Orientation Map tool; Rainfall and Flood Estimation software applications; On-screen Stepwise Guidance; FSU Guidance Handbook; Flood Estimation Reports print/export facility; Flood Estimation database with data and software download facility; Users Forum and other common website features such as links to documents and related third party websites; News page, and Feedback facility.

Based on feedback received from users of the Portal (via email to: fsuhelpdesk@opw.ie), the OPW will identify future improvements to be made to the Portal and will perform periodic updates of the associated methodologies. This paper briefly outlines some of the new concepts that are incorporated in the FSU Web Portal. It also examines some of the implications that future changes to datasets will have and concludes by providing information on possible improvements identified to date by the FSU management team and from user feedback.

1 INTRODUCTION

The FSU methodologies are now the preferred methodologies for extreme rainfall and flood estimation in Ireland. Since the launch of the FSU Web Portal the FSU management team has monitored feedback received via the Portal's FSU Helpdesk facility in order to gauge the needs of the end user. Further feedback received in the coming years will be used to guide how the Portal should be adapted to best meet the needs of its end users. Future improvements to the FSU Web Portal will also take cognisance of changes in spatial datasets, additional hydrometeorological data, and new methods of flood estimation. Much of the data and methodologies behind the FSU were developed over a number of years between 2005 and 2011. It is inevitable that new data and methodologies will become available in the future and the following questions then arise: *When should the FSU data and methodologies be updated?* And *how often should such updates take place?* With this in mind, at the outset of the FSU Programme it was decided that the best means of disseminating the FSU methodologies would be via a web-based applications Portal.

2 DETERMINING FACTORS FOR WEB DISSEMINATION OF THE FSU METHODOLOGIES

From the beginning of the FSU Programme it was agreed that the outputs of the research should be made available via a free to use online suite of rainfall and flood estimation tools. Web-based dissemination was the obvious choice as it enables seamless updates of the datasets and methodologies incorporated in the FSU Web Portal and provides a single source of information for all those who use the methodologies. The following sections outline the main reasons why web dissemination was chosen over traditional hardcopy dissemination.

2.1 A single point of contact and information for users

One of the main criticisms of the Flood Studies Report (FSR) (NERC, 1975) and the Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999) was that there was no direct contact point for providing feedback on suggested improvements to the methodologies. With this in mind, the FSU Web Portal is provided with a feedback facility. Through this feedback facility, users can provide their suggestions for improvements directly to the FSU management team. There is also a users forum whereby users can post their queries or discuss different aspects of the Web Portal. Both of these facilities are used by the FSU management team to monitor the needs of the user and to consider future changes to the Portal.

Similarly, users of the FSR and FEH also reported that they were often unaware as to when any updates to the respective methodologies were released which often led to confusion as to what method was the most current. The Portal seeks to also act as a single source of information for users. Users who have registered with the Portal will be contacted directly by email to inform them of any updates to the FSU methodologies or datasets, and such notices will also be published on the News page of the Portal. Furthermore, the FSU Web Portal provides download facilities for documents, data and software where the latest research papers and documents on flood estimation in Ireland may be sourced.

2.2 A subscription free suite of online tools

A major advantage of the online implementation of the FSU research is that it is free to use. Subscription to the Portal and the software tools incorporated in it is free of charge and there is no cost for acquiring the accompanying documentation which includes all of the FSU Research Reports and the FSU Guidance Handbook (the user manual that accompanies the FSU tools). The data download module of the FSU Web Portal allows the download of the datasets that were used in the FSU research. In comparison, the hardcopy of the UK FEH Volumes costs £295 (approx €370 ex. VAT), while the WINFAP CD ROM which contains flood frequency analysis software is currently on sale for £990 (€1,270 ex. VAT). Furthermore, the FEH CD ROM that contains the FEH datasets costs £945 (€1,200 ex. VAT) for first time commercial buyers.

2.3 Seamless updating of the FSU methodologies and datasets

The state of knowledge in flood estimation is constantly changing and in the past this has been reflected in the numerous updates and revisions to flood estimation methodologies that have been employed in both the UK and Ireland. Between 1977 and 1988 a total of 18 Flood Studies Supplementary Reports (FSSRs) were issued. In the early 1990s, the range of these supplementary reports, together with new concepts such as hydrological similarity (use of similar catchments rather than geographically close catchments) and the longer length of record, led to a complete update of flood estimation techniques in the UK (FEH) (Institute of Hydrology, 1999). Indeed since the launch of the FEH, the Supplementary Report on 'The revitalised FSR/FEH rainfall-runoff method' was published (CEH, 2007). In this time 47 errata/corrigenda have also been issued to the FEH volumes. A number of other publications have since been published that suggest improvements to the FEH methods, such as the report on "Improving the FEH statistical procedures for flood frequency estimation" (Environment Agency, 2008).

The Portal easily allows for any such changes to be made without any visible changes to the front end interface, and without the requirement for the user to purchase/download new software or documentation. As the data used in the FSU methodologies change they will also be implemented in the Portal at agreed intervals. The advent of web mapping services now also allows the background mapping used in the Portal to be dynamically updated.

3 NEW CONCEPTS EMPLOYED IN THE FSU METHODOLOGIES

The FSU effectively replaces the methodologies that arose from the 1975 Flood Studies Report, and many of the approaches to flood estimation have changed since then. The following sections provide a brief explanation of some of the new and more notable concepts that are employed in the FSU methodologies.

3.1 Physical Catchment Descriptors (PCDs) in digital format

The foundation of all the spatial datasets used in the FSU research is the Blueline River Network (BRN) which is effectively the map of all the river centrelines in the country. This map was originally developed by Ordnance Survey Ireland (OSi) and further improved by the Environmental Protection Agency (EPA) for use in the implementation of the Water Framework Directive. These improvements included the addition of directional flow lines and closing many of the gaps in the mapped centrelines where rivers were interrupted by river crossings or culverted. Under the FSU research 134,000 nodes representing ungauged locations were placed at 500m centres along the 42,000 km of the BRN. Using the OSi Digital Elevation Model, catchment outlines were derived for each of these nodes. Once these ungauged catchment outlines had been delineated it was then possible to extract the metrics for different land uses, soil types, and average annual rainfalls for each ungauged catchment. It was also possible to extract metrics regarding the BRN itself within these catchments. These statistics have become what are now known as physical catchment descriptors (PCDs). A PCD describes a characteristic of a catchment as a single number. A list of the most commonly used PCDs in the FSU methodologies are summarised in Table 1 below:

Table 1: *PCDs most commonly used in the FSU methodologies*

PCD name	Description	Units
AREA	Catchment surface area	km^2
SAAR	Standard period (1961-‘90) average annual rainfall	mm
BFIsoil	Baseflow Index derived from soils data	from 0 - 1
FARL	Flood attenuation from reservoirs and lakes.	from 0 - 1
DRAIND	Ratio of length of river network to catchment area	km/km^2
S1085	Slope of the main stream between the 10 and 85 percentiles of the main stream length	m/km
ARTDRAIN2	Proportion of the river network that is included in drainage schemes.	from 0 - 1
URBEXT	Proportion of the catchment area that is urbanised (per Corine Landcover 2000 dataset).	from 0 - 1
ALLUV	Proportion of the catchment area that is covered by alluvial deposits.	from 0 - 1
FOREST	Proportion of the catchment area that is covered by forest (per Corine Landcover 2000 and FIPS datasets)	from 0 - 1

The PCDs listed in Table 1 were derived for all 134,000 ungauged catchments, and similarly for the 215 gauged catchments used in the FSU analysis. PCDs were then used to formulate generalised relationships between catchment characteristics and flood variables. The most notable of these being the 7-variable equation for estimation of the index flood ($QMED_{rural}$), and the equations for hydrograph width analysis. PCDs were also used to form pooling groups of hydrologically similar gauged catchments for the purposes of flood growth curve analysis.

3.2 The concept of Pivotal Sites for adjusting QMED estimates

The median annual maximum flood magnitude, QMED, is used as the index flood for design flood estimation in the FSU (as opposed to Qbar which is used in the FSR). This measure is equivalent to the 2-year return period flood. QMED is used because the median is less sensitive to large extreme floods and to flood measurement error in general. The estimation method for ungauged locations is based on a regression analysis relating gauged $QMED_{rural}$ values to PCDs at gauged locations in Ireland, given by the following equation:

[illegible]

$QMED_{rural}$ is an estimated value for a catchment that contains no urban area and has a factorial standard error of 1.37, which means that there is approximately a 66% chance of the true value for $QMED_{rural}$ lying between $0.73QMED_{rural}$ and $1.37QMED_{rural}$. If the quoted error associated with the number of available Annual Maxima is examined at a gauged location, it can be seen that a factorial standard error of 1.37 is more or less equivalent to having between one and two years of data at a gauge (see Table 2).

Table 2: *Factorial standard error of gauged values of QMED at different record lengths*

Number of Gauged Annual Maxima	Factorial Standard Error (in QMED)
1	1.433
2	1.290
5	1.175
7	1.146
10	1.121
12	1.110
15	1.097
17	1.091
20	1.083
22	1.080
25	1.075

In any flood frequency estimate, the majority of error will be associated with the estimate of QMED. It is therefore of utmost importance that the value for QMED is calculated as accurately as possible. In order to improve the first estimate achieved by the use of the $QMED_{rural}$ equation an adjustment must be applied. A new and important principle in the FSU research is the concept of the 'pivotal site'. A pivotal site is defined as the gauging station that is considered most relevant to a particular flood estimation calculation at the subject site (usually an ungauged location), and is used to adjust the first estimate from the $QMED_{rural}$ equation. Ideally, a pivotal site will lie a short distance upstream or downstream from the subject site at which the flood estimation is required, but it can also be geographically close or hydrologically similar to the subject site. The thinking behind the use of a pivotal site is that if a gauged catchment is identified that behaves in a similar way to our subject site it can be inferred that the degree of error arising from using the $QMED_{rural}$ equation at the pivotal site would be expected to be the same for the subject site. The general procedure is to infer an adjustment factor to the $QMED_{rural}$ estimate by examining the performance of the regression-based model at the pivotal site. This adjustment factor, AdjFac, is calculated at the pivotal site as follows:

$$AdjFac = \frac{QMED_{rural,gauged}}{QMED_{rural,PCD}}$$

Where: $QMED_{rural,gauged}$ is the gauged value for QMED at the pivotal site, and
$QMED_{rural,PCD}$ is the value for $QMED_{rural}$ calculated at the pivotal site

The adjustment is then made at the subject site:

$$QMED_{adjusted} = QMED_{rural} \times AdjFac$$

In simple terms, if the gauged value of $QMED_{rural}$ at the pivotal site is found to be 20% greater than the PCD-based estimate, it is assumed that the regression model will be similarly in error at the subject site. Thus, the estimate of $QMED_{rural}$ at the subject site is adjusted by a factor of 1.20.

A final adjustment to the QMED estimate may be made. This is an adjustment to account for urbanisation, calculated from $(1+URBEXT)^{1.482}$.

This idea of adjusting the first estimate is in keeping with current practice in the UK where the notion of analogue and donor sites is used. Similar conclusions have been drawn elsewhere by other researchers such as Merz and Blöschl (2008) highlighting the benefit of incorporating local data into flood frequency analysis. The FSU research has produced the first Irish national set of methodologies that uses this concept. In contrast to the FSR, all of the flow data and PCDs are now in digital format which allows for more complex analysis to be performed on the data. This allows further examination of how best to perform the adjustment based on pivotal sites.

3.3 Design Hydrographs by the FSU method

Perhaps the technique where the FSU departs most from methods used previously in the UK and Ireland is in the area of synthesising design hydrographs. The rainfall-runoff method used in the FSR has been abandoned in favour of a parametric approach to deriving design hydrographs, without use of a design rainfall as input. Instead the method is based wholly on recorded hydrograph data from flow gauging stations in Ireland using three different shape parameters, n, Tr, and C that describe a design hydrograph shape:

- *n* is the *shape parameter* of the Gamma hydrograph that defines the shape of the rising limb and peak of the hydrograph
- *Tr* is the *translation parameter* of the Gamma hydrograph (in hours) and is analogous to the rise time of the Hydrograph.
- *C* is the *recession parameter* for the exponential recession curve (in hours) that defines the shape of the recession limb of the hydrograph beyond the point of inflection on the receding limb (i.e. beyond $t=Tr/(n-1)1/2$).

All of these parameters may be derived at gauged locations for later use in regression analysis to generalise a method for deriving them at ungauged locations.

The reason for using a non rainfall based approach was primarily due to the wide availability of flood hydrograph data and the paucity of high resolution rainfall data in Ireland. Archer *et al.*(2000) suggested that the asymmetric profile derived from observed flood hydrographs provides "a more realistic basis for generating a design flood hydrograph than standard FSR methods". The method is claimed to be "simpler and quicker" than the available FSR methods, and "does not require the separate assessment of base flow and storm runoff" (Archer et al., 2000). Finally, the method allows the hydrograph to be fitted directly to a peak flow of any return period.

The 'Hydrograph Width Analysis' research took as its starting point the method developed by Archer *et al.* (2000) for specifying a design flood hydrograph at gauged sites. Each annual maximum flood hydrograph was examined and the widths of the hydrographs at selected percentiles of peak flow were obtained. The median values of these hydrograph widths at each percentile of the peak flow were extracted and a hydrograph which is non-dimensional with respect to discharge (i.e. with a peak of 1.0) was derived. This is termed the derived median hydrograph. The 'characteristic hydrograph' for the gauging station in question is a parametric model that is fitted to the derived median hydrograph. From the characteristic hydrograph the three shape parameters can be derived. The three hydrograph shape parameters are then related to catchment PCDs, thus allowing the hydrograph shape to be estimated at all ungauged locations along the Blueline River Network.

3.4 The concept of Pivotal Sites for adjusting Hydrograph shape parameters

In a similar fashion to the pivotal site adjustment for QMED, a hydrograph pivotal site is used when constructing hydrographs using the FSU methodologies. The three hydrograph shape parameters are first calculated for the subject site using the generalised FSU equations for *n*, *Tr* and *C*. In the next step, these parameters are calculated for a hydrograph pivotal site, again using the generalised FSU equations. The user is then provided with a graphical display showing the observed/gauged hydrograph shapes and values for *n*, *Tr*, and *C* at the pivotal site. The PCD estimates for the parameters are then adjusted to match the gauged values at the pivotal site. This same adjustment is then transferred to the shape parameters at the subject site.

4 CONSEQUENCES OF CHANGES TO THE UNDERLYING FSU DATASETS.

It should be noted that one of the main requirements for the FSU spatial datasets is that they should have a national coverage to ensure consistency of data types across all regions of the country, and hence consistency in the way that the FSU equations are applied. Any changes or updates to a national dataset such as the standard period average annual rainfall or the national soils maps could in theory mean that the FSU datasets and hence the corresponding methodologies and equations might need to be revisited on foot of such changes. In this regard it is necessary to first understand the implications of new and emerging datasets becoming available and how these will be dealt with.

4.1 Future Changes to the Blueline River Network

As previously noted, the Blueline River Network was not created specifically for the FSU Programme. Any future updates to the PCDs used in the FSU would be heavily dependent on having a fully verified and accurate BRN in place. Errors in the BRN propagate into the delineation of catchment outlines, which further propagate into the derivation of PCDs for those catchment areas. It is for this reason that the main focus in coming years will be on improving the BRN, and work is already underway to compare the existing BRN to the extensive river centreline surveys that were carried out as part of the OPW's Catchment-based Flood Risk Assessment and Management (CFRAM) Programme. Within current resources it is impossible to confirm that all parts of the BRN are fully correct, and it is in this regard that the FSU will be used as one of the means by which any discrepancies that are identified by users via the feedback facility may be recorded for further investigation.

4.2 Changes to the National Digital Elevation Model

Once an improved BRN is available the process of revising the sub-catchment outlines for the 134,000 nodes used in the FSU Web Portal would follow. This could be achieved using a new National Digital Elevation Model (DEM) based on Interferometric Synthetic Aperture Radar (IFSAR) survey data which has recently become available to the OPW. The quoted accuracy of this new DEM is ±0.7m in contrast to the quoted accuracy of ± 2m for the OSi Digital Elevation Model that was used in the FSU. The most obvious improvements that can be gained from the use of a more accurate DEM is that flatter catchments may be more accurately defined, and localised obstructions such as road/railway embankments may be accounted for. Until now, most gauged catchment outlines in Ireland have been derived manually using paper maps (6 inch OS maps) or using the existing OSi DEM. It may transpire that the extent of some of these catchments may require adjustment once a more accurate DTM is used.

4.3 Changes to Spatial Datasets

Changes to the ungauged catchment outlines may also mean that there could be consequent changes to the PCDs for those catchments. Coupled with the new mapping that has become available in the past few years such as the Met Éireann 1981-2010 annual average rainfall, the CORINE landcover dataset (update due to be published in late 2014) and the new Teagasc soil maps (http://gis.teagasc.ie/soils/map.php) will mean that a full revisiting of PCDs will become necessary. While existing spatial datasets are constantly being updated it is important that the FSU management team takes a measured approach to how and when these changes are to be incorporated into the FSU Web Portal.

4.4 Changes to Flow Data

Flow data used in the FSU research included Annual Maxima up to and including the 2004 water (hydrometric) year. In the years since then there have been a number of notable flood events in Ireland, especially those of November 2009 and there is currently the perception that this would necessitate an overhaul of the FSU $QMED_{rural}$ equation. Seeing as the $QMED_{rural}$ equation is a generalised equation based on a regression analysis between PCDs and gauged QMED values for all of the gauging stations used in the FSU research, the changes in QMED across the country were examined between 2004 and 2012 to see if there has been a clear increase in the observed QMED on a national basis. The analysis showed that six gauging stations experienced an increase in their gauged QMED values of greater than 5% while three experienced a decrease in the gauged QMED values of greater than 5%. In that time, the average QMED value across all gauging stations increased by a mere 0.4%. Comparison of the 2004 and the 2012 QMED dataset shows a linear relationship between the two (see Figure 1).

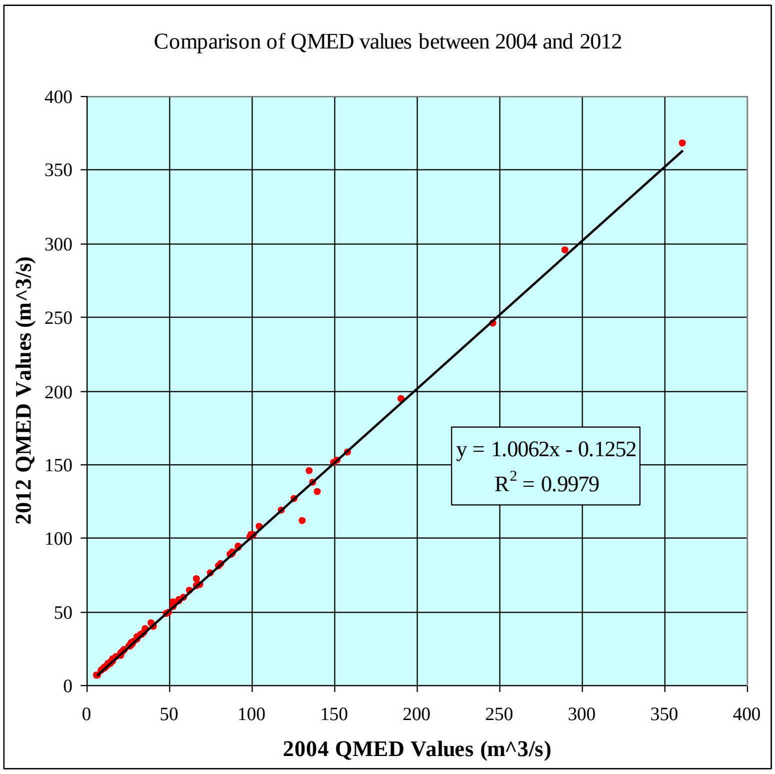

***Figure 1:** Comparison of gauged QMED values in 2004 compared to gauged QMED values in 2012*

These results would appear to suggest that the FSU $QMED_{rural}$ equation is still more than adequate despite the non-inclusion of the November 2009 flood events. This is most likely due to the fact that the value of QMED is less sensitive to larger outliers in the Annual Maximum series. For users of the FSU Web Portal who may be concerned that recent extreme events may have affected the QMED values at a particular gauge that they intend to use as a pivotal site, the Portal provides a facility whereby they may upload their own data for that site. This ensures that any perceived changes that may have occurred to the QMED values at pivotal sites can be accounted for in their calculations.

5 UPDATING ESTIMATION METHODS

As with all flood estimation methodologies, the state-of-the-art is always changing and it is imperative that the FSU research should be at the forefront of such initiatives. The FSU management team are currently looking at possible improvements to the FSU methodologies and will be trialling and testing these over the coming years. The current research is looking at methods of improving the pivotal site adjustments for estimation of QMED.

5.1 Exploring alternative methods of adjustment to QMED estimates

Some initial research by the OPW has shown that using more than one pivotal site to adjust the $QMED_{rural}$ estimate may bring improvements in the estimation of QMED at ungauged locations. A number of different approaches using more than one pivotal site were tested. The approach that performed the best was that which used a pool of up to the ten most hydrologically similar catchments as pivotal sites. In this scheme, an inverse distance weighting is used whereby the adjustment factors at the more hydrologically similar catchments are given the greatest weighting. A visualisation of how this pooling scheme is constructed is shown in Figure 2.

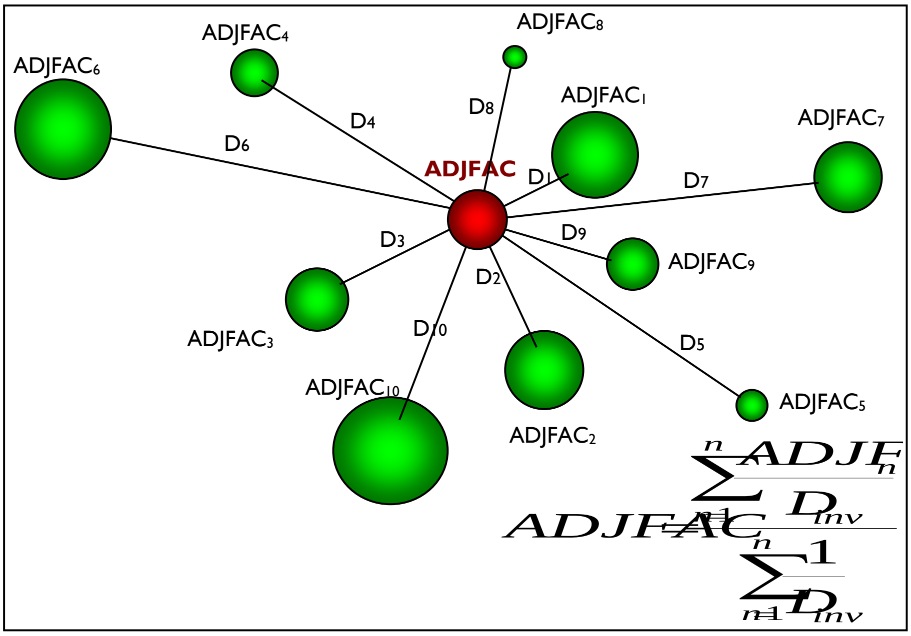

Figure 2: The inverse distance weighting pooling scheme for calculation of the adjustment factor (AdjFac).

The initial results from this 'pooled' model show an improvement in the factorial standard error of the estimate in comparison to the $QMED_{rural}$ equation from 1.37 to 1.22 and has a quoted R-squared value of 0.98 compared to the R-squared value of 0.90 for the $QMED_{rural}$ equation (see Figure 3).

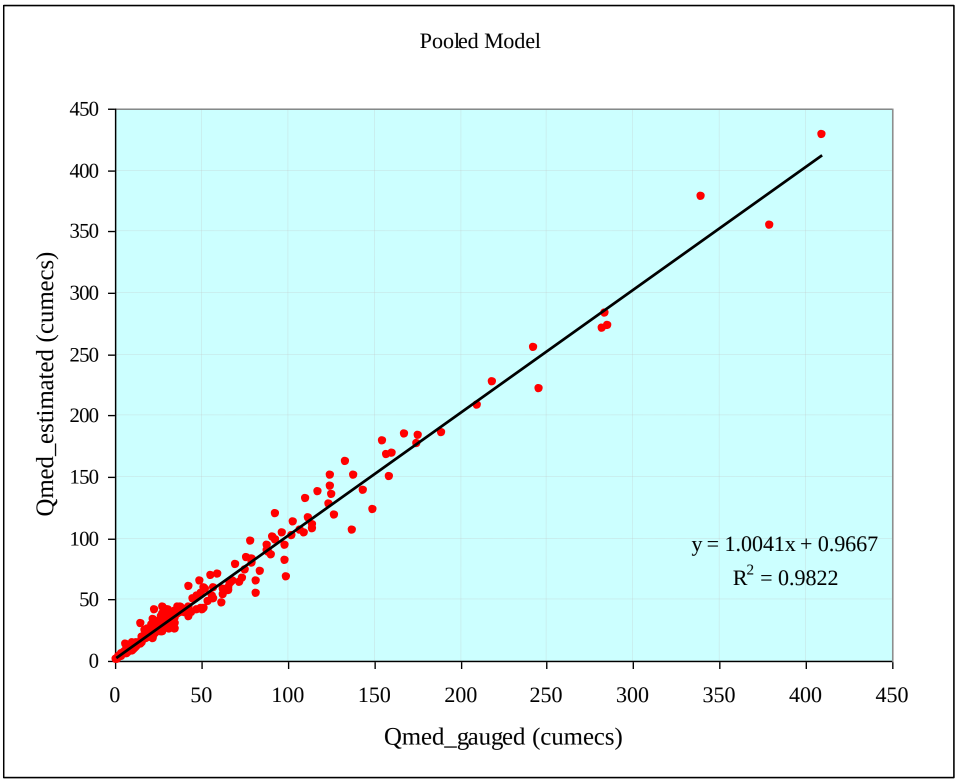

Figure 3: *Plot of the observed Vs estimated QMED for the Pooled Adjustment Model*

Until further testing and checking of the methodology is complete, these results must be treated with caution as the process of choosing the pivotal sites is automated and does not take account of special features such as lakes or arterial drainage in the catchment of the subject site. Neither does the method take account of the number of years of Annual Maxima at the pivotal sites, the quality of the record nor the connectivity of the river network between the pivotal sites and the subject site (i.e. the pivotal sites are not necessarily on the same river as the subject site). It is therefore not recommended that this method be used to apply pivotal adjustments to the subject site until the methodology has been shown to be robust.

Some comfort can be taken from similar research that was recently completed in the UK. Kjeldsen et al. (2014) have carried out research into using multiple pivotal sites to enhance flood estimation in ungauged catchments. In this approach a pool of at least six pivotal sites was used. The pool is formed by choosing the pivotal sites that have the smallest inter-centroidal distance (geographically closest) and each pivotal site in the pool is weighted according to the inter-centroidal distance.

5.2 Planning for future updates to the FSU methodologies

As can be seen from the preceding sections the requirement for updates to the FSU Web Portal and methodologies is inevitable. However it is important that these changes be implemented in a structured and controlled manner. For this reason it is planned that the next update to the FSU methodologies should take place no earlier than 2016. This will allow time for users to become comfortable with the FSU Web Portal and methodologies. It is not considered feasible to rush into making over-frequent updates to the Portal for the simple reason that it will cause confusion. A period of at least two to three years between updates is considered most likely . This will allow users to become accustomed to the FSU Web Portal and its workings but will also allow the FSU management team to first assess any new datasets and methodologies that may arise during that time.

6 CONCLUSION

The FSU Web Portal represents a giant leap forward in how design flows are to be estimated in Ireland over the coming years, however there is the realisation that changes in available data and flood estimation techniques will drive future improvements to the Portal. Already measures are being put in place by the FSU management team to explore possible improvements to flood estimation methods in Ireland, and any such progress will be reported through the FSU Web Portal. The most important driver for change and improvement will be user feedback, and it is in this regard that the FSU management team hope to give users a feeling of ownership of the FSU Web Portal by allowing their feedback to shape the future direction of the Portal.

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