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DESIGN STORM & ANTECEDENT CONDITION FOR URBAN DRAINAGE IN THE REPUBLIC OF IRELAND

Final Report to Integrated Hydro Systems

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Summary

Aspects of the 'Wallingford Procedure' of urban drainage analysis that are based on UK conditions are reviewed in Section 1 of this report, and the need for local data analysis for application to the Republic of Ireland[1] is discussed. The minimum requirement is an analysis of local storm rainfall and soil moisture conditions to determine if the standard UK design recommendations could be adopted. It is recommended in Section 2 that the depth-duration-frequency model in the Wallingford Procedure is adjusted to represent Logue's(1975) results, and a subroutine to form the basis of the adjustments is given in Appendix 1. In Section 3.3, Table 3.10 gives recommended design profiles for Ireland, where for consistency with the simulation+sensitivity analysis of the Wallingford procedure, the column 2 profiles should be used. However, short duration storms typically used for sewer design exhibit flatter profiles, and there is enough uncertainty in the data and analysis methods to recommend that a simplified simulation+sensitivity analysis is followed using a simplified form of the runoff model. In Section 4.1 it is recommended that the Penman-Grindley soil moisture model is included in the Wallingford Procedure, while in Section 4.2 it is recommended that the design UCWI:AAR curve for the UK can also be used in Ireland.

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[1] Further references to Ireland and Irish in this report relate to the Republic of Ireland, unless specifically denoted N.Ireland or all Ireland.

Contents

1 Background

As part of an EC supported SPRINT project, the 'Wallingford Procedure' for urban drainage modelling is being transferred to the Republic of Ireland. This Procedure incorporates rainfall and surface runoff models developed on UK data. The surface delay and percentage runoff models are embedded in the WALLRUS/SPIDA/HYDROWORKS code, though certain model parameters can be changed via the PRM file (described in the manuals and help system). The recommended design storm and antecedent conditions are also based on UK data. For optimum accuracy when transferring the Procedure, these models/parameters/inputs should be confirmed through a systematic study of a number of local test catchments. However, in locations where drainage practices and climate are largely similar to the UK, such a commitment may seem unreasonable, and the existing models could be adopted, on a trial or interim basis, with local amendments considered only in (i) percentage runoff estimation and (ii) the specification of design storm and antecedent conditions.

The standard UK percentage runoff model (the PR equation) involves three catchment and storm variables (PIMP, SOIL & UCWI). Determining percentage imperviousness (PIMP) would appear to present no local problems, though how the area is connected to the sewer may be important (note too that the UK data set used to derive the PR equation included no high-rise housing estates or industrial estates, and local monitoring of such areas should be considered). The other PR equation variables (SOIL, UCWI) are particular to the UK.

SOIL derives from a five level index (ordered classification) of soil properties (slope, texture, depth) to which, following extensive runoff analyses, scalar values of the typical winter percentage runoff were attached (namely 15,30,40,45 & 50%). If the required SOIL index is not available, either the soil properties or the winter runoff percentage could be used to determine suitable values. In fact, the SOIL index was determined for all Ireland as part of the Floods Study Report (NERC, 1975).

UCWI is an index of catchment wetness condition based on (i) SMD - a running soil moisture balance of rainfall and evaporation, and (ii) API - an exponentially weighted average of antecedent daily rainfall amounts. SMD is defined as the Soil Moisture Deficit below field capacity (the maximum moisture content held by capillary suction after drainage has occurred), and is found from the original 'Penman-Grindley' model developed by the UK Met.Office. The API term uses a fast exponential decay on daily rainfall such that the effect of antecedent rainfall 'drains away' in five days. It is intended to extend the SMD model to include soil moisture above field capacity. To derive UCWI values, API can usually be easily found, but the effect of alternative definitions of SMD may need to be explored.

It should be noted that UCWI values are needed on specific days to simulate particular storm events (for model verification), but also design values are needed for use with design storms to predict T-year runoff peaks.

Design storms and UCWI values were defined in the original 'Wallingford Procedure' via (i) simulating catchments over a long period (c.100-years) to derive time series of T-year flood peaks, and (ii) sensitivity analysis to define what single combination of rainfall depth, duration, profile and UCWI value could be used to get the same flood peaks. It was found that the largest flow peak should be taken from modelling storms of a range of duration (15,30,60,120 minutes), each duration having the corresponding T-year rainfall depth, each storm having the median (middle) peakedness summer profile, and each event starting from the median summer 'end of month' UCWI value.

In the UK, T-year rainfall depth for specified duration is estimated by the 'Flood Studies' FSR model (NERC,1975) which has been included in the Wallingford Procedure. Users need only specify the 5-year depth for 60-minute and 2-day durations (read from maps) and a location index (1 = England-Wales, 2 = Scotland-N.Ireland) governing the 'growth' from 5- to T-year depth. Outside the UK, users normally have to specify the full depth-duration curve for the required T-year return period as a set of data points. The UK rainfall model has though been applied to the Republic of Ireland (Logue,1975), albeit with some differences in the final recommendations. These differences could be incorporated in the Wallingford Procedure as location index 3 (= Ireland) having (i) a modified depth-duration model and (ii) 'growth' factors governed by Average Annual Rainfall and storm duration. These changes are described in the next section.

Before applying the UK design storm profiles in other countries, the 'simulation + sensitivity analysis' should properly be followed, particularly if the seasonality of profile shape and antecedent condition differs from the UK (where summer T-year short duration rainfall may be twice that of winter; profiles almost twice as peaky; and SMD values rising to 150mm against practically zero in winter). As an interim measure however, the original broad findings of the 'Wallingford Procedure' might be accepted, and local information on just median summer profile and UCWI could be sought. The main part of this report describes such analyses of storm profiles and UCWI/SMD.

These studies should be considered as the minimum requirement, and more substantial research on percentage runoff and 'simulation + sensitivity' should be contemplated.

2 Rainfall depth-duration-frequency model

The FSR depth-duration-frequency model has two stages. First from given values of 5-year return period rain depth at 60-minute and 2-day duration, 5-year depth is interpolated at the desired duration. Interpolation is based on the FSR equation relating mean rainfall intensity (mm/h) to duration d(h):

$$I\{d\} = I_0/(1+Bd)^n$$

where B is a parameter (now set to 15), and I_0 and n are parameters determined from the given 60-minute and 2-day depths. (Note that the mixed time units are significant. The 60-minute and 2-day values are defined with respect to integer clock/calendar periods, whereas d in the equation refers to durations starting at anytime within the hour. A standard conversion factor of 1.06 is applied to 2-day rainfall to convert 2-day to 48 hour rainfall). The close fit of this interpolation model to the tabulated depth-duration data given in the FSR is shown in Figure 2.1.

Second, a growth factor is used to derive the required T-year return period depth from the 5-year depth. Growth factors were derived for two regions: England-Wales, and Scotland-N.Ireland. Within each region, growth factors depended on return period(T) and on 5-year depth. For T greater than 5 years, exponential equations are used to derive growth factor from T and 5-year depth; for T less than 5 years, linear interpolation within a look up table is used. These tables include adjustments converting the factors from 'annual maximum' to 'annual exceedence' ('annual maximum' analysis concerns the largest value each year, 'annual exceedence' concerns the largest N values in N years).

UK data & model

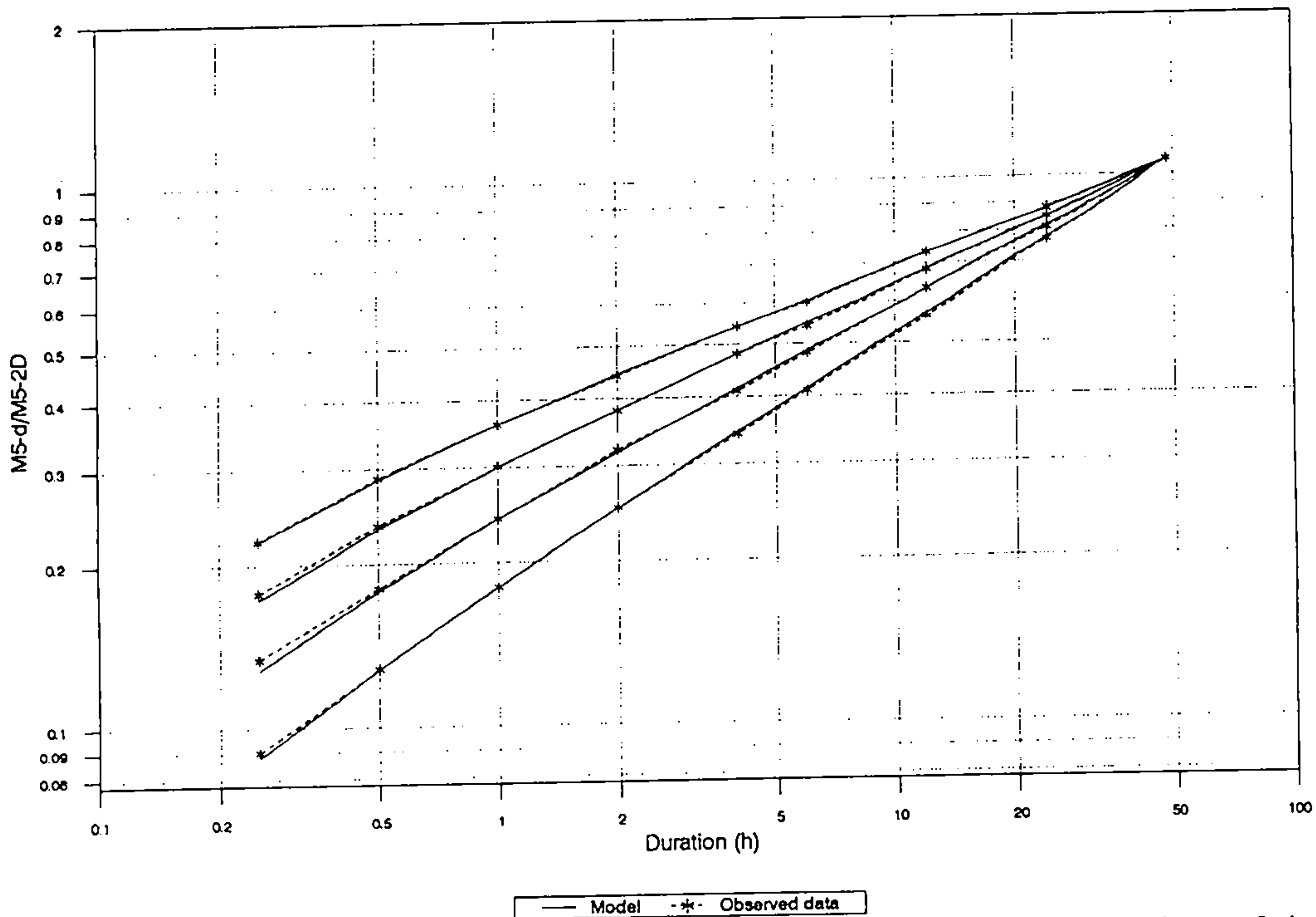


Figure 2.1

As mentioned above, the depth-duration-frequency model developed for Ireland by Logue(1975) differs slightly from the UK model. For depth-duration estimates, Logue does not use the UK interpolation model, but uses log-log interpolation within a depth-duration table (where, as in the FSR, depth values are given as proportions of 2-day depth). Figure 2.2 shows the UK interpolation model fitted to Logue's data table. Marked discrepancies are obvious for durations above 4-hours, giving differences in storm depth of up to 15% for 12-hour durations; such differences would feed through virtually pro-rata to peak discharge estimates. The discrepancies cannot be explained without further analysis, but Logue's results must be accepted as the best information for Ireland.

Although these discrepancies are only apparent at durations much longer than normally used in urban drainage design (except perhaps where large storm tanks are being used, *eg* for sea outfalls), the modification necessary to the Wallingford Procedure are relatively simple and should be made. Either the UK interpolation model should be replaced by a log-log interpolation table, or a modified version of the UK model derived. Figure 2.3 shows the fit of such a modified model, where the basic equation has been adopted for durations up to 4-hours, but refitted using a lower B-value for durations 4 to 48 hours. The lower B values (b2) depend on r (the ratio of 60 minute to 2-day depth) according to:

b2 = 0.2*(2.0**(r/0.06 -3.0))

The fit is quite good, and this approach is probably the more attractive, but the equation above should be restricted to r greater than 0.18 (otherwise the exponent in the equation goes negative). This restriction would rarely be invoked; low r values only occur where hourly maxima are much less than 2-day maxima, mainly in areas of high relief, remote and un-urbanised. Logue does not map r for Ireland, but a map is given in the FSR, showing values below 0.18 only in some mountainous areas of Kerry and Connemara.

Logue's depth-frequency model differs more significantly from the FSR model. Rather than relating T-year growth factors to the 5-year depth and region, he presents a series of standard growth curves relating to one variable: the ratio of 5-year to 2-year depth (M5/M2). As the variation with M5/M2 is slow, only a subset of his curves need be considered (as in Table 2.1 below); intermediate values may be found by log-linear interpolation.

The ratio M5/M2 might have been related to 5-year depth (creating a parallel to the FSR). Logue however argues quite credibly that such a relationship arises as a consequence of a prior dependence on storm duration and Average Annual Rainfall (AAR). He therefore presents another table for M5/M2, reproduced below as Table 2.2.

Implementing Logue's model within the Wallingford Procedure is not within the terms of this report. However, the FORTRAN code given in Appendix 1 could be used as a basis for the depth-duration model. Alternatively, if the tabular approach is preferred, the code includes Logue's complete depth-duration table as a data statement. Implementing the tabular depth-frequency model instead of the UK model is also quite easy. Duration and AAR are already known, allowing M5/M2 to be interpolated from Table 2.2 (a subset involving AARs of 700, 800, 1000, 1200, 1600 & 2000 should suffice). The M5/M2 value (rather than M5) is then used to interpolate growth factor from Table 2.1 (rather than from the UK growth factor tables for $T < 5y$; only one regional table is necessary, with no break in method for $T > 5y$).

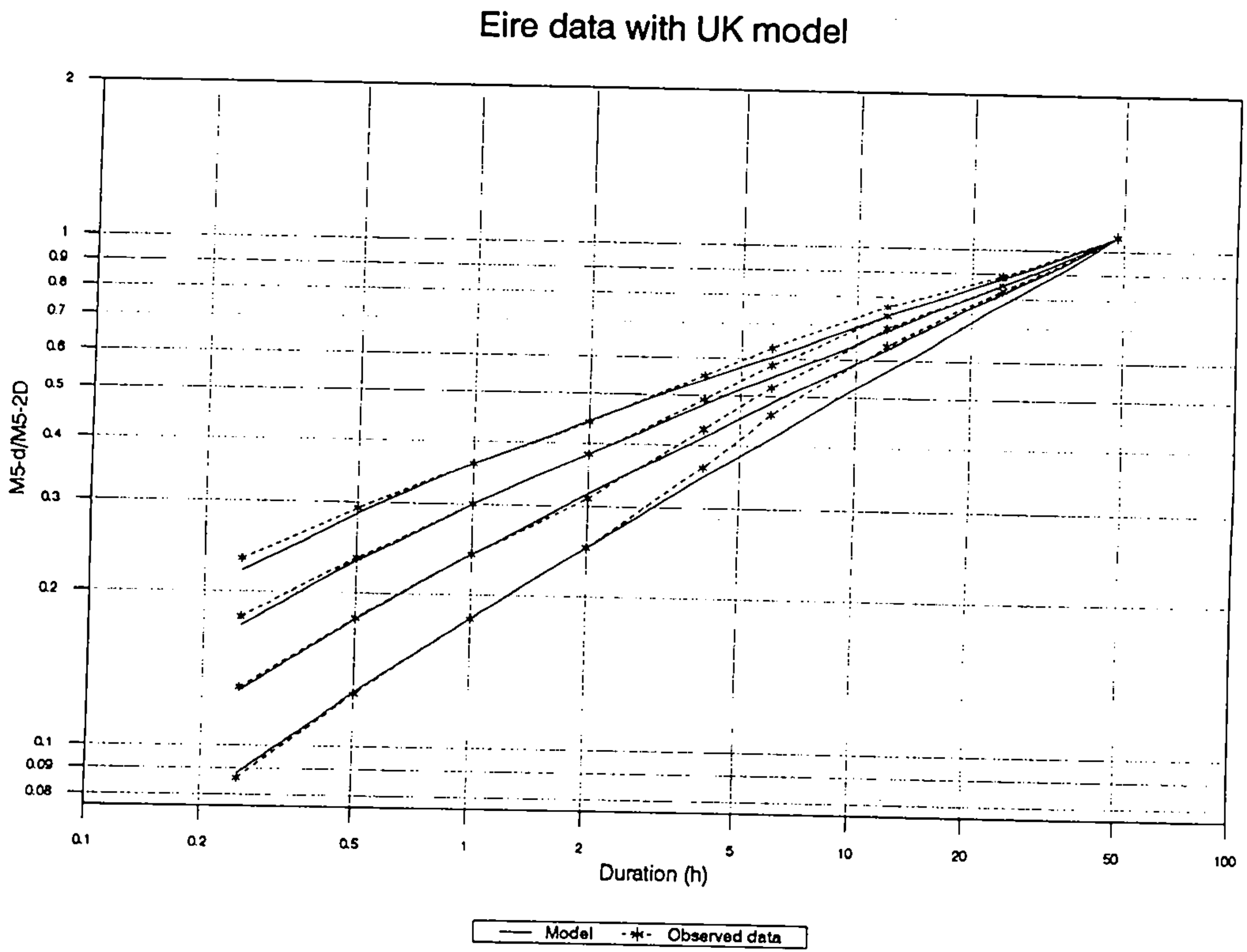

Eire data with UK model
M5-d/M5-2D
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.1
0.2
0.5
1
2
5
10
20
50
100
Duration (h)
Model
Observed data

Figure 2.2

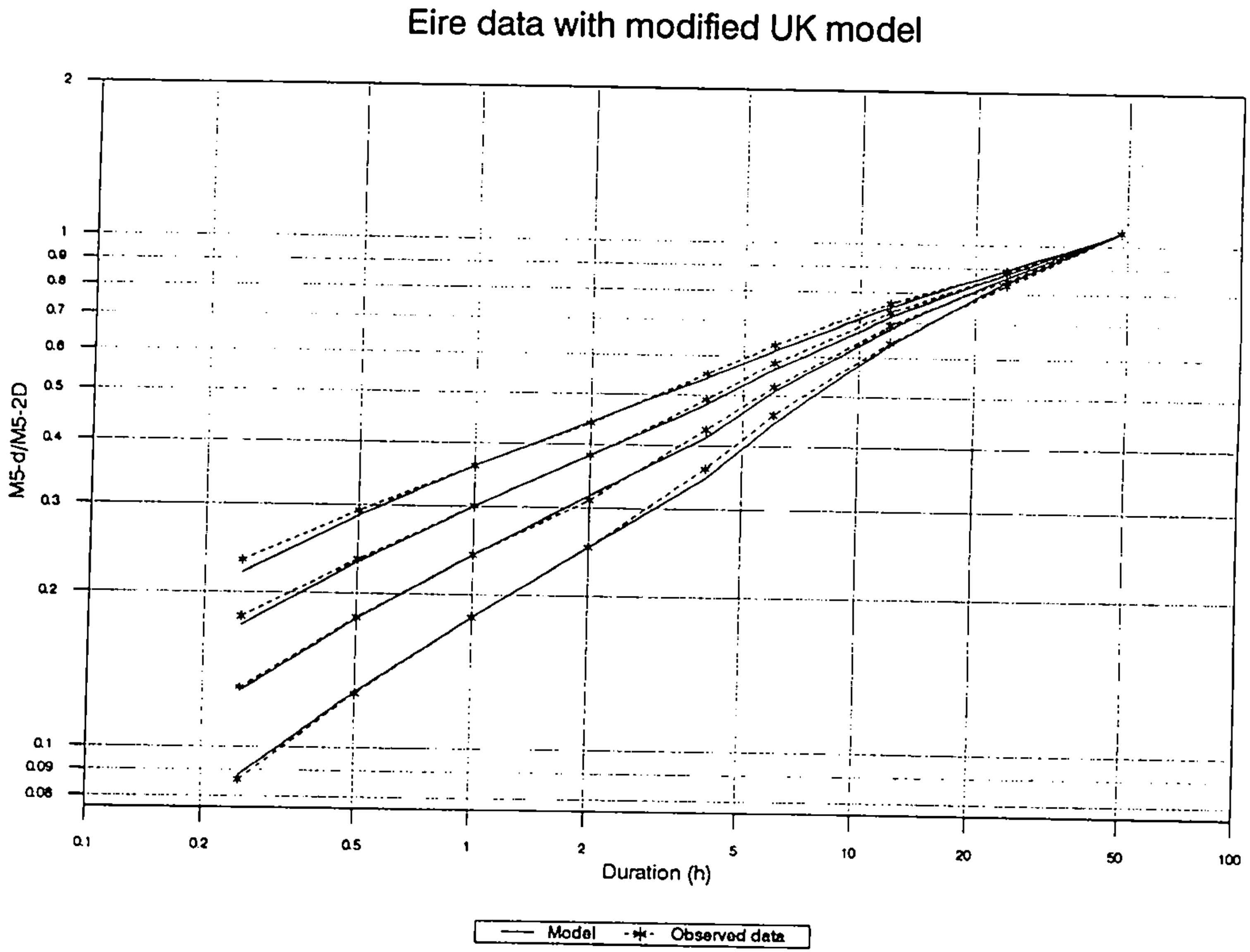

Eire data with modified UK model
M5-d/M5-2D
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.1
0.2
0.5
1
2
5
10
20
50
100
Duration (h)
Model
Observed data

Figure 2.3

Table 2.1 Rainfalls of various return periods as a proportion of M5

M5/M2	2M/M5	1M/M5	M2/M5	M10/M5	M20/M5	M50/M5
1.42	0.48	0.62	0.70	1.25	1.55	2.03
1.34	0.54	0.67	0.75	1.20	1.43	1.79
1.26	0.61	0.73	0.79	1.16	1.32	1.58
1.18	0.69	0.79	0.85	1.11	1.22	1.37
1.10	0.79	0.87	0.91	1.06	1.11	1.18

Table 2.2 Ratio M5/M2 as a function of duration and AAR

	AAR(mm)										
Duration	700	800	900	1000	1100	1200	1400	1600	2000	2400	3000
15 min	1.42	1.40	1.38	1.37	1.36	1.35	1.33	1.31	1.28	1.26	1.23
30 min	1.41	1.39	1.37	1.36	1.35	1.33	1.32	1.30	1.27	1.25	1.23
60 min	1.39	1.37	1.36	1.34	1.33	1.32	1.30	1.28	1.26	1.24	1.21
120 min	1.36	1.34	1.33	1.32	1.30	1.29	1.28	1.26	1.24	1.22	1.19
240 min	1.32	1.30	1.29	1.28	1.27	1.26	1.25	1.23	1.21	1.19	1.17
360 min	1.31	1.29	1.28	1.27	1.26	1.25	1.24	1.22	1.20	1.18	1.16
12 h	1.29	1.28	1.27	1.26	1.25	1.24	1.23	1.21	1.19	1.17	1.15
24 h	1.28	1.27	1.26	1.25	1.24	1.23	1.22	1.21	1.18	1.17	1.15

Logue's growth factors only extend to the 50 year return period; he specifically concluded that no sound basis existed for extending them further. This is probably not a real problem for urban drainage modelling, but some tentative values for the 100 year return period could be estimated by distribution/curve fitting if necessary.

The effect of implementing Logue's results instead of the existing UK(FSR) model will vary with storm duration and location. Table 2.3 compares results obtained for 15-minute durations at Dublin and Cork, showing the FSR model (a) gives the same storm depths for each location (at this duration), and (b) gives on average 5% lower depth for 1-year return period and 20% lower depth for 50-year return period. These differences will affect peak discharges approximately pro rata.

Table 2.3 Comparison of Logue(1975) and NERC(1975) rainfall models

	Mapped AAR	Mapped M5-1hr	Mapped M5-2d	Logue M1-15min	Logue M5-15min	Logue M50-15min	FSR M1-15min	FSR M5-15min	FSR M50-15min
Dublin	760	16	55	5.8	9.4	18.8	5.6	9.0	14.9
Cork	1100	17	70	6.0	9.1	16.8	5.6	9.0	14.9

3 Rainfall profiles

To adopt the UK design storm criteria (50% summer profile and median UCWI) without full simulation studies, and without previous studies of rainfall profiles available for Ireland, a new profile analysis was needed, mirroring the UK analysis. Storms of duration up to 24 hours were thus to be considered. Such durations are longer than normally used in sewer design, but the existing UK profiles are based almost entirely on 24-hour storms (sensitivity of profile shape to storm duration was found by the Met.Office to be small). Crucially though, the resulting 50% summer profile gave T-year flood estimates that agreed closely with those obtained by long-term simulation. For this reason, studying long duration storms is quite valid, though the profiles obtained should be compared with those derived from shorter storms to confirm profile variation with duration is small.

3.1 AVAILABLE RAINFALL (AND EVAPORATION/SMD) DATA

The Irish Meteorological Service operate a number of synoptic weather stations which include rainfall chart recorders and hourly rainfall observations along with the usual meteorological parameters to allow monthly estimation of Penman evaporation (but not soil moisture status). Most of these stations have records back to the 1950's. Since 1991, 10-day evaporation estimates have been made on a trial basis by the Makkink method (ignoring wind-effects) and used to estimate soil moisture by a proprietary method. Actual soil moisture is also measured by lysimeter at five agroclimatic stations.

For this study, five synoptic weather stations (shown on Figure 3.1) have been selected as representative of the broad climate of urban areas of Ireland. The Galway station only ran from 1979 till 1988. The others are still running and have computerised hourly and daily rainfall and monthly Penman evaporation dating back to 1958 (1962 at Cork). All the computerised daily rainfall and monthly evaporation data have been obtained upto 1988 (and for 1991-3) at each station in order to derive 'end-of-month' Penman-Grindley SMD and UCWI series.

Rainfall profile analysis was to consider storms of a range of durations from 1-24 hours. The computerised hourly rainfall data was not considered adequate to define profiles for storms of duration less than 12 hours, particularly as it relates to 'on the hour' measurements. Thus the rainfall charts were examined (over the shorter period 1979-1988) with the intention of selecting at each gauge approximately four 'flood producing storms' each summer and winter to be digitised at 5-minute intervals. It was considered that about 40 storms each season would be sufficient to define quartiles of peakedness, and 10-years of data would be sufficient to produce these storms. As with the UK analysis, no attempt was made to examine any sampling effects, but the period 1979-1988 was examined to confirm it was not particularly unusual in terms of rainfall or evaporation.

Rainfall charts were selected initially using relatively low local thresholds on daily depth and maximum rainfall intensity (the computerised hourly data could not unfortunately be used in this selection process). These charts were then examined to identify isolated storms, maybe crossing day boundaries, with total depth exceeding higher thresholds. The resulting charts (779 covering 485 events) were photocopied for digitising. The larger than expected number of charts was mainly due to more storms crossing day boundaries.

To reduce the number of charts to digitise, it was decided to use the computerised hourly data for longer duration storms (12 & 24 hours). Thus a further selection of the charts was made

Synoptic weather stations used in Storm and UCWI analysis

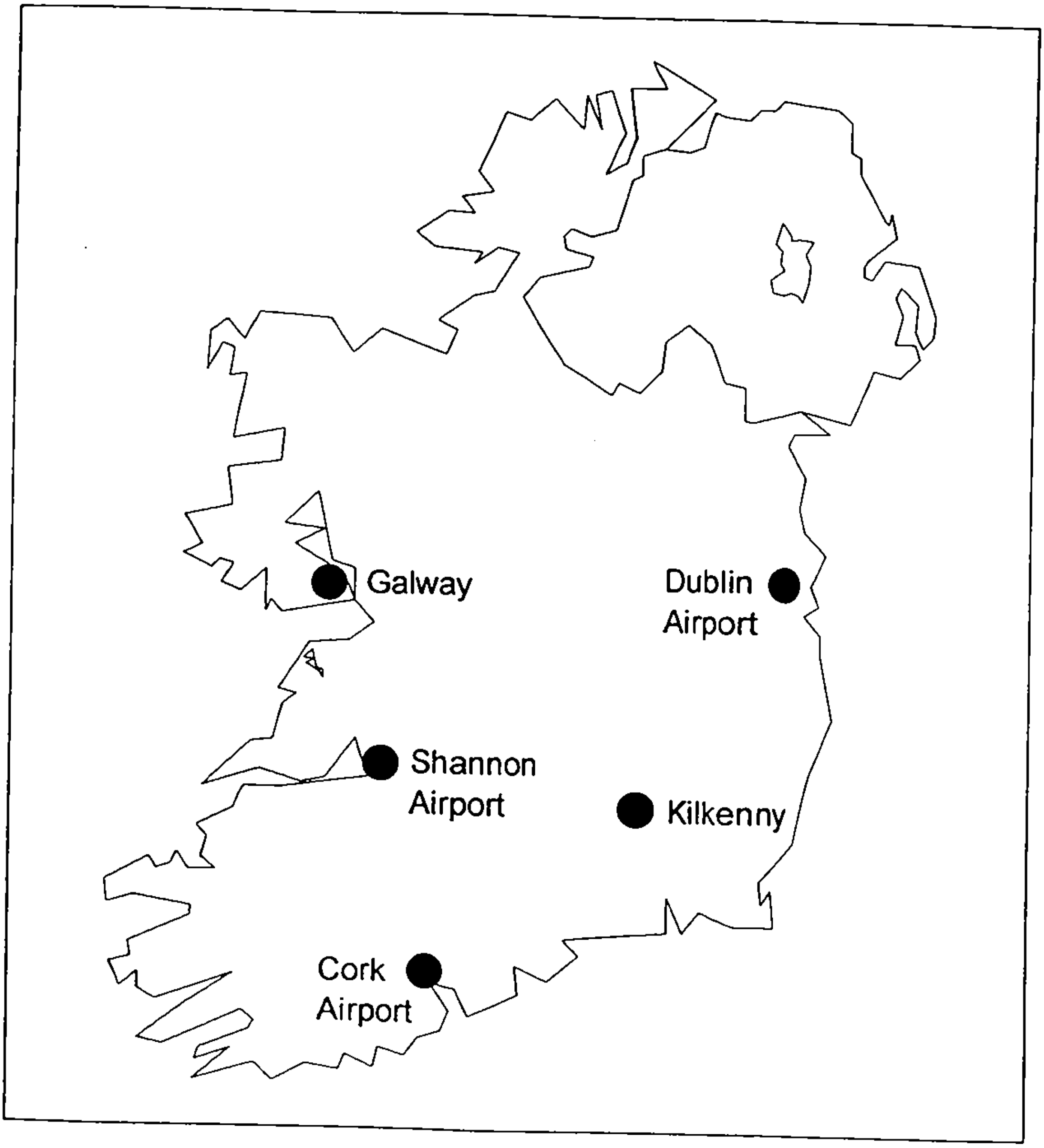


Figure 3.1

(based on the hourly totals in durations 1,2,4,6,12,& 24 hours), resulting finally in 315 charts being digitised, covering 231 events. Table 3.1 summarises the events available for each raingauge according to the various criteria (column formats change, but show the variation between stations; more severe limits for Cork still gave more events extending over more days, Shannon gave surprisingly few events).

Table 3.1 *Selection of events for digitising at each raingauge*

Thresholds & Numbers(N) depth(mm), intensity (mm/h)	Dublin	Kilkenny	Raingauge Cork	Shannon	Galway
Daily depth, No. selected Intensity, No. selected[1]	15,N=81 15,N=105	15,N=91 15,N=113	20,N=122 15,N=153	17½,N=65 15, N=121	17½,N=82 15, N=133
Event depth, depth+intensity No. selected[2]	20,10+15 N=77	20,10+15 N=81	25,15+15 N=131	20,10+15 N=108	20,15+15 N=88
1 hour depth, No.	6,N=34	6,N=29	8,N=52	6,N=17	6,N=32
2 hour depth, No.	9,N=37	9,N=35	12,N=58	9,N=22	9,N=34
4 hour depth, No.	13½,N=34	13½,N=27	18,N=60	13½,N=20	13½,N=29
6 hour depth, No.	16,N=34	16,N=31	21,N=62	16,N=22	16,N=34
12 hour depth, No.	24,N=19	24,N=15	32,N=47	24,N=11	24,N=19
24 hour depth, No.	36,N=15	36,N=8	48,N=21	36,N=4	36,N=10
Overall (charts/events)	N=61/47	N=61/46	N=90/64	N=43/31	N=60/43

[1]Each criteria applied individually. [2]Both criteria applied at once

In digitising the charts and deriving five-minute depths, no corrections for check gauge totals were made. The aim was to study profile shape, and a simple factoring of the data would have had minimal effect (and only on storms crossing check gauge reading times). However, all daily and hourly totals derived from the five-minute data were compared with those given in the computerised hourly data. Any significant differences (exceeding 1mm+10% of the hourly data) were noted and both data series were checked visually against the charts. Most of the discrepancies were due to timing differences when heavy rain occurred across hour boundaries; they could be ignored in this study. Some small corrections were made to a few events in the 5-minute data.

The 12 and 24 hour limits specified in Table 3.1 were mainly for interest (to flag storms 'critical' over the full range of durations). Only one of the 231 events chosen for digitising failed the limits at all four of the shorter durations. Meanwhile, 12 and 24 hour storms were analysed using the hourly data, and the limits and number of events selected are given in Table 3.2.

The hourly and 5-minute data discussed above were the main data sources. Also available however were the five sequences of 1-minute UK rainfall used in the Wallingford Procedure's 'simulation + sensitivity' analysis. It was envisaged that these could be used to bridge between the profile analysis in the Flood Studies Report (based mainly 24-hour storms) and the analysis for Ireland (including shorter duration storms). The relevance of a bridge is that the analysis described in the FSR differs slightly from that explained to the author in 1975, and the storm data used by that analysis was not available for corroboration. However, the 1-minute UK data has not so far been used in this way.

Table 3.2 Selection of 12 & 24 hour events for winter and summer

Thresholds & Numbers depth (mm)	Dublin	Kilkenny	Raingauge Cork	Shannon	Galway
12 hour depth	18	18	24	18	18
Winter/Summer events	N=23/33	N=18/31	N=32/35	N=17/26	N=20/37
24 hour depth	24	23	32	24	24
Winter/Summer events	N=13/20	N=12/25	N=24/21	N=16/21	N=12/22

3.2 PROFILE ANALYSIS

The profile analysis technique was as given in the Flood Studies Report (though the FSR data was not available to allow a check on interpretation and repeatability):

(1) Storms were selected as the most intense rainfalls in the chosen duration, not as isolated bursts. Thus they included intense portions of longer duration events, and therefore their depths were compatible with those derived for depth-duration-frequency analysis.

(2) Storms were averaged as single samples and in quartiles of peakedness (determined by the proportion of depth in the most intense 20% or 5/24) of the duration.

(3) In the quartile analysis, averages in each quartile were derived, corresponding to 12.5, 37.5, 62.5 and 87.5% peakedness; interpolation was then used to define 25, 50 and 75% peakedness profiles.

(4) To derive average profiles, each storm was first centred on the mid point of the shortest duration that contained half the full storm depth (note that the implication that the FSR sets this shortest duration to an odd number of timesteps has been followed here to simplify the analysis).

(5) Storm depth was then re-evaluated as the depth in the chosen duration (see 1), split 'half and half' either side of the storm centre (note that equivalent half timesteps were used for the furthest steps about the centre).

(6) Proportions of this centred depth occurring in successive odd numbers of timesteps about the storm centre were derived, and averaged over all storms in the sample/quartile.

There are a number of points to make about the strict application of this averaging process. Obviously the centred storm depth is less than (or equal to) the originally derived storm depth, and thus the centralised proportional depths of individual storms will normally be somewhat exaggerated. However, as storms could be negatively or positively skewed about their centres, the averaged storm peak can only be flatter than typical of individual storms (where 'typical' may be defined by allowing the storm centre to move such that successive proportional depths are maximised). The averaged storm could even have an 'inverted' peak (see later), particularly when multiburst storms are included (with 'centres' that could lie in a dry period between two bursts). Though using a 'fixed centre' may not represent peakedness faithfully, the crucial point is that using the 50% summer design storm determined that way gave a good match to peaks found by long-term simulation. The centralised analysis has thus been used here, except that (i) storms with re-centralised depth less than 70% of the original were excluded, and (ii) as the author had been informed in 1975 that a 'moving centre' approach was used to derive the FSR profiles, the 'moving centre' storms were also derived for comparison.

An extensive range of profile analyses have been performed on the hourly and 5-minute data. The main results are summarised in Figures 3.2 to 3.6 and in Tables 3.2 to 3.10 below; fuller results appear in Appendix 2. To clarify the considerable and confusing variation in profile shape between the different data sets a 'sensitivity' measure has been derived. This is the standardised peak output the profile gives when routed through a triangular unit hydrograph having a 'time of concentration' equal to the profile duration. A uniform rainfall profile would give the value 1.00. The sensitivity is meant to approximate the effect of changing profile shape on the peak flow generated by the Wallingford Procedure.

It may be noted from Appendix 2 that the sensitivity for the FSR 50%-Summer storm is 1.44, rising 10% to 1.59 for the 75%-Summer storm, and falling 9% to 1.31 for the 25%-Summer storm. These changes compare with the approximate ±15% change given by Figure 6.2 in Kidd & Packman(1980) for the development version of the Wallingford Procedure (no tests available for more recent versions of the Procedure). That roughly 50% bigger effect probably arises from the fact that Kidd & Packman's results relate to 30 minute storms on a catchment of 20 minute time of concentration; the catchment thus sampled the most intense central part of the storm, seeing (in effect) a peakier storm of shorter duration, and thus enhancing sensitivity to profile shape. An equivalent effect could probably have been achieved in this report if sensitivity had been derived using a unit hydrograph of timebase two thirds the profile duration. This though was not done, and thus the sensitivities quoted herein are probably about 50% lower than the real sensitivity of the Wallingford Procedure. However, the current sensitivity remains a useful index of the effective difference between profiles, and as such it has been used in the present analysis. Sensitivities have been derived for individual (observed) profiles and for the averaged profiles (as given in Appendix 2).

3.3 PROFILE RESULTS

Figures 3.2 a-b (and Appendix 2) give average 24-hour winter and summer profiles for the five selected raingauges, individually and together. As in the FSR, symmetrical profiles are derived in this report, and only the 'second halves' are shown in the various figures. Winter profiles are based on the 12 'largest' storms at each station over the 10-year period 1978-1987, while Summer profiles are based on the 20 'largest' storms. It can be seen that there is considerable geographical variation in profile particularly in the central 10% (the FSR does not discuss geographical variation except to say that the differences are 'confounded' in the seasonal variation and the frequencies of storm types, implying fair geographical consistency in seasonal storms). The geographical variability can be seen in the 'sensitivity' values given in Table 3.3 below

Table 3.3 Geographical variation of 24-hour profile sensitivity

	Dublin	Kilkenny	Cork	Shannon	Galway	Average
Winter	1.34	1.42	1.42	1.30	1.44	1.38
Summer	1.52	1.50	1.49	1.44	1.49	1.49

24 hour storms

Average storms @ gauges

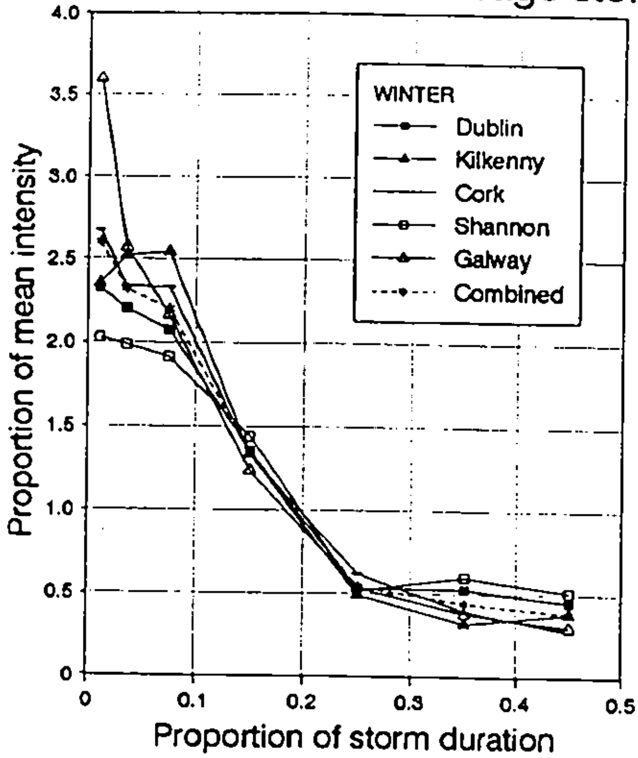


Figure 3.2a

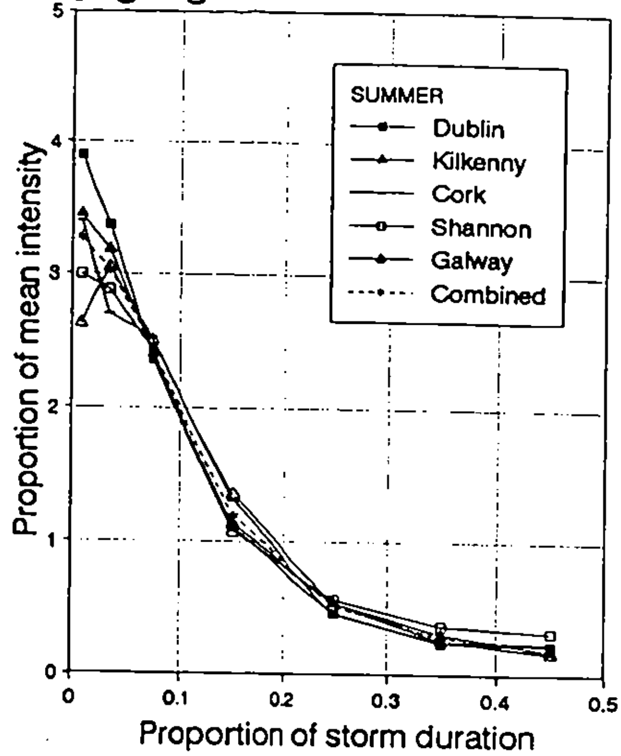


Figure 3.2b

Quartile storms for all gauges combined

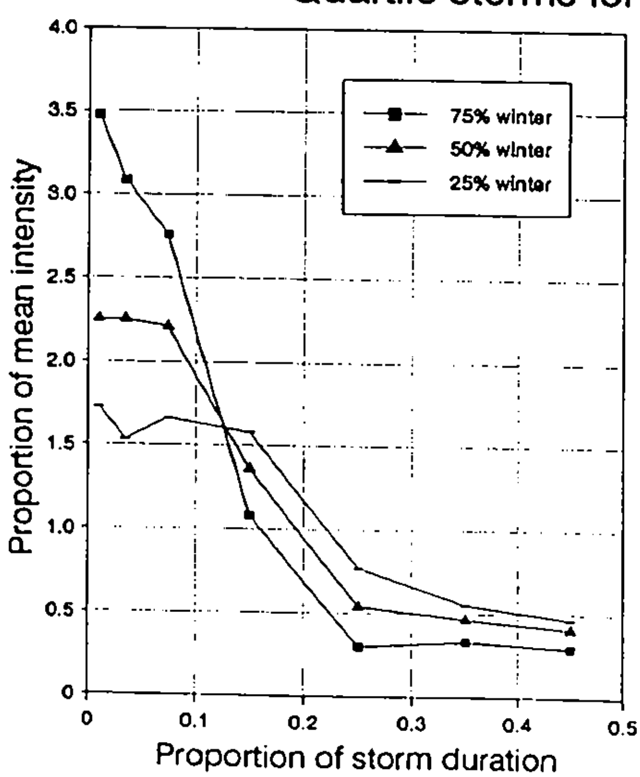


Figure 3.2c

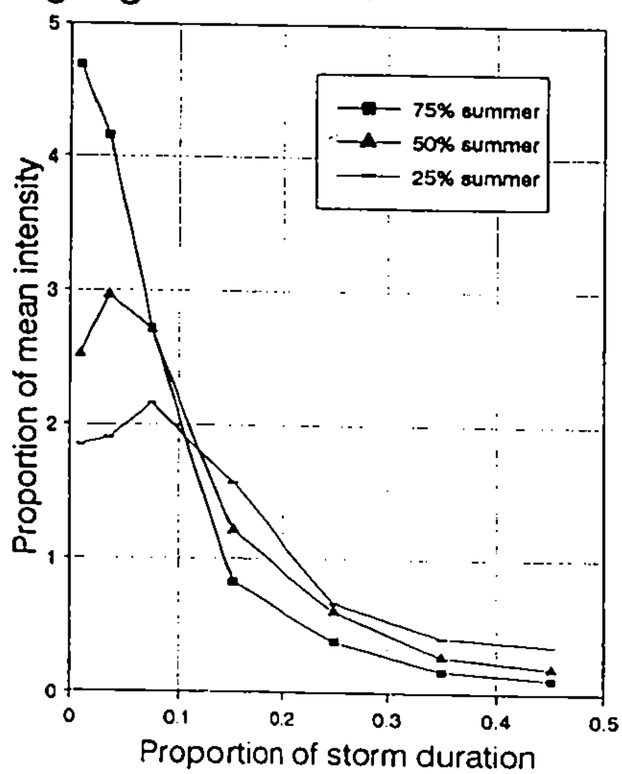


Figure 3.2d

The standard deviation of mean sensitivity at each location is about .04, suggesting the Shannon profiles in particular are significantly flatter than the others. However, ignoring these differences, the storms were combined and a quartile analysis performed. The results are presented in Figures 3.2 c-d, while the sensitivities of the combined profiles are compared in Table 3.4 with the FSR values. Full details are in Appendix 2.

Table 3.4 *Sensitivity of Irish and UK 24-hour storm profiles by quartiles*

	Ireland Winter	UK-FSR Winter	Ireland Summer	UK-FSR Summer
75%	1.50	1.39	1.62	1.59
50%	1.36	1.31	1.48	1.44
25%	1.27	1.25	1.36	1.31

These results are directly comparable; the Irish sensitivities are based on 60 winter and 100 summer storms, while those of the FSR are based on 32 winter and 80 summer storms. The results are within 4% of each other (factorially), except for 75% winter with 8%. Remembering that the Wallingford Procedure is probably 1½ times as sensitive as these values, using the Irish 50% summer and 75% winter profiles would probably increase peak discharges by about (1.5*[1.48/1.44-1])=4% and (1.5*[1.5/1.39-1])=12% respectively. It would thus seem right that the profiles in Appendix 2 (with additional interpolation) should replace the UK profiles in WALLRUS/SPIDA. However (i) it should be shown these profiles apply also to shorter and more infrequent storms; (ii) geographical differences have been ignored; and (iii) the profiles of Figure 3.2d particularly have inverted peaks.

Concentrating first on point one above, storms of a range of durations from 30 minutes to 24 hours were analysed. The results (given in Appendix 2 under the heading 'All duration Irish profiles') need to be considered carefully:

(1) As already seen in Table 3.2, there are more storms of a given depth in summer than winter (except at Cork where the numbers are about equal). At shorter durations this became more apparent, such that many fewer events were available for winter. Some scatter in profiles could be caused by comparing samples of different sizes (and thus storms of different severities). Note here that sample sizes used were always multiples of four so that local quartiles could be properly defined.

(2) Some profile scatter could be due to the change in number of timesteps used (1 hour step for both 24 and 12 hour storms). Note the analysis always used 'clock' timesteps and even with the 5-minute data did not apply shifts to maximise intensities. Note also that using linear interpolation with a long timestep can artificially flatten peaks.

(3) Both points 1 & 2 would seem to be confirmed by the consistent changes seen in Table 3.5 giving the results of comparing 12 and 24 hour profiles averaged over different numbers of events. However further tests reported in Appendix 2 do not really confirm this. Tests on 6 hour storms at Dublin using from 6 to 72 timesteps produced appreciable changes in sensitivity only for the 6 step case, though the profile began to flatten for 12 steps. Tests on 2 hour storms at all gauges gave similar results, as did tests on 12 hour storms (using the 5-minute data). Further tests

on the number of events also showed no consistent trends, maybe just the 'hint' of slightly flatter profiles when using fewer (larger) events. In spite of this it was determined to make future comparisons (where possible) on equi-sized samples of profiles, each defined over 24 timesteps (the computer program cannot currently average profiles having different numbers of timesteps).

Table 3.5 *Sensitivity for differing no.of events(N) and duration (or no.steps)*

Season	24h/1h	24h/1h	12h/1h	12h/1h
Winter	1.38,N=12	1.35,N=8	1.33,N=12	1.31,N=8
Summer	1.49,N=20	1.47,N=12	1.36,N=20	1.34,N=12

(4) Two lines in the 'All duration' section of Appendix 2 have the same label as the preceding line but for an added '*'. These lines relate to a small change in the analytical procedure affecting these and all the lines after the third '*'. The effect of the change is seen to be very small; it concerns the removal of a restriction forcing the whole storm 'centre' (containing half the depth) to lie within the originally selected storm period (see Section 3.2 step 4).

(5) In determining average profiles for some of the shorter durations, it was realised that some storms were included that did not meet that duration's digitising limit (given in Table 3.1) - they had been chosen for digitising at a different duration. To limit the effect this might have, a smaller number of events was used for the final analysis. The number of events and the resulting storm depth limits are summarised in Table 3.6 (showing again the geographic variation, especially at Cork)

Table 3.6 *Final numbers and lowest storm depths for profile analysis*
(Depths below digitising limit shown in italics - mostly just below)

	Winter					Summer				
Duration	24h	720m	360m	240m	120m	24h	720m	360m	240m	120m
No.events	8	4	8	8	4	12	12	12	12	12
Dublin	27.7	25.1	*15.4*	*11.9*	10.2	29.4	*23.3*	19.6	16.1	12.8
Kilkenny	26.4	*19.5*	16.0	*12.2*	10.1	28.3	*23.7*	17.7	16.1	11.5
Cork	45.5	33.3	22.1	18.7	13.4	39.1	*31.6*	25.5	20.5	15.1
Shannon	27.2	*20.5*	*15.2*	*12.2*	9.5	26.1	*20.4*	17.8	13.7	10.8
Galway	27.6	27.3	18.2	14.1	12.1	29.7	*23.1*	18.1	15.6	12.0
Sensitivity	1.35	1.32	1.24	1.22	1.23	1.47	1.36	1.32	1.33	1.35
Depth @25%						0.60	0.51	0.48		

Average profiles at each duration are shown in Figures 3.3 and Appendix 2. The variability between durations is reflected in the sensitivity values given in Table 3.6. Also shown in the table for three summer durations is the proportion of total rain falling in the central 25% of the duration. These values may be compared with the values 0.63, 0.55 and 0.56 given for the UK by the FSR. Having obtained values of 0.64 and 0.57 for 4-day and one hour storms, the FSR concluded there was no systematic variation of profile with duration, allowing their 24-hour profiles to be applied to any duration. For Ireland, with a 10% average increase in sensitivity between 360 minute and 24 hour storms, this seemed unwise, and it was decided to split the profiles into two groups - those above and those below 9 hours duration.

Figures 3.4 a-d show the resulting winter and summer, long and short storms for each raingauge and for all combined. The full profiles are in appendix 2 while the sensitivies are given in Table 3.7 below.

Table 3.7 *Mean sensitivity of grouped storms - variation with location*

Season	Winter		Summer	
Duration No. events	Long(>9h) 12/gauge	Short(<9h) 20/gauge	Long(>9h) 24/gauge	Short(<9h) 36/gauge
Dublin	1.30 ±.05	1.24 ±.03	1.42 ±.04	1.39 ±.03
Kilkenny	1.39 "	1.25 "	1.48 "	1.36 "
Cork	1.39 "	1.19 "	1.38 "	1.27 "
Shannon	1.34 "	1.27 "	1.42 "	1.33 "
Galway	1.41 "	1.24 "	1.40 "	1.33 "
Average	1.37	1.24	1.42	1.34

±Figure = approximate standard error associated with gauge averages

No consistent or significant trends are apparent in this table, except that short duration profiles at Cork are flatter than the others. In the original 24-hour storm analysis of Table 3.3 it was not Cork but Shannon that gave the flatter peaks. For long duration winter storms Shannon profiles are still rather flat, but for the different sample used here (fewer 24-hour events, but some 720-minute events) they seem to be closer to the others. These results have been double checked as sample variability effects must question how different the locations really are. Cork and Shannon however have both stood out throughout this analysis: Cork having many more storms (longer and heavier), Shannon having relatively fewer storms.

Overall it was considered the gauges could be lumped together and a new quartile analysis performed, except that for 'short' storms, quartiles were derived with and without Cork and for Cork alone. The results are presented in Figures 3.5 a-f, while the sensitivities are given in Table 3.8. It may be noted that the long duration sensitivities remain quite similar to those of the FSR (75% winter excepted). However the short duration (no Cork) and short duration (Cork) seem different enough to be significant, giving successive 5% reductions in peak sensitivity. Unfortunately a number of the profiles shown in Figure 3.5 have inverted peaks, which are intuitively unattractive.

Variation of combined profiles with storm duration

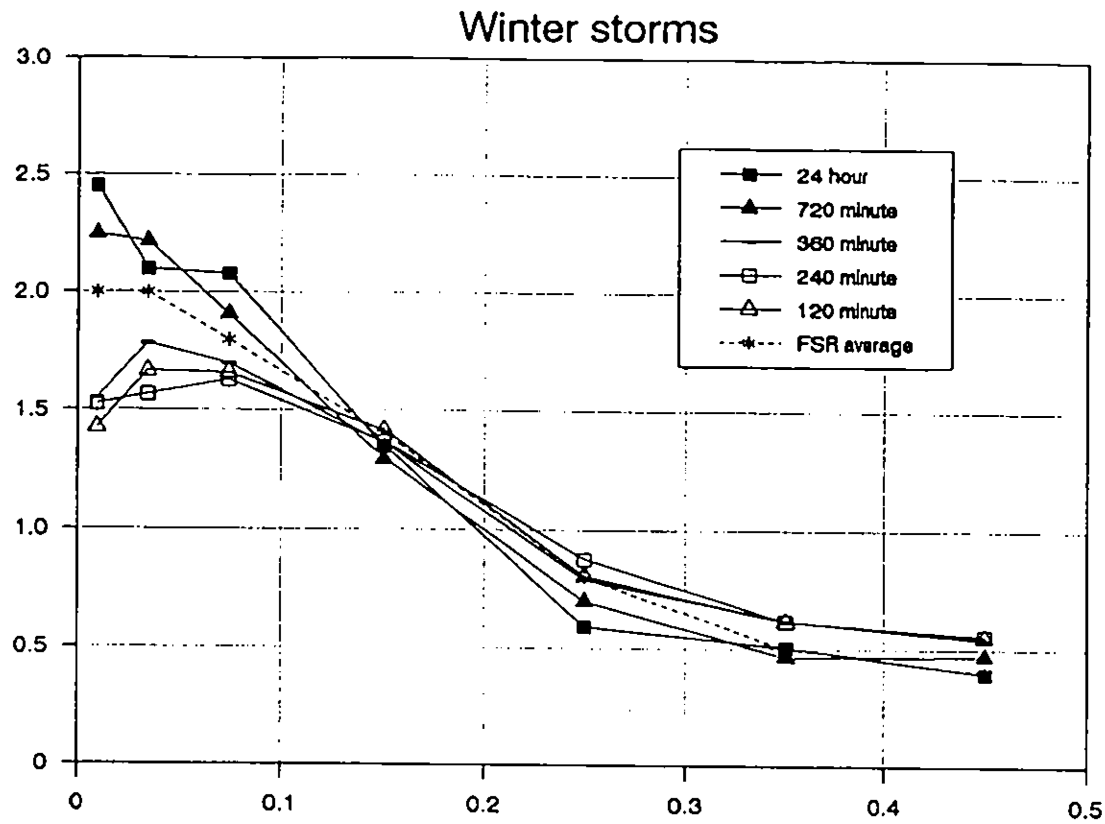


Figure 3.3a

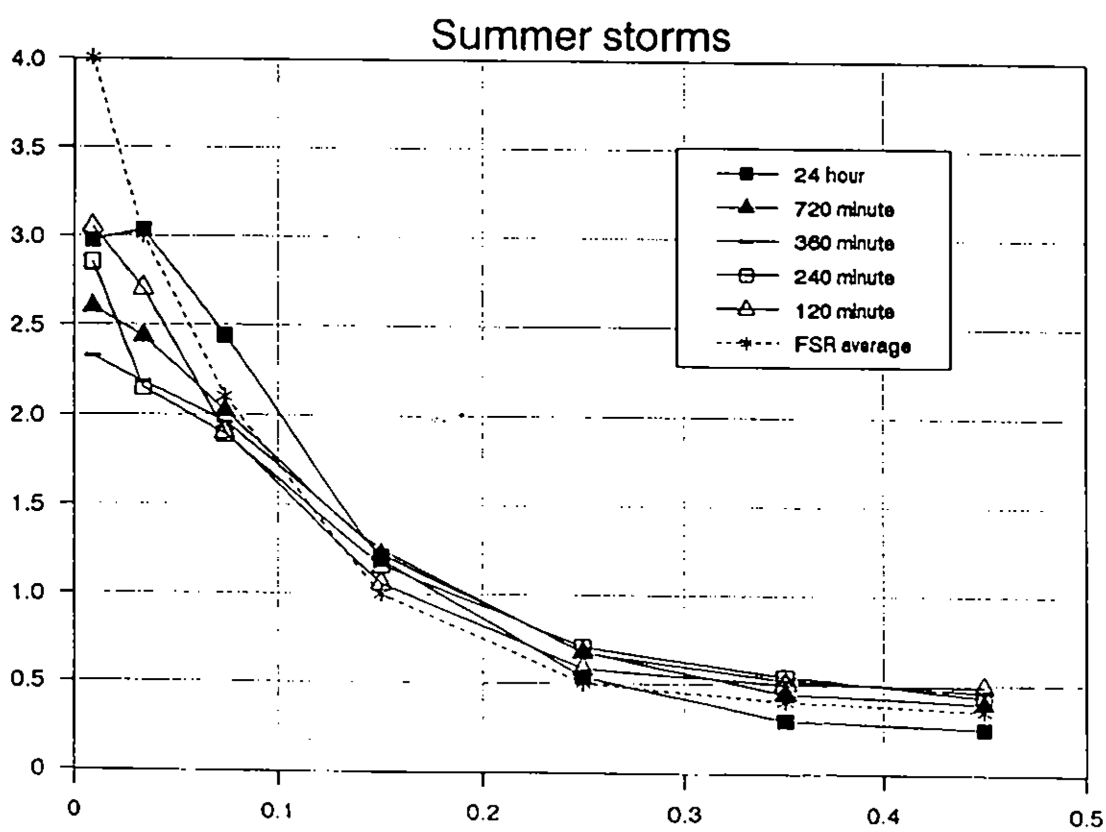


Figure 3.3b

Average long & short storms @ gauges and combined

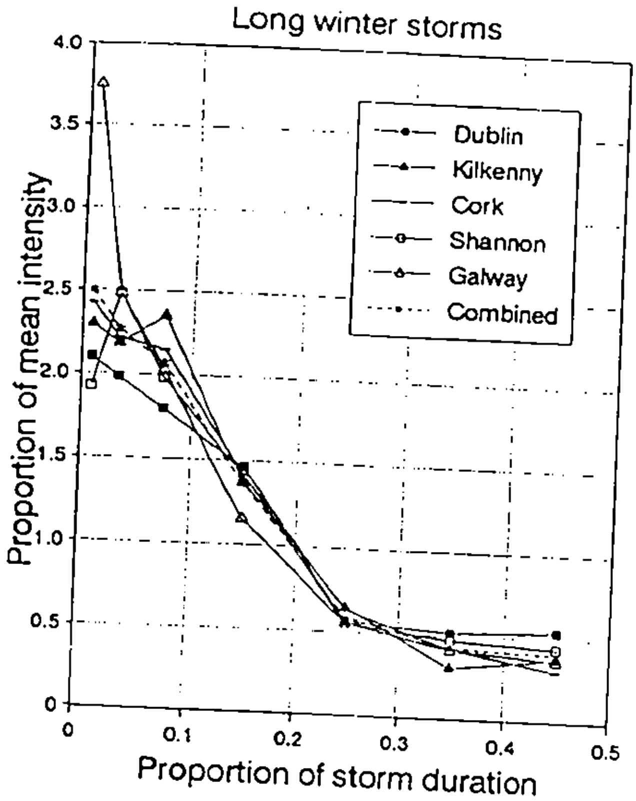


Figure 3.4a

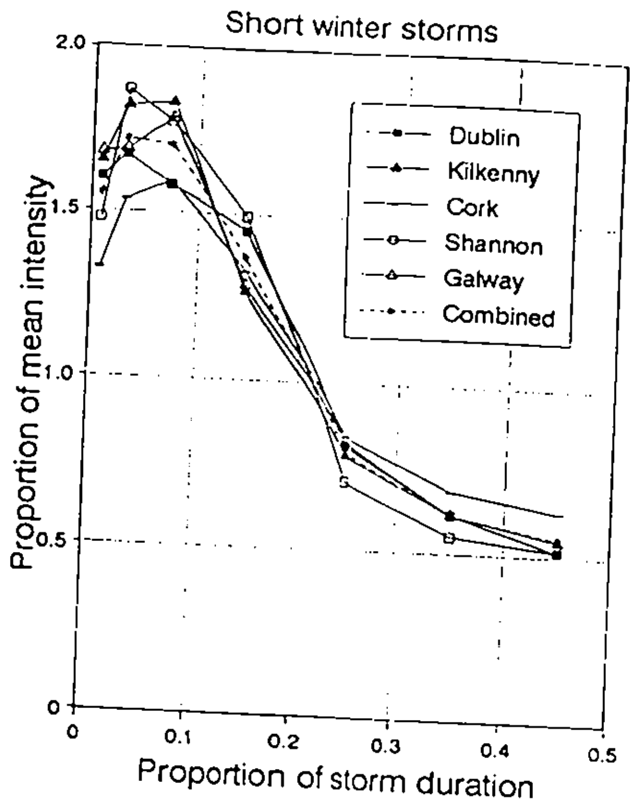


Figure 3.4b

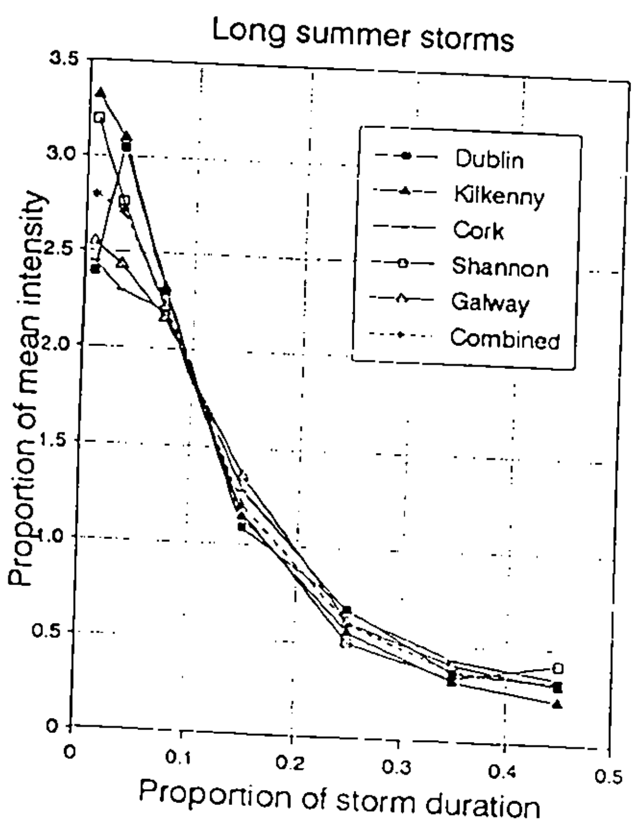


Figure 3.4c

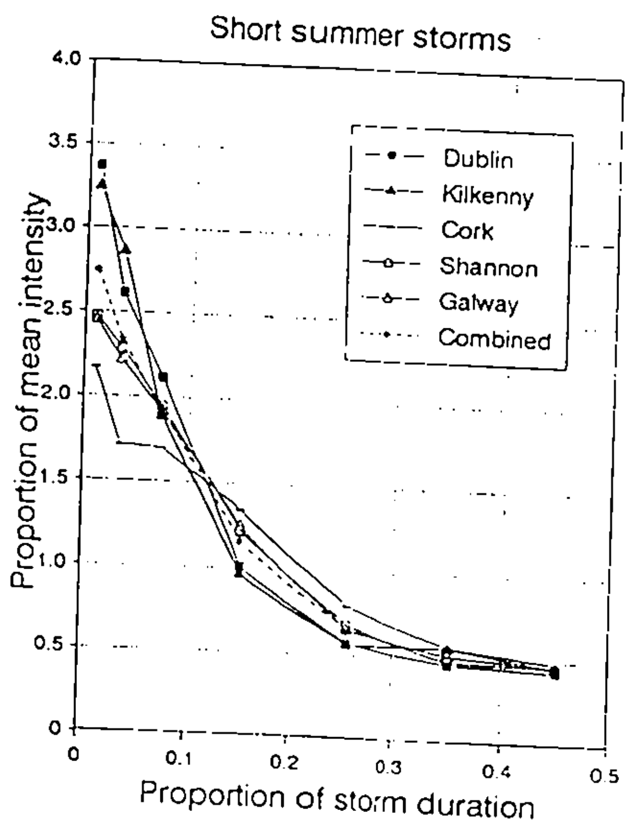


Figure 3.4d

Quartile analysis of short & long storms

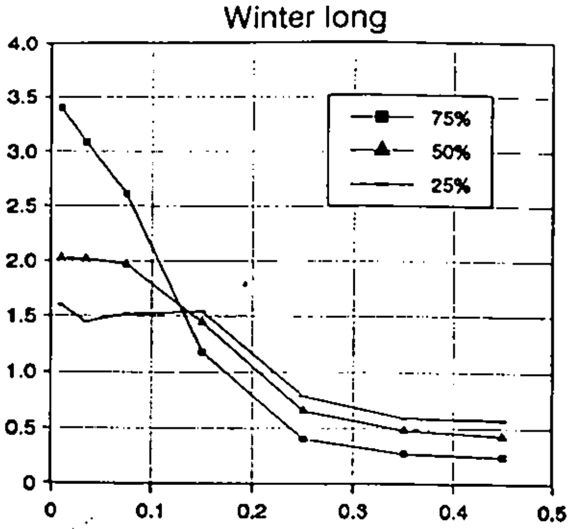


Figure 3.5a

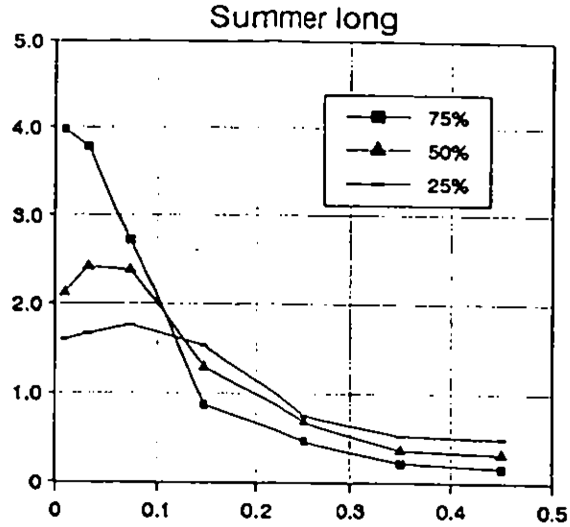


Figure 3.5b

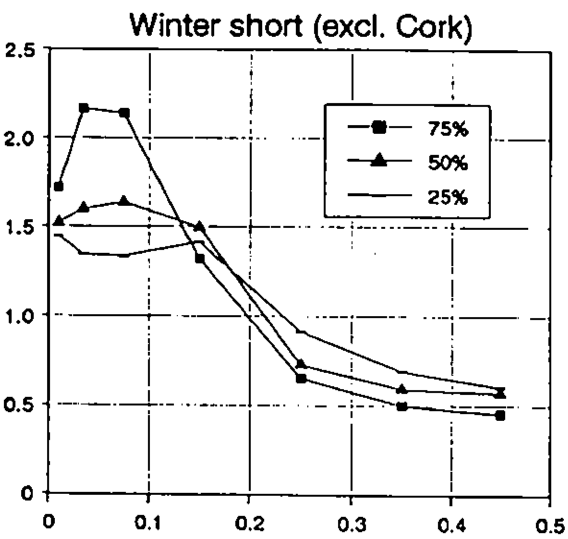


Figure 3.5c

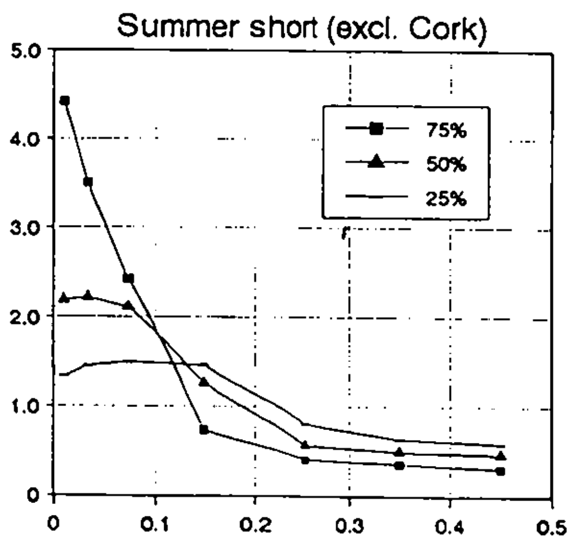


Figure 3.5d

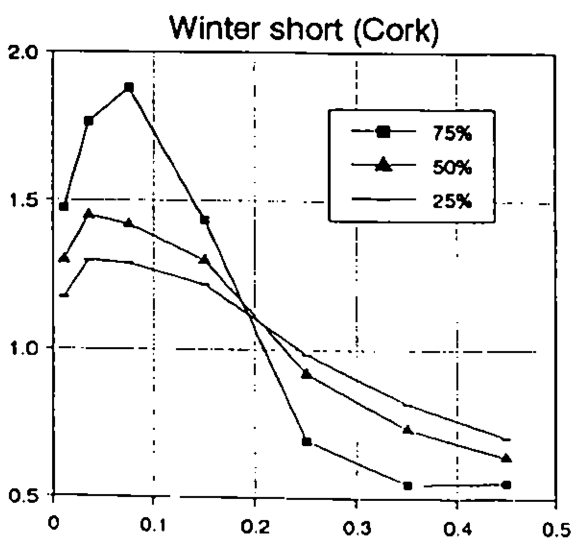


Figure 3.5e

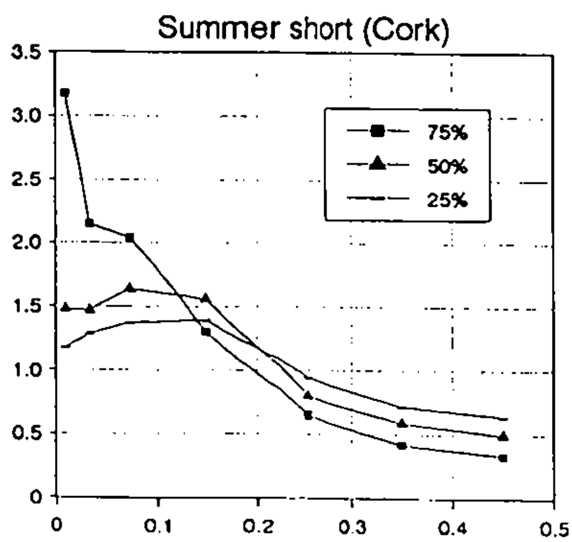


Figure 3.5f

As discussed earlier in Section 3.2, the inverted peaks arise from the fixed centre averaging. The final group analysis of Table 3.8 has thus been compared with a moving centre averaging. It might appear that the moving centre approach compounds 'worst cases' - like defining profile shape from a depth-duration-frequency curve. It might give a peakier than typical profile. However the moving centre approach does still only use storms critical at the full duration, rather than combine the worst of short and long duration storms. The truth probably lies between the two approaches. A form of moving centre approach was adopted by Pilgrim et al (1969), who also applied the depth-duration data obtained in a moving centre sense (rather than the nested FSR type profiles). Their approach has recently been adopted in determining long duration design storms for Scotland. Unfortunately the performance of these design storms in T-year flood terms has not been investigated.

Table 3.8 Profile sensitivity for quartiles of peakedness

Season	Winter				Summer			
Duration no events	Long(>9h) 12/gauge	Short(<9h) 20/gauge			Long(>9h) 24/gauge	Short(<9h) 36/gauge		
		All	noCork	Cork		All	noCork	Cork
75%	1.50	1.32	1.32	1.26	1.56	1.48	1.50	1.39
50%	1.33	1.22	1.24	1.12	1.40	1.32	1.33	1.24
25%	1.23	1.16	1.18	1.12	1.27	1.19	1.20	1.16

Table 3.9 gives the results of the moving centre analysis, retaining though the fixed centre nesting of the derived averages. The sensitivities are surprisingly similar to the fixed centre case, only the 75% winter is much changed (and that makes it more similar to the FSR value).

Table 3.9 Moving centre' profiles: sensitivity for quartiles of peakedness

Season	Winter				Summer			
Duration no events	Long(>9h) 12/gauge	Short(<9h) 20/gauge			Long(>9h) 24/gauge	Short(<9h) 36/gauge		
		All	noCork	Cork		All	noCork	Cork
75%	1.44	1.31	1.32	1.25	1.58	1.48	1.50	1.39
50%	1.33	1.21	1.22	1.15	1.42	1.31	1.33	1.24
25%	1.23	1.14	1.16	1.10	1.29	1.18	1.20	1.15

Perhaps the similarity of Tables 3.8 and 3.9 is not so surprising since the results are all based on the same basic data. However, comparing Figures 3.5 and 3.6 a-f shows that the moving centre profiles are considerably peakier. The maximum intensities of 75% Winter and 50% Summer long profiles are 4.3 & 4.2, compared with 3.4 & 2.4 for the fixed centre profiles (and 2.5 & 3.75 for the FSR); and the sensitivities would be greater for storm durations longer than 'time of concentration'. For these reasons, a weighted average of the two sets of profiles has been derived, just sufficient to remove the inverted peaks in the fixed centre profiles. The profiles are given in Appendix 2 and shown in Figures 3.7 a-f. For long

Quartile analysis on "moving centre" storms

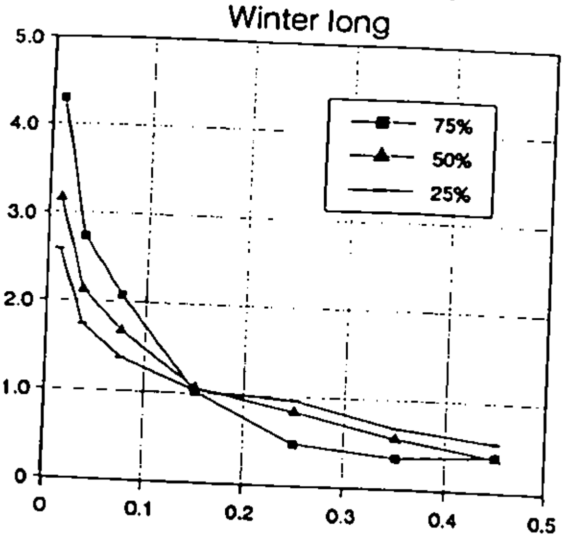


Figure 3.6a

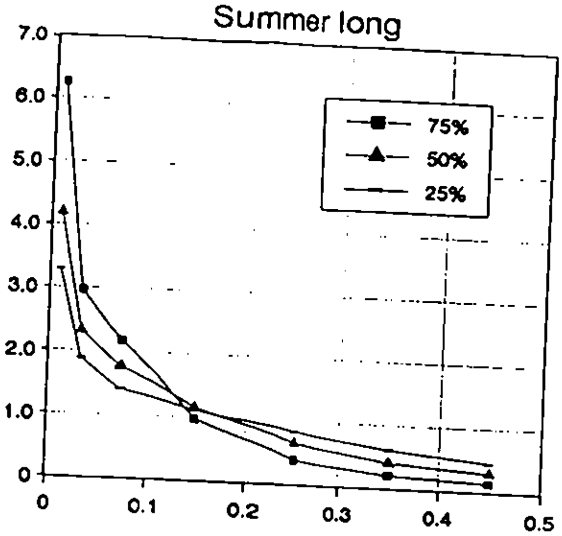


Figure 3.6b

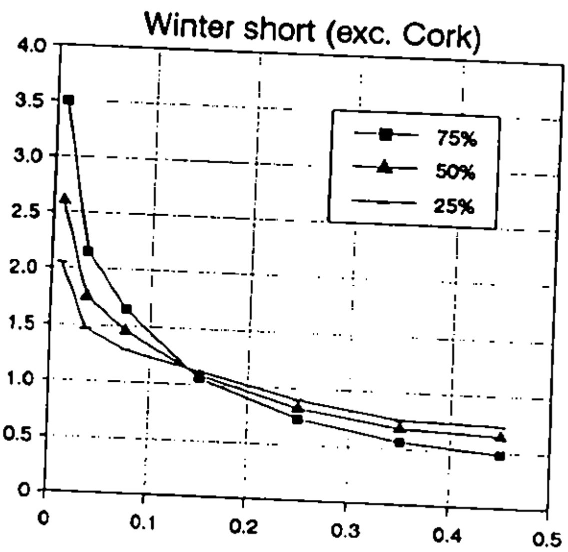


Figure 3.6c

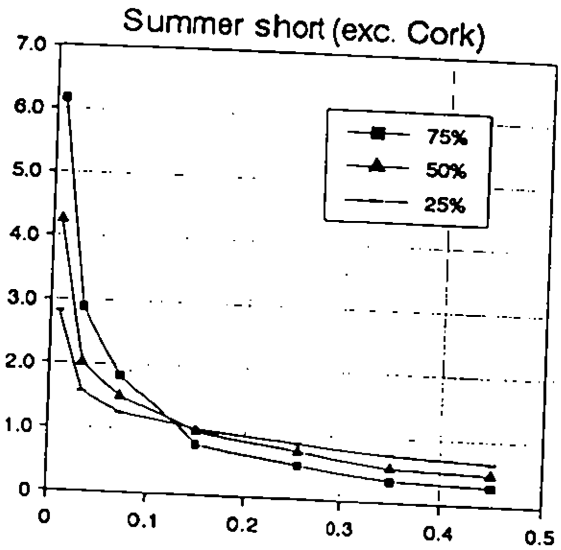


Figure 3.6d

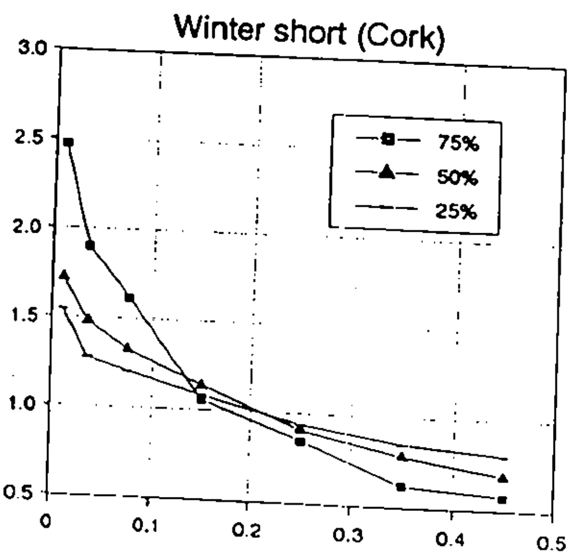


Figure 3.6e

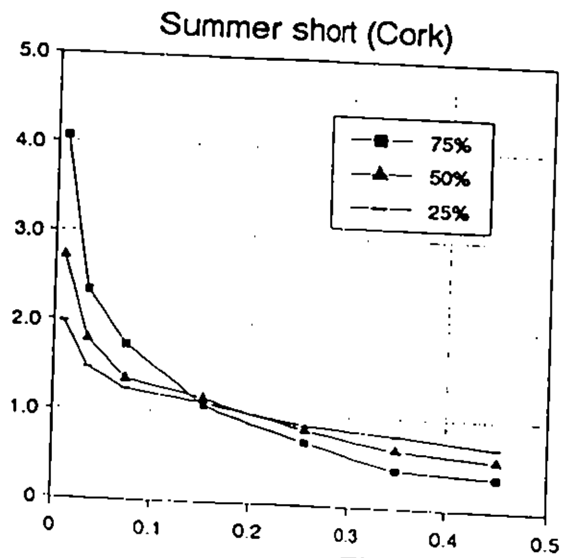


Figure 3.6f

Weighted quartile analysis (X% Fig 3.5 + (100-X)% Fig 3.6)

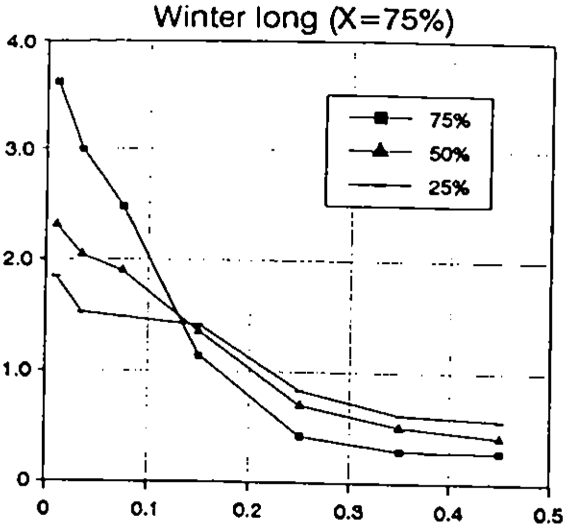


Figure 3.7a

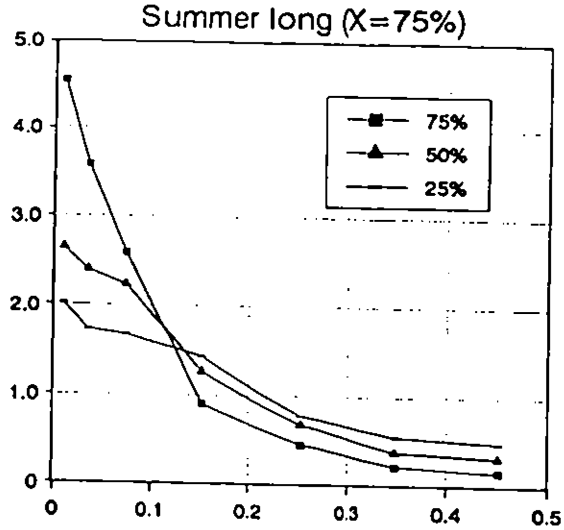


Figure 3.7b

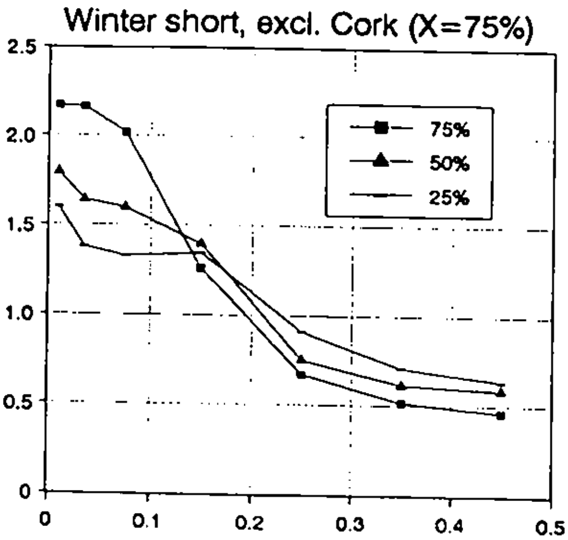


Figure 3.7c

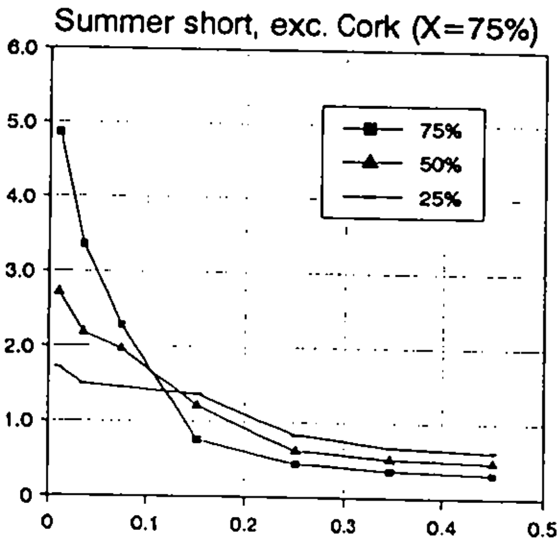


Figure 3.7d

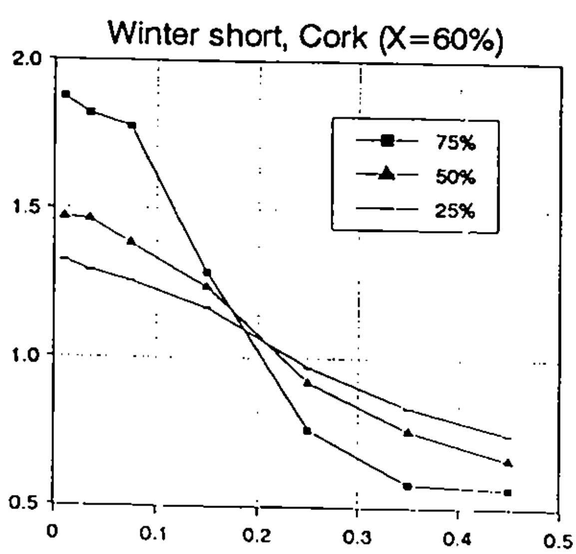


Figure 3.7e

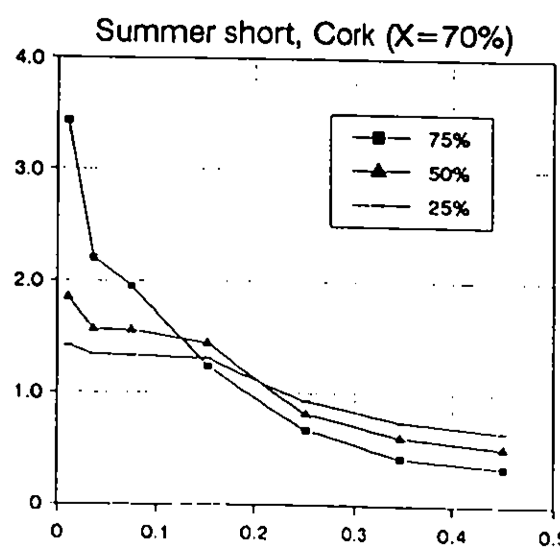


Figure 3.7f

duration storms and short duration storms (excluding Cork) the 'fixed centre':'moving centre' weights were 0.75:0.25. For short duration storms at Cork, the weights were 0.6:0.4 for winter and 0.7:0.3 for summer. Moving centre averaged profiles have also been derived for the 24-hour profiles of Table 3.4 and a 0.75:0.25 weighted average found.

3.4 PROFILE CONCLUSIONS

From the above analysis, there are two possible profile sets for final recommendation (assuming the basic design will use the 50% summer storm, or occasionally the 75% winter storm): (1) the weighted average 24-hour profiles based on Table 3.4 (mirroring the FSR choice); or (2) one of three storms for (a) over nine hours, (b) under nine hours (except South West Ireland), and (c) under nine hours (South West Ireland). The corresponding proportional depths against centralised proportional depth have been extracted from Appendix 2 and are presented both in Table 3.10 below and as Figures 3.8 a-b. The first option (Column 2: 24-hour storms) should probably be adopted as the Irish design profiles as it represents the closer equivalent to the FSR profile analysis. However the considerably flatter profiles obtained for shorter duration storms (columns 3b and 3c) give much concern; the sensitivity of the 50% summer profiles in column 3b is 11% less than that of column 2. It should also be remembered that the quoted sensitivity probably underestimates the true effect of profile shape on peak discharge by 50%, suggesting the profiles derived from shorter duration storms (normally relevant to sewer design) could give 16% lower peaks than the profiles derived from 24-hour storms. Note also (from columns 2 and 3a) that including 12 hour storms (and reducing the number of 24 hour storms) has also flattened long storms in summer. These concerns suggest at least a simplified 'simulation+sensitivity' analysis should be undertaken, perhaps using the unit hydrograph approach started here to avoid excessive runs of the full WALLRUS/SPIDA/HYDROWORKS model.

Table 3.10 *Profile sets* (%depth in central %duration)

Dur-ation	1. FSR storms		2. 24-hour storms		3a. Long storms		3b.Short storms (not SW)		3c. Short storms (SW)	
%	50% Summer	75% Winter	50% Summer	75% Winter	50% Summer	75% Winter	50% Summer	75% Winter	50% Summer	75% Winter
4	15	10	12.3	14.9	10.6	14.5	10.9	8.7	7.4	7.5
10	33	24	29.6	32.9	25.0	32.5	24.0	21.7	16.8	18.4
20	54	45	54.8	58.8	47.3	57.3	43.6	41.8	32.4	36.2
40	74	72	79.0	80.0	72.5	80.2	67.8	67.0	80.3	80.6
60	85	85	90.7	86.8	86.2	88.6	80.2	80.5	77.5	77.1
80	93	94	96.1	93.6	93.7	94.4	90.5	90.8	89.7	88.7
100	100	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sens	1.44	1.39	1.49	1.48	1.40	1.49	1.33	1.32	1.24	1.26

The profile data given in Appendix 2 and Table 3.10 above may not be the form in which it is used in the Wallingford Procedure. Wallingford Software can presumably handle any reformatting and additional interpolation required.

Design storm profiles for Eire (24 hour recommended)

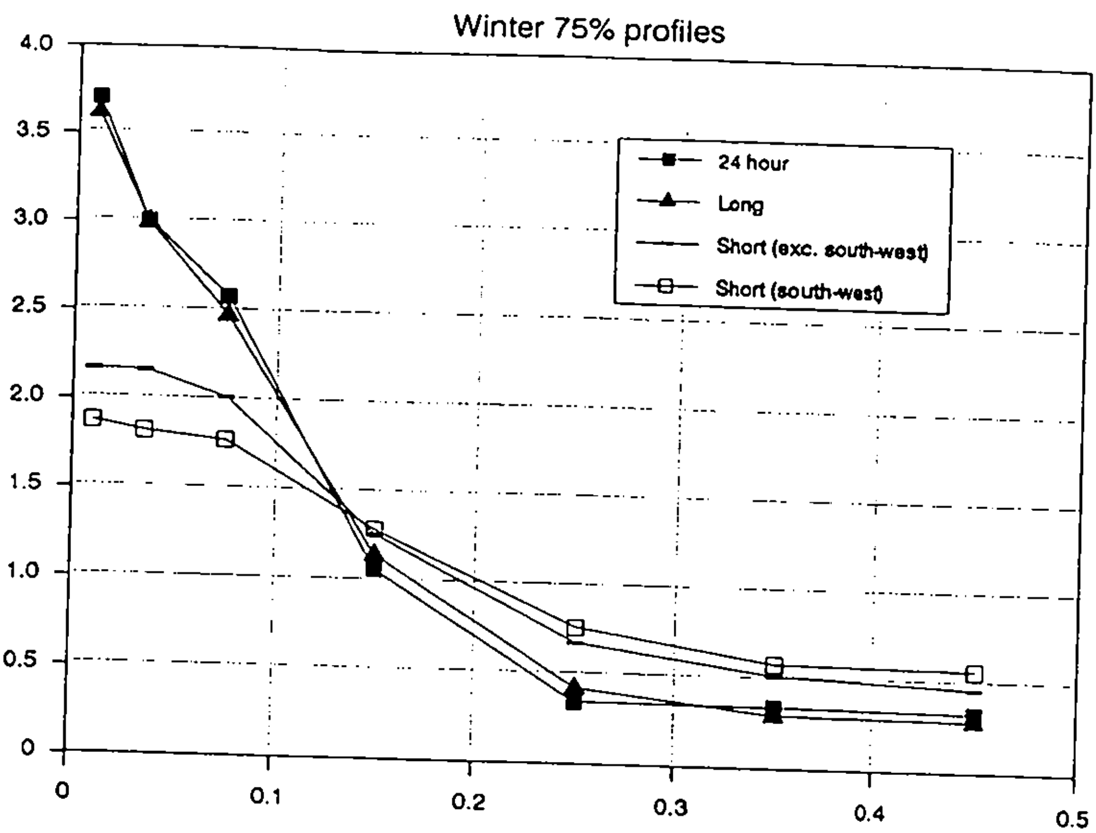


Figure 3.8a

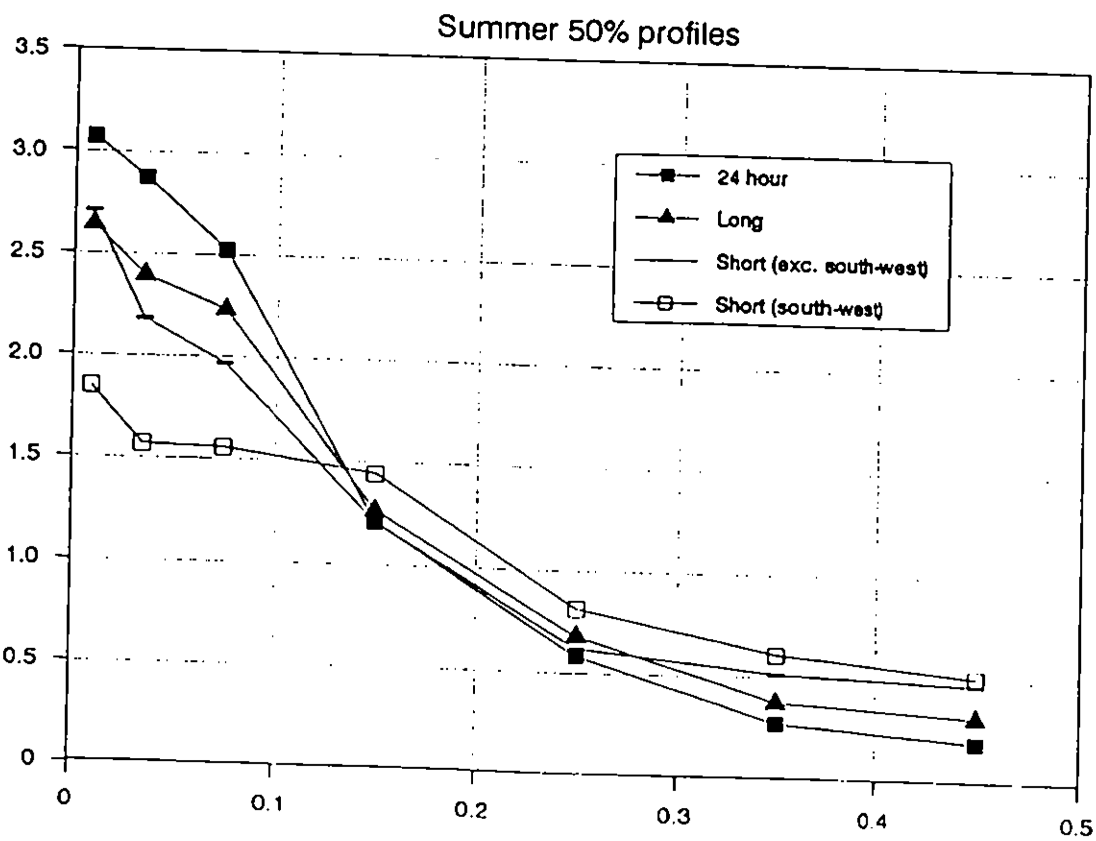


Figure 3.8b

4 Urban Catchment Wetness Index

As described in Section 1, the standard UK percentage runoff model in the Wallingford Procedure involves soil type, imperviousness, but more specifically the Urban Catchment Wetness Index (UCWI). This latter is a combination of Soil Moisture Deficit (SMD) and an exponential weighted average of antecedent precipitation (API):

UCWI = 125 - SMD + 8.API5

where SMD and API5 (at daily intervals and in mm) are derived respectively from (i) the Penman-Grindley soil moisture model (see below) as run by the UK Met.Office, and (ii) the previous five days rainfall (P1 to P5) as:

API5 = .707*P1 + .354*P2 + .177*P3 + .088*P4 + .044*P5

These values may be updated to some time t hours into the day as:

SMD' = MAX(0,SMD-P)

API5' = API5*(.5)**(t/24) + P*(.5)**(t/48)

where P is the rain(mm) falling in those t hours.

To model specific events, UCWI values corresponding to the start time of the event must be derived, while for design use the UK 'simulation+sensitivity' analysis (Kidd and Packman, 1980) found that the median summer 'end of month' value was appropriate. This end of month value could be estimated from Average Annual Rainfall.

The Penman-Grindley (PG) soil moisture model is not used in Ireland, though monthly Penman evaporation estimates are made at climatological stations, and an alternative Makkink-Ashling-Keane (MAK) soil moisture model has been applied over the last three years. The aim of the current study was to apply the PG soil moisture model to evaporation and rainfall data at the five climatological stations previously selected (see Figure 3.1). From this, mean summer 'end of month' SMD and UCWI would be derived and if possible related to Average Annual Rainfall. A comparison would also be made between the PG and MAK deficits to attempt a simple method of estimating the PG deficits.

The PG model (Grindley,1969) was developed as a quick (manual) method of deriving an estimated soil moisture deficit (ESMD) for use in runoff estimation. Its use in the UK has now been largely superseded by the more detailed computer based MORECS method, but this was not available at the time for the catchments used in developing the Wallingford Procedure. For this reason ESMD was and is still used in the Wallingford Procedure. However, in 1994 the UK Met.Office stopped producing ESMD, and the Author has been involved in a study to relate ESMD to MORECS for continuity purposes. The alternative of simply including the PG model code within the Wallingford Procedure is though quite attractive, and would avoid the need to relate ESMD to MORECS or MAK. Input to the PG model is daily rainfall and monthly evaporation (or monthly sunshine and average monthly evaporation); the author's 'new runoff model' for the Wallingford Procedure includes its own soil wetness model (in place of ESMD and MORECS) and also requires daily rainfall and average monthly evaporation.

4.1 PENMAN-GRINDLEY AND MAKKINK-ASHLING-KEANE SOIL MOISTURE MODELS

The Penman-Grindley (PG) model, described by Grindley(1969) is a daily water balance model of rainfall, evaporation, soil moisture, and runoff. Daily potential evaporation is estimated from monthly using 'the slope of the annual march of the evaporation curve'. Originally monthly evaporation was taken as (i) the average monthly Penman evaporation during winter months, and (ii) an actual:average sunshine moderation of average monthly Penman evaporation during the summer months. Subsequently this seems to have been replaced by actual Penman evaporation in both cases. Evapotranspiration from the soil is allowed at the potential rate until a deficit builds up to exceed the 'root constant' of the vegetation. Thereafter a deficit table is used to relate actual deficit to potential deficit. Rainfall replenishes the deficit and returns evaporation to the potential rate until the deficit regains its previous maximum value (when it reverts to the deficit table). When rainfall returns the deficit to zero, any excess rain becomes runoff. The model assumes a distribution of root constant over the area comprising 50% at 75mm, 30% at 200mm, and 20% at infinity (the permanently wet/riparian area from which evaporation is always at the potential rate).

Using the monthly Penman evaporation estimates and daily rainfall data supplied by the Irish Met.Service, daily ESMD, API5 and UCWI values were derived. End of month values were extracted and median summer(May-October) and winter(November-April) values found. Comparisons of the derived ESMD values with the MAK model follow later in this section, while analysis of median UCWI is described in Section 4.2

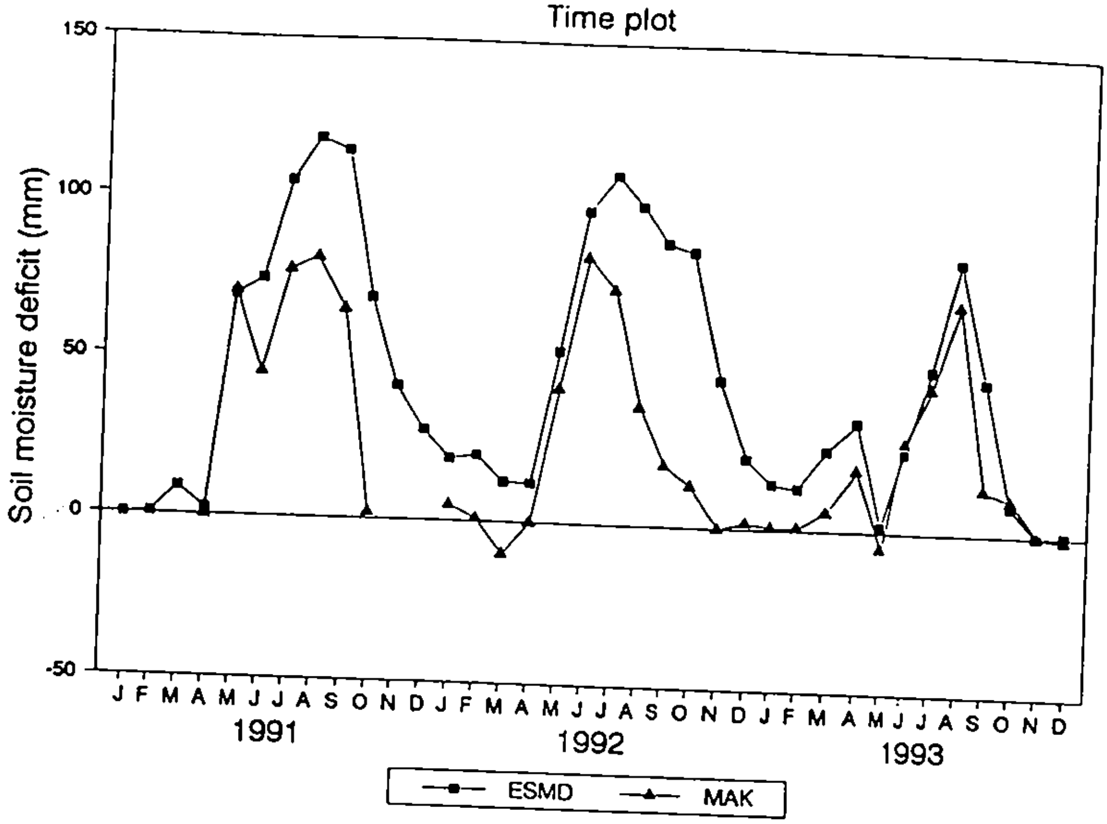
The Makkink-Ashling-Keane (MAK) model (Keane,1994) uses the Makkink(1957) evaporation model which includes net radiation and temperature effects, but not wind (see de Bruin,1987). This is coupled with the Aslyng(1965) scale allowing evaporation at the potential rate until soil moisture deficit builds to 30mm, whence the actual/potential evaporation ratio drops linearly to zero at a deficit of 120mm. Keane allows 10mm above field capacity from which the potential evaporation plus 3mm/day drainage can occur. All rainfall above this 10mm goes to runoff.

The model has been applied to 14 climate stations in Ireland starting in April 1991. Estimates of soil moisture deficit on the 10th, 20th and last day of each month have been obtained in manuscript up to December 1993.

Figures 4.1 to 4.4 show time and scatter plots of the MAK and ESMD values (note Galway data was not available for these comparisons). The data are quite similar for deficits up to about 70mm, when the MAK model begins to limit evaporation. As a result, the MAK model returns to zero SMD in the autumn much earlier than ESMD, and there is a 'hysteresis' in the scatter plots of MAK against ESMD. This effect is particularly noticeable for the drier eastern stations of Dublin and Kilkenny. Simple factors relating ESMD to MAK deficit values are presented for interest in Table 4.1, but their use is not recommended. A more detailed relationship between ESMD and MAK involving seasonal variation in lag-correlation might be sought, but this complexity would seem inappropriate considering the relatively arbitrariness in the calculation of both ESMD and MAK. The recommendation is therefore to include the ESMD model in the Wallingford Procedure, whether for use in the UK or elsewhere (remembering as previously mentioned that ESMD is no longer being derived by the UK Met.Office).

Inclusion of ESMD within the Wallingford Procedure means that daily rainfall and monthly Penman evaporation will be needed for the nearest available gauge site and from the start of the relevant calendar year. If Penman data is not readily available, experience in the UK suggests an average monthly distribution can be used with minimal degradation in ESMD estimate.

MAK and ESMD values for Dublin



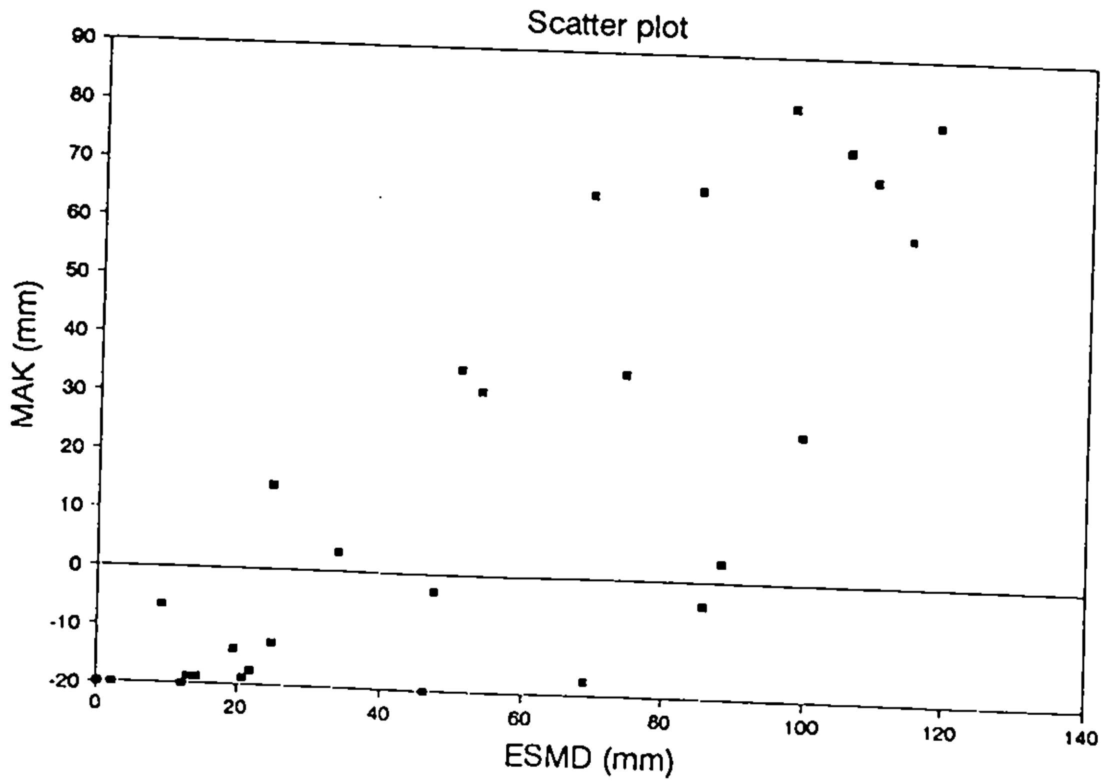
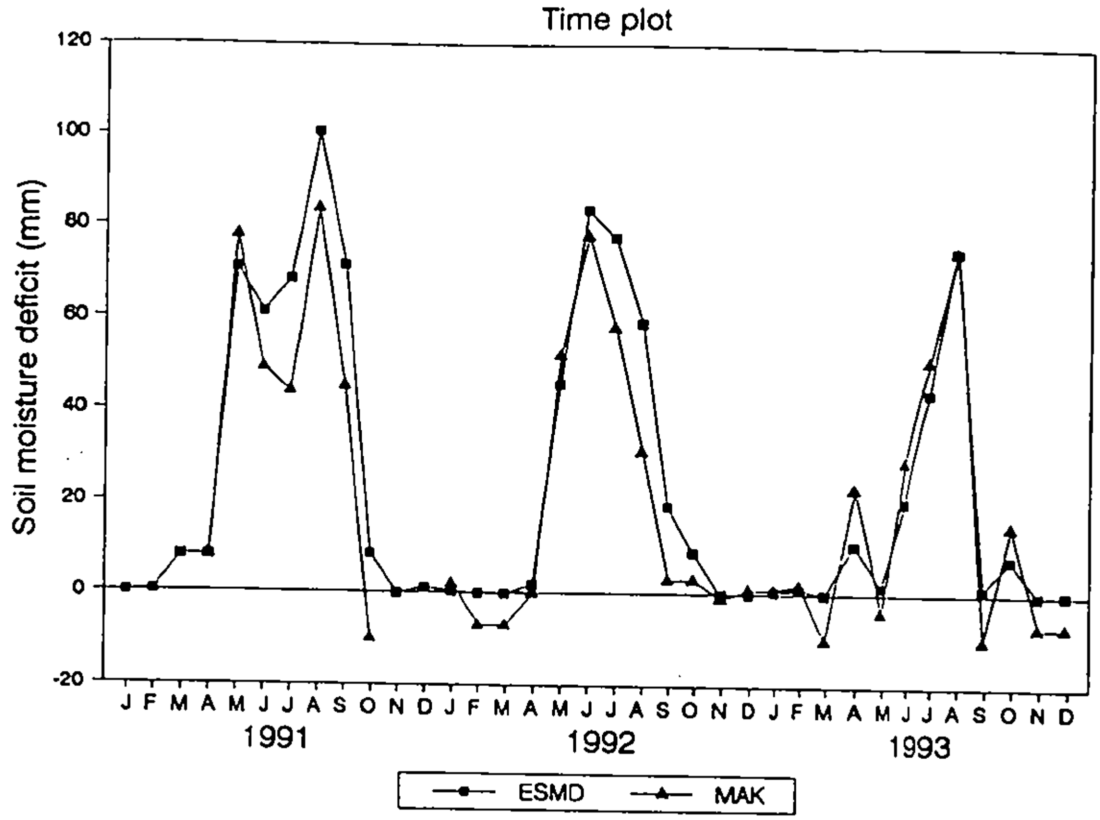


Figure 4.1

MAK and ESMD values for Kilkenny



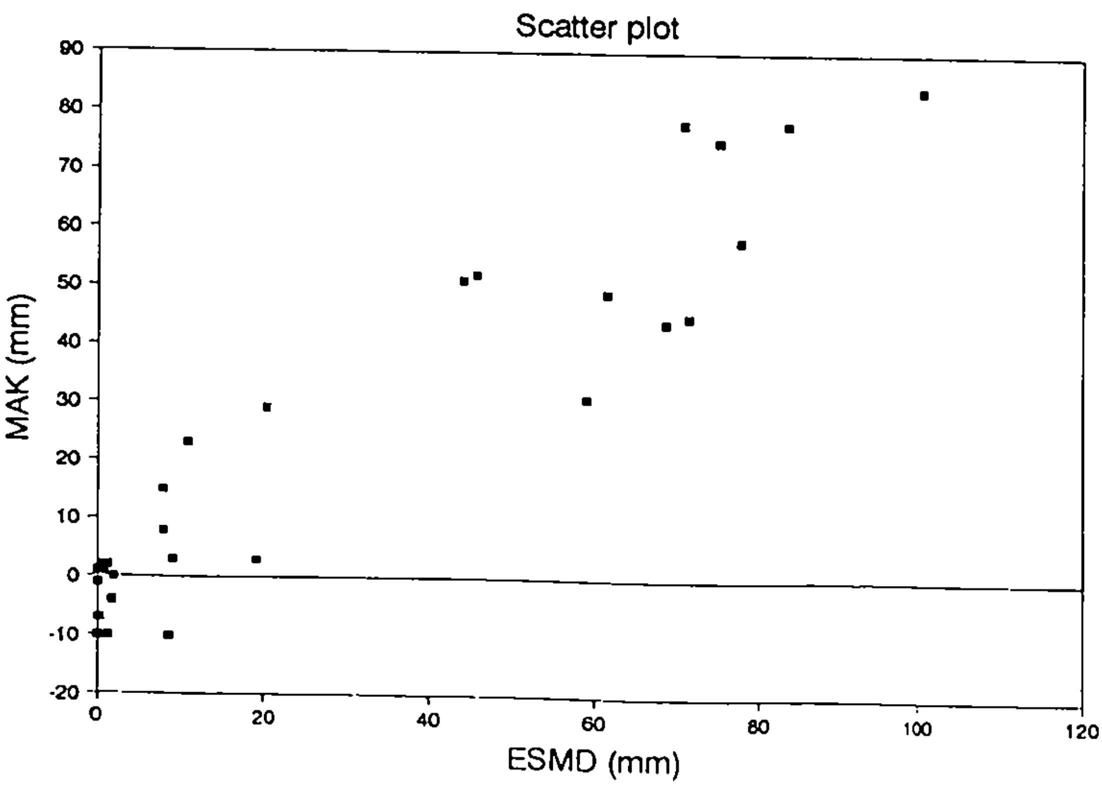
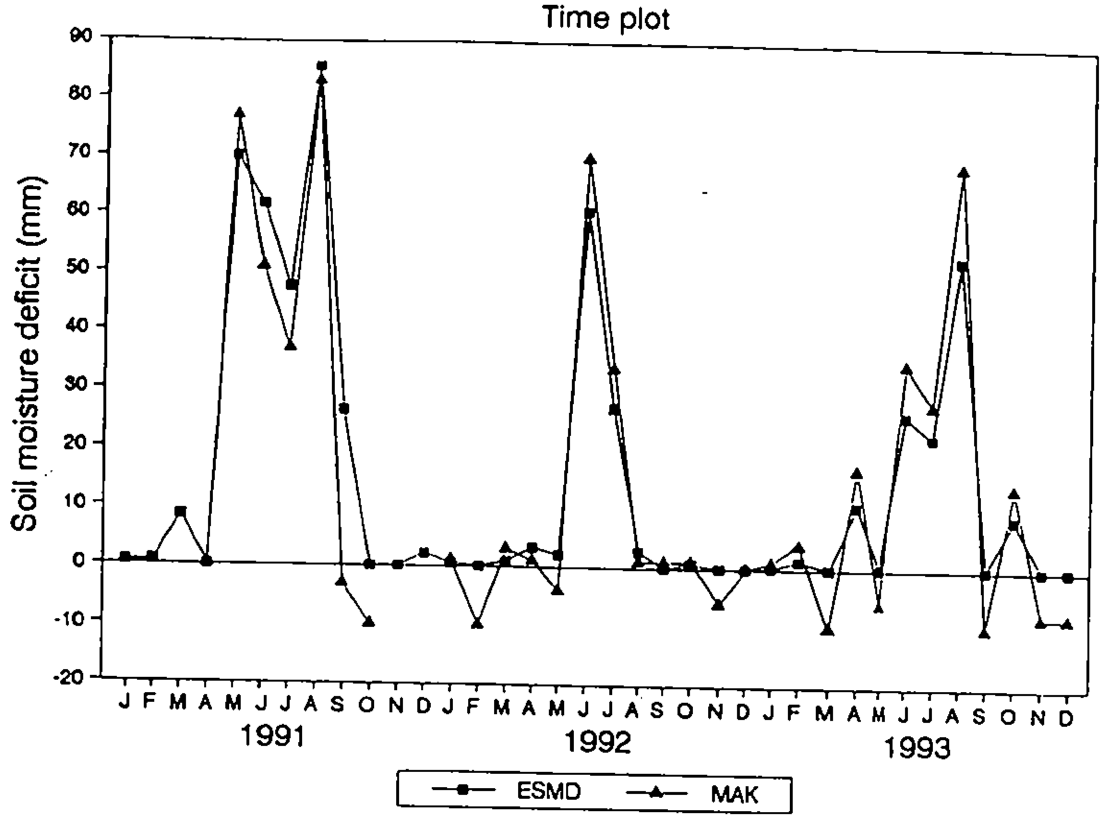


Figure 4.2

MAK and ESMD values for Cork



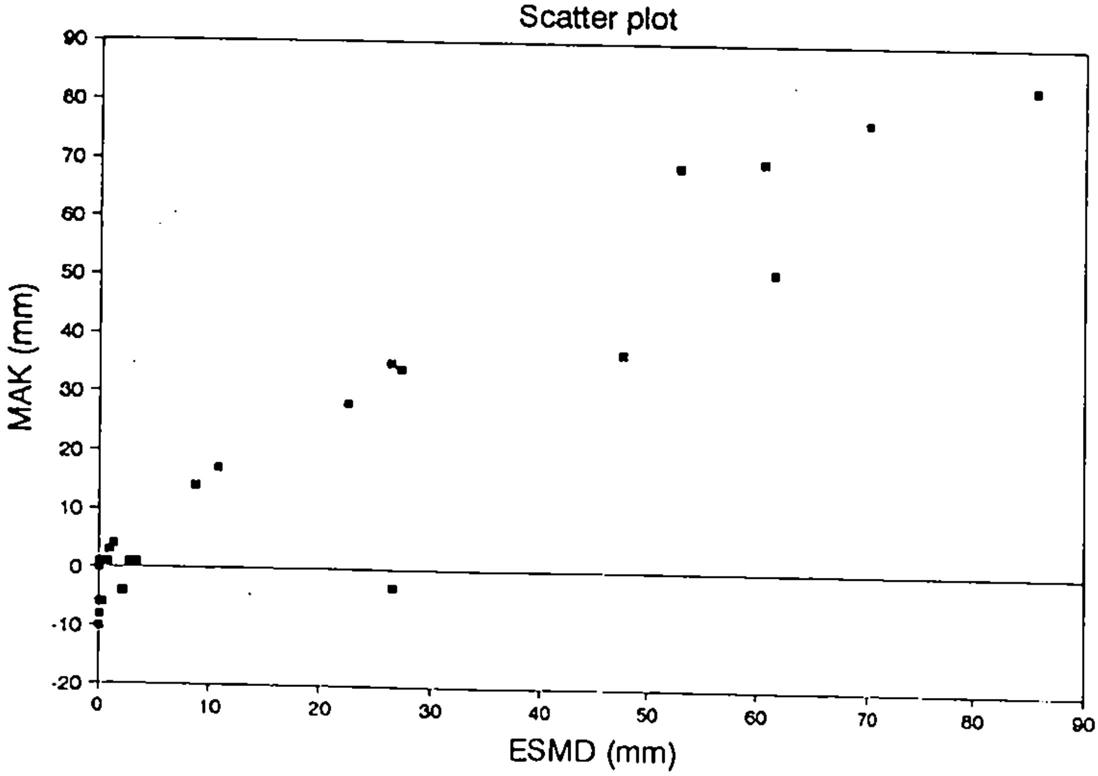
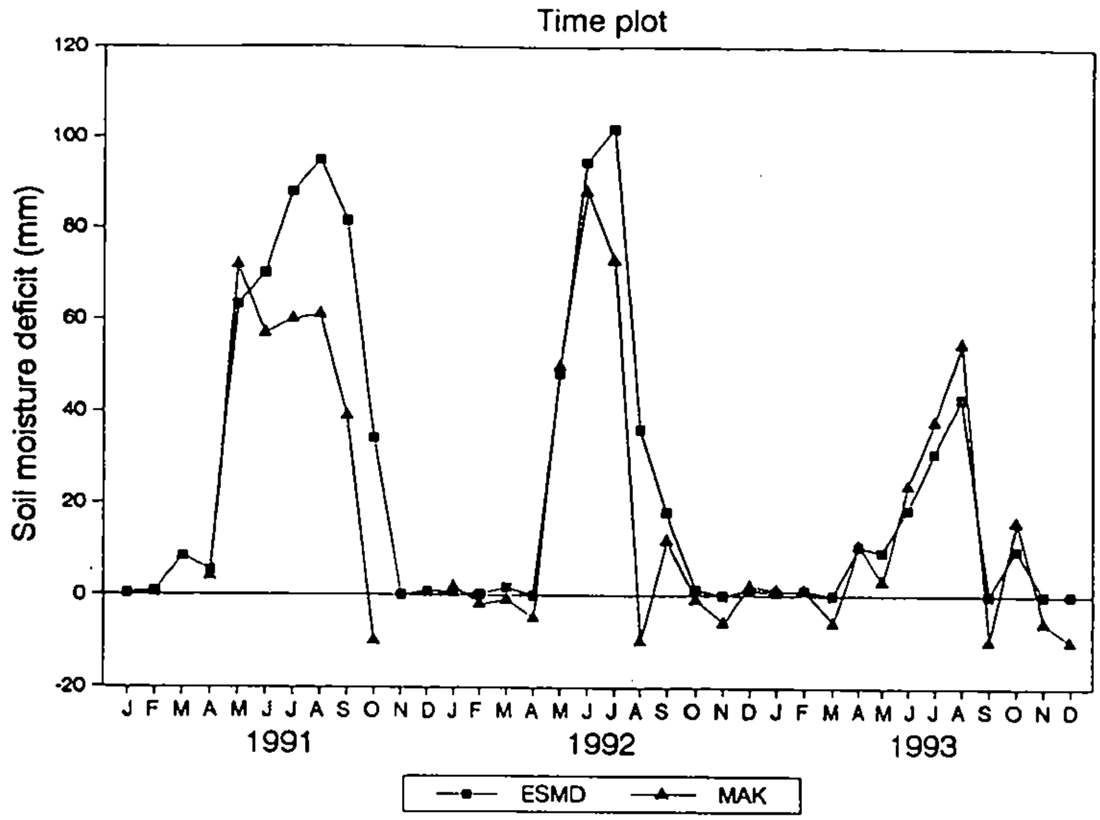


Figure 4.3

MAK and ESMD values for Shannon



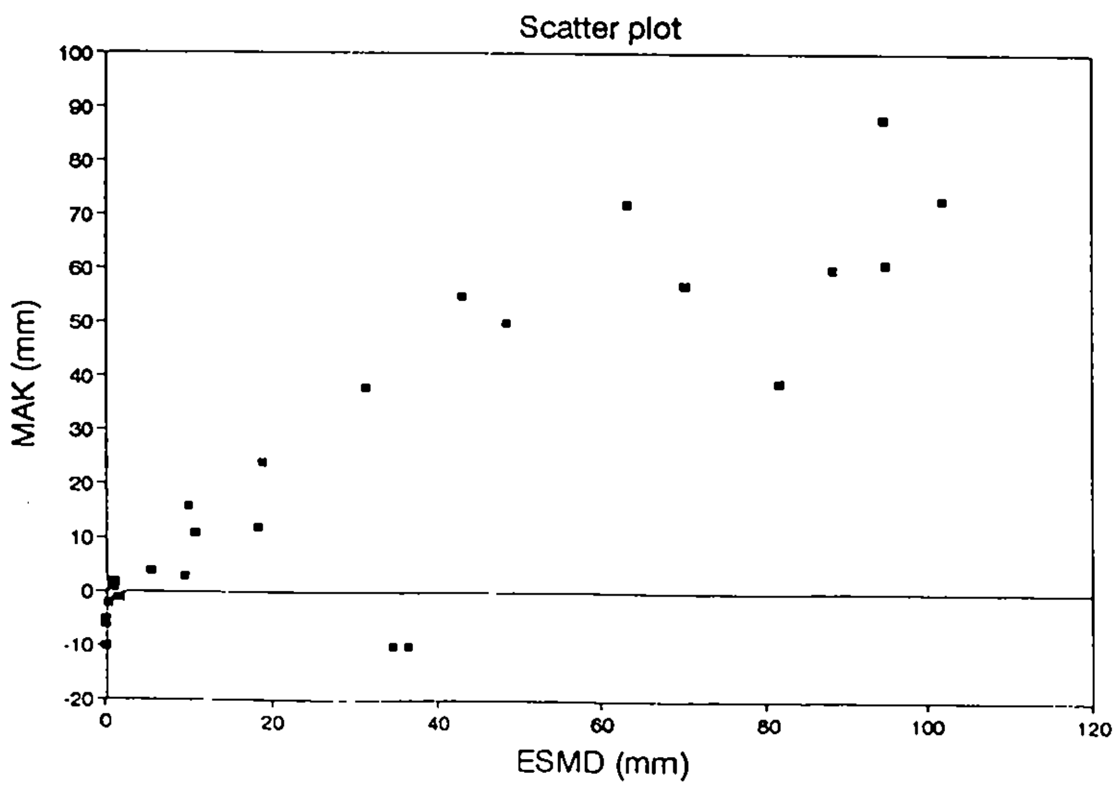


Figure 4.4

Table 4.1 Factors converting MAK to ESMD estimates

Dublin	Kilkenny	Cork	Shannon	Overall
1.76	1.18	0.99	1.35	1.40

4.2 MEDIAN UCWI VALUES FOR DESIGN USE

Median UCWI values for Ireland have been derived over the maximum period of available data at each station and over the longest common period, 1979-1988. Moreover, as median UCWI values for the UK were defined over the period 1961-80, for consistency, median UCWI has also been derived for that period here. Since Galway data was only available for 1979-88, median values for that common period at all gauges were used to define average adjustments to apply to the Galway data. The corresponding results are given in Table 4.2, together with the station Average Annual Rainfall(AAR) defined from the full data record available at each gauge. The median summer and winter UCWI values are plotted with the UK data against AAR in Figure 4.5. The data are close enough to recommend the same design UCWI relationship as used in the UK

Table 4.2 Median UCWI values

Station	Dublin	Kilkenny	Cork[1]	Shannon	Galway
Summer 1979-88	85	105	121	108	128
Winter 1979-88	126	133	147	135	138
Summer 1961-80	73	92	110	92	*115*
Winter 1961-80	131	136	140	141	*140*
Summer 1958-88	78	97	114	101	121
Winter 1958-88	131	137	140	142	*141*
Av.Ann.Rainfall	756	841	1222	936	1146

[1] Data starts 1963. Figures in Italics are estimated values.

Seasonal UCWI relationship with SAAR

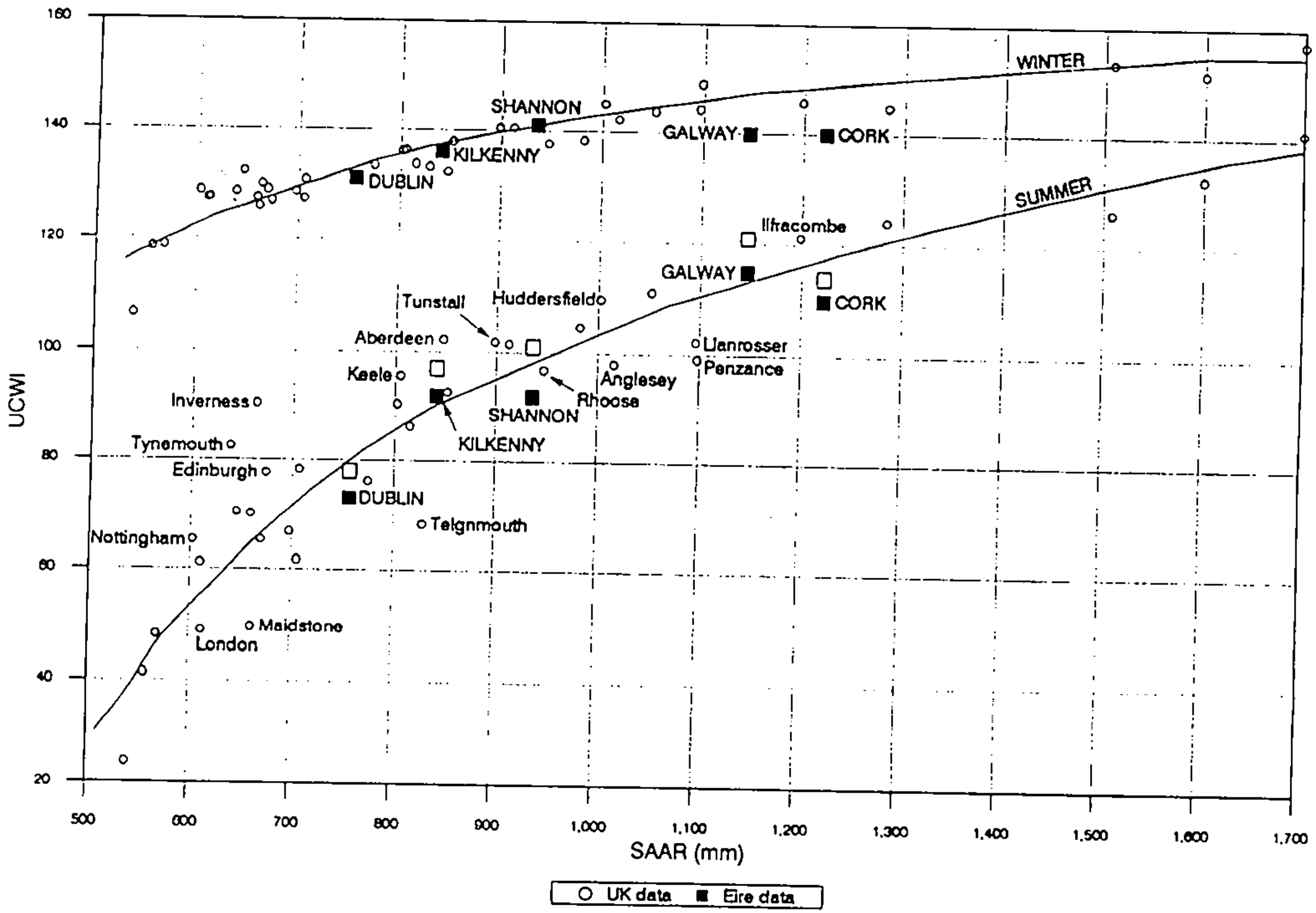


Figure 4.5

5 Conclusions

The recommendations made in this report may be summarised as:

* Logue's (1975) depth-duration-frequency model for Irish rainfall should be programmed into the Wallingford Procedure, either in his original tabular form, or as the supplied variation on the standard UK model (see Section 2 and Appendix 1).

* The storm profiles of Table 3.10 are recommended as design profiles for Ireland, where for consistency with the simulation+sensitivity analysis of the Wallingford procedure, the column 1 profiles should be used.

* Notwithstanding the above recommendation, there is enough uncertainty in the data to recommend that at least a simplified simulation + sensitivity analysis is followed using a simplified runoff model.

* The Penman-Grindley soil moisture model (see Section 4.1) should be included in the Wallingford Procedure.

* The UK design curve of UCWI:AAR can also be used in Ireland (see Section 4.2).

Acknowledgements

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Appendix 1 Modified Depth-duration model for Ireland

```
      dimension d(9),data(9,12),rf(9)
      data d    / .25,   .5,  1.,  2.,  4.,  6.., 12., 24.,  48./
c      Irish data from Logue(1975) Table 2
      data data /.232, .292, .36, .44, .55, .63, .76, .89, 1.06,
     -           .214, .273, .34, .42, .53, .61, .75, .89, 1.06,
     -           .196, .254, .32, .40, .51, .59, .74, .88, 1.06,
     -           .179, .234, .30, .38, .49, .58, .73, .88, 1.06,
     -           .162, .216, .28, .36, .47, .56, .71, .87, 1.06,
     -           .146, .197, .26, .34, .45, .54, .70, .86, 1.06,
     -           .130, .179, .24, .31, .43, .52, .69, .85, 1.06,
     -           .115, .161, .22, .29, .41, .50, .67, .85, 1.06,
     -           .100, .144, .20, .27, .39, .48, .65, .84, 1.06,
     -           .086, .127, .18, .25, .36, .46, .64, .83, 1.06,
     -           .073, .110, .16, .23, .34, .43, .62, .82, 1.06,
     -           .060, .094, .14, .20, .31, .41, .59, .80, 1.06/
c
      b = 15
      write(6,"('   r     d=',f5.2,8f8.1)") d
c
c......analyse model for r=.18, .24, .30 and .36
c
   15 do 50 i=18,36,6
        r = .01*float(i)
        do 20 j=1,12
          k = j
          if ( abs(r-data(3,k)).lt..001 ) go to 30
   20   continue
          write(6,*) 'r=',r,' not found'
          go to 50
c........fit model to r at 1h and 1.06 at 48h
   30   c = alog(1.06/(48.*r))/alog((1.+b)/(1.+48.*b))
        r4h = (4.*1.06/48.)*((1.+48*b)/(1.+4.*b))**c
        b2 = .2*(2.**(r/.06 -3.))
        c2 = alog(4*1.06/(48.*r4h))/alog((1.+4.*b2)/(1.+48.*b2))
c........test model at d(j) durations
        do 40 j=1,9
          if ( d(j).gt.4. ) go to 35
            rf(j) = (d(j)*1.06/48.)*((1.+48*b)/(1.+d(j)*b))**c
            go to 40
   35     rf(j) = (d(j)*1.06/48.)*((1.+48*b2)/(1.+d(j)*b2))**c2
   40   continue
        write(6,'(f4.2,(t6,a3,9f8.3))') r,'est',(rf(j),j=1,9),
     -                                       'obs',(data(j,k),j=1,9)
   50 continue
      stop
      end
```

Appendix 2 FSR and derived Irish profiles (depth ratio, sensitivity, label, intensity ratio)

-----Central	Duration(%)	-----				Sens	Label	----Duration(%)	from centre	of storm-----				
4	10	20	40	60	80		(Key @ end)	1	3.5	7.5	15	25	35	45
							FSR profiles							
.10	.24	.45	.72	.85	.94	1.39	fsrw75	2.500	2.333	2.100	1.350	0.650	0.450	0.300
.08	.19	.37	.66	.82	.92	1.31	fsrw50	2.000	1.833	1.800	1.450	0.800	0.500	0.400
.07	.17	.33	.61	.79	.90	1.25	fsrw25	1.750	1.667	1.600	1.400	0.900	0.550	0.500
.08	.20	.38	.66	.82	.92	1.31	fsrwav	2.000	2.000	1.800	1.400	0.800	0.500	0.400
.24	.48	.69	.84	.91	.96	1.59	fsrs75	6.000	4.000	2.100	0.750	0.350	0.250	0.200
.15	.33	.54	.74	.85	.93	1.44	fsrs50	3.750	3.000	2.100	1.000	0.550	0.400	0.350
.09	.22	.41	.66	.80	.91	1.31	fsrs25	2.250	2.167	1.900	1.250	0.700	0.550	0.450
.16	.34	.55	.75	.85	.93	1.45	fsrsav	4.000	3.000	2.100	1.000	0.500	0.400	0.350
							24h Irish profiles, Label=SeasonDuration/step(number)site							
.093	.225	.432	.702	.807	.911	1.34	w24h/1h(12)d	2.325	2.200	2.070	1.350	0.525	0.520	0.445
.094	.245	.499	.765	.862	.925	1.42	w24h/1h(12)k	2.350	2.517	2.540	1.330	0.485	0.315	0.375
.107	.247	.480	.745	.868	.946	1.42	w24h/1h(12)c	2.675	2.333	2.330	1.325	0.615	0.390	0.270
.081	.200	.391	.678	.780	.899	1.30	w24h/1h(12)s	2.025	1.983	1.910	1.435	0.510	0.595	0.505
.144	.298	.514	.760	.866	.941	1.44	w24h/1h(12)g	3.600	2.567	2.160	1.230	0.530	0.375	0.295
.104	.243	.463	.730	.837	.924	1.38	w24h/1h(12)	2.600	2.317	2.200	1.335	0.535	0.435	0.380
.156	.358	.594	.815	.908	.955	1.52	s24h/1h(20)d	3.900	3.367	2.360	1.105	0.465	0.235	0.225
.138	.329	.569	.795	.903	.964	1.50	s24h/1h(20)k	3.450	3.183	2.400	1.130	0.540	0.305	0.180
.136	.298	.550	.812	.903	.953	1.49	s24h/1h(20)c	3.400	2.700	2.520	1.310	0.455	0.250	0.235
.120	.293	.535	.750	.863	.936	1.44	s24h/1h(20)s	3.000	2.883	2.420	1.075	0.565	0.365	0.320
.105	.288	.538	.808	.916	.967	1.49	s24h/1h(20)g	2.625	3.050	2.500	1.350	0.540	0.255	0.165
.131	.313	.557	.796	.899	.955	1.49	s24/1h(20)	3.275	3.033	2.440	1.195	0.515	0.280	0.225
							24h (quartiles)							
.139	.324	.600	.816	.876	.942	1.50	w24h75	3.475	3.083	2.760	1.080	0.300	0.330	0.290
.090	.225	.446	.718	.826	.919	1.36	w24h50	2.250	2.250	2.210	1.360	0.540	0.465	0.405
.069	.161	.327	.643	.797	.907	1.27	w24h25	1.725	1.533	1.660	1.580	0.770	0.550	0.465
.188	.438	.710	.874	.949	.980	1.62	s24h75	4.700	4.167	2.720	0.820	0.375	0.155	0.100
.101	.279	.550	.791	.911	.964	1.48	s24h50	2.525	2.967	2.710	1.205	0.600	0.265	0.180
.074	.188	.404	.717	.849	.930	1.36	s24h25	1.850	1.900	2.160	1.565	0.660	0.405	0.350
							All duration Irish profiles							
.104	.243	.463	.730	.837	.924	1.38	w24h/1h(12)	2.600	2.317	2.200	1.335	0.535	0.435	0.380
.082	.201	.384	.679	.829	.924	1.33	w12h/1h(12)	2.050	1.983	1.830	1.475	0.750	0.475	0.380
.098	.224	.432	.702	.820	.921	1.35	w24h/1h(8)	2.450	2.100	2.080	1.350	0.590	0.505	0.395
.079	.194	.374	.669	.822	.919	1.31	w12h/1h(8)	1.975	1.917	1.800	1.475	0.765	0.485	0.405
.090	.223	.414	.673	.813	.906	1.32	w720/30(4)	2.250	2.217	1.910	1.295	0.700	0.465	0.470
.062	.169	.339	.611	.769	.892	1.24	w360/15(8)	1.550	1.783	1.700	1.360	0.790	0.615	0.540
.061	.155	.318	.591	.766	.889	1.22	w240/10(8)	1.525	1.567	1.630	1.365	0.875	0.615	0.555
.057	.157	.323	.606	.767	.890	1.23	w120/5(4)	1.425	1.667	1.660	1.415	0.805	0.615	0.550
.071	.177	.345	.608	.769	.887	1.24	w60/5(2)	1.775	1.767	1.680	1.315	0.805	0.590	0.565
.131	.313	.557	.796	.899	.955	1.49	s24h/1h(20)	3.275	3.033	2.440	1.195	0.515	0.280	0.225
.094	.228	.429	.703	.836	.928	1.36	s12h/1h(20)	2.350	2.233	2.010	1.370	0.665	0.460	0.360
.112	.268	.475	.731	.856	.938	1.40	s720/60(20)	2.800	2.600	2.070	1.280	0.625	0.410	0.310
.124	.290	.505	.727	.855	.933	1.41	s720/30(20)	3.100	2.767	2.150	1.110	0.640	0.390	0.335
.120	.254	.448	.693	.819	.915	1.36	s360/15(20)	3.000	2.233	1.940	1.225	0.630	0.480	0.425
.122	.255	.449	.695	.821	.915	1.36	s360/15(20)*	3.050	2.217	1.940	1.230	0.630	0.470	0.425
.109	.238	.420	.660	.803	.911	1.32	s240/10(20)	2.725	2.150	1.820	1.200	0.715	0.540	0.445
.107	.250	.430	.666	.798	.902	1.32	s120/5(20)	2.675	2.383	1.800	1.180	0.660	0.520	0.490
.109	.251	.433	.667	.798	.902	1.33	s120/5(20)*	2.725	2.367	1.820	1.170	0.655	0.520	0.490
.092	.224	.417	.684	.817	.911	1.33	s60/5(20)	2.300	2.200	1.930	1.335	0.665	0.470	0.445
.071	.177	.342	.624	.816	.920	1.28	s30/5(20)	1.775	1.767	1.650	1.410	0.960	0.520	0.400
							*							
.119	.301	.545	.784	.891	.950	1.47	s24h/1h(12)	2.975	3.033	2.440	1.195	0.535	0.295	0.250
.085	.209	.403	.693	.829	.917	1.34	s12h/1h(12)	2.125	2.067	1.940	1.450	0.680	0.440	0.415
.091	.223	.418	.698	.840	.929	1.36	s720/60(12)	2.275	2.200	1.950	1.400	0.710	0.445	0.355
.104	.250	.452	.697	.832	.921	1.36	s720/30(12)	2.600	2.433	2.020	1.225	0.675	0.445	0.395
.093	.224	.420	.670	.804	.908	1.32	s360/15(12)	2.325	2.183	1.960	1.250	0.670	0.520	0.460
.114	.243	.432	.665	.806	.914	1.33	s240/10(12)	2.850	2.150	1.890	1.165	0.705	0.540	0.430
.122	.284	.474	.686	.802	.902	1.35	s120/5(12)	3.050	2.700	1.900	1.060	0.580	0.500	0.490

Tests on the effect of timestep

.133	.261	.470	.704	.829	.918	1.38	s360/5(20)d	3.325	2.133	2.090	1.170	0.625	0.445	0.410
.119	.255	.462	.704	.819	.920	1.37	s360/10(20)d	2.975	2.267	2.070	1.210	0.575	0.505	0.400
.120	.258	.479	.705	.829	.914	1.38	s360/10(20)d	3.000	2.300	2.210	1.130	0.620	0.425	0.430
.136	.252	.470	.712	.834	.922	1.38	s360/15(20)d	3.400	1.933	2.180	1.210	0.610	0.440	0.390
.101	.242	.436	.687	.831	.926	1.36	s360/30(20)d	2.525	2.350	1.940	1.255	0.720	0.475	0.370
.083	.208	.388	.634	.810	.917	1.30	s360/60(20)d	2.075	2.083	1.800	1.230	0.880	0.535	0.415
.109	.251	.433	.667	.798	.902	1.33	s120/5(20)	2.725	2.367	1.820	1.170	0.655	0.520	0.490
.102	.242	.418	.666	.799	.901	1.32	s120/10(20)	2.550	2.333	1.760	1.240	0.665	0.510	0.495
.082	.205	.384	.634	.809	.910	1.30	s120/20(20)	2.050	2.050	1.790	1.250	0.875	0.505	0.450

Tests on the number of events (more=more small events)

.104	.243	.463	.730	.837	.924	1.38	w24h/1h(12)	2.600	2.317	2.200	1.335	0.535	0.435	0.380
.098	.224	.432	.702	.820	.921	1.35	w24h/1h(8)	2.450	2.100	2.080	1.350	0.590	0.505	0.395
.089	.209	.418	.697	.835	.929	1.35	w24h/1h(4)	2.225	2.000	2.090	1.395	0.690	0.470	0.355
.082	.201	.384	.679	.829	.924	1.33	w12h/1h(16)	2.050	1.983	1.830	1.475	0.750	0.475	0.380
.083	.203	.383	.675	.825	.921	1.32	w12h/1h(12)	2.075	2.000	1.800	1.460	0.750	0.480	0.395
.079	.194	.374	.669	.822	.919	1.31	w12h/1h(8)	1.975	1.917	1.800	1.475	0.765	0.485	0.405
.079	.192	.360	.652	.803	.903	1.29	w12h/1h(4)	1.975	1.833	1.680	1.460	0.755	0.500	0.485
.131	.313	.557	.796	.899	.955	1.49	s24h/1h(20)	3.275	3.033	2.440	1.195	0.515	0.280	0.225
.123	.305	.549	.785	.894	.952	1.48	s24h/1h(16)	3.075	3.033	2.440	1.180	0.545	0.290	0.240
.119	.301	.545	.784	.891	.950	1.47	s24h/1h(12)	2.975	3.033	2.440	1.195	0.535	0.295	0.250
.126	.320	.579	.799	.909	.963	1.50	s24h/1h(8)	3.150	3.233	2.590	1.100	0.550	0.270	0.185
.128	.329	.579	.801	.906	.963	1.51	s24h/1h(4)	3.200	3.350	2.500	1.110	0.525	0.285	0.185
.094	.228	.429	.703	.836	.928	1.36	s12h/1h(20)	2.350	2.233	2.010	1.370	0.665	0.460	0.360
.085	.209	.403	.693	.829	.917	1.34	s12h/1h(12)	2.125	2.067	1.940	1.450	0.680	0.440	0.415
.122	.255	.449	.695	.821	.915	1.36	s360/15(20)	3.050	2.217	1.940	1.230	0.630	0.470	0.425
.117	.247	.439	.682	.811	.910	1.34	s360/15(16)	2.925	2.167	1.920	1.215	0.645	0.495	0.450
.093	.224	.420	.670	.804	.908	1.32	s360/15(12)	2.325	2.183	1.960	1.250	0.670	0.520	0.460
.071	.194	.391	.661	.795	.905	1.30	s360/15(8)	1.775	2.050	1.970	1.350	0.670	0.550	0.475
.069	.208	.394	.661	.794	.910	1.30	s360/15(4)	1.725	2.317	1.860	1.335	0.665	0.580	0.450
.109	.251	.433	.667	.798	.902	1.33	s120/5(20)	2.725	2.367	1.820	1.170	0.655	0.520	0.490
.111	.261	.451	.675	.799	.902	1.34	s120/5(16)	2.775	2.500	1.900	1.120	0.620	0.515	0.490
.122	.284	.474	.686	.802	.902	1.35	s120/5(12)	3.050	2.700	1.900	1.060	0.580	0.500	0.490
.115	.283	.458	.678	.792	.892	1.34	s120/5(8)	2.875	2.800	1.750	1.100	0.570	0.500	0.540
.129	.316	.496	.693	.798	.896	1.36	s120/5(4)	3.225	3.117	1.800	0.985	0.525	0.490	0.520

Mixed duration averages

winter short(2,4,6h) storms

.064	.164	.322	.611	.774	.897	1.24	ws(20)d	1.600	1.667	1.580	1.445	0.815	0.615	0.515
.066	.175	.358	.611	.768	.891	1.25	ws(20)k	1.650	1.817	1.830	1.265	0.785	0.615	0.545
.053	.145	.304	.569	.737	.874	1.19	ws(20)c	1.325	1.533	1.590	1.325	0.840	0.685	0.630
.059	.171	.348	.646	.787	.897	1.27	ws(20)s	1.475	1.867	1.770	1.490	0.705	0.550	0.515
.067	.168	.346	.603	.768	.891	1.24	ws(20)g	1.675	1.683	1.780	1.285	0.825	0.615	0.545
.062	.165	.335	.608	.767	.890	1.24	ws(20)	1.550	1.717	1.700	1.365	0.795	0.615	0.550

winter long(12,24h) storms

.084	.203	.383	.675	.788	.892	1.30	wl(12)d	2.100	1.983	1.800	1.460	0.565	0.520	0.540
.092	.223	.458	.732	.862	.924	1.39	wl(12)k	2.300	2.183	2.350	1.370	0.650	0.310	0.380
.097	.230	.445	.728	.855	.939	1.39	wl(12)c	2.425	2.217	2.150	1.415	0.635	0.420	0.305
.077	.226	.424	.706	.817	.912	1.34	wl(12)s	1.925	2.483	1.980	1.410	0.555	0.475	0.440
.150	.299	.502	.732	.844	.927	1.41	wl(12)g	3.750	2.483	2.030	1.150	0.560	0.415	0.365
.100	.236	.443	.714	.833	.919	1.37	wl(12)	2.500	2.267	2.070	1.355	0.595	0.430	0.405

summer short(2,4,6h) storms

.135	.292	.504	.706	.820	.913	1.39	ss(36)d	3.375	2.617	2.120	1.010	0.570	0.465	0.435
.130	.302	.491	.684	.796	.908	1.36	ss(36)k	3.250	2.867	1.890	0.965	0.560	0.560	0.460
.087	.190	.360	.630	.789	.903	1.27	ss(36)c	2.175	1.717	1.700	1.350	0.795	0.570	0.485
.099	.236	.431	.676	.812	.908	1.33	ss(36)s	2.475	2.283	1.950	1.225	0.680	0.480	0.460
.098	.231	.423	.673	.804	.907	1.33	ss(36)g	2.450	2.217	1.920	1.250	0.655	0.515	0.465
.110	.250	.442	.674	.804	.908	1.34	ss(36)	2.750	2.333	1.920	1.160	0.650	0.520	0.460

summer long(12,24h) storms

.096	.279	.509	.727	.864	.936	1.42	sl(24)d	2.400	3.050	2.300	1.090	0.685	0.360	0.320
.133	.319	.551	.780	.892	.955	1.48	sl(24)k	3.325	3.100	2.320	1.145	0.560	0.315	0.225
.098	.236	.456	.712	.845	.931	1.38	sl(24)c	2.450	2.300	2.200	1.280	0.665	0.430	0.345
.128	.294	.514	.748	.849	.916	1.42	sl(24)s	3.200	2.767	2.200	1.170	0.505	0.335	0.420
.102	.248	.464	.735	.858	.939	1.40	sl(24)g	2.550	2.433	2.160	1.355	0.615	0.405	0.305
.112	.275	.499	.740	.861	.935	1.42	sl(24)	2.800	2.717	2.240	1.205	0.605	0.370	0.325

Mixed duration quartiles

winter long(12,24h) quartiles(local/global)

.130	.312	.575	.813	.890	.946	1.49	wl75l(12)	3.250	3.033	2.630	1.190	0.385	0.280	0.270
.102	.234	.430	.707	.831	.917	1.36	wl50l(12)	2.550	2.200	1.960	1.385	0.620	0.430	0.415
.070	.160	.310	.616	.777	.892	1.24	wl25l(12)	1.750	1.500	1.500	1.530	0.805	0.575	0.540
.136	.321	.582	.818	.898	.952	1.50	wl75g(12)	3.400	3.083	2.610	1.180	0.400	0.270	0.240
.081	.202	.399	.688	.819	.915	1.33	wl50g(12)	2.025	2.017	1.970	1.445	0.655	0.480	0.425
.064	.151	.303	.611	.768	.886	1.23	wl25g(12)	1.600	1.450	1.520	1.540	0.785	0.590	0.570

summer long(12,24h) quartiles(local/global)

.156	.376	.637	.818	.912	.961	1.54	sl75l(24)	3.900	3.667	2.610	0.905	0.470	0.245	0.195
.087	.240	.478	.731	.858	.935	1.40	sl50l(24)	2.175	2.550	2.380	1.265	0.635	0.385	0.325
.067	.174	.361	.662	.811	.910	1.29	sl25l(24)	1.675	1.783	1.870	1.505	0.745	0.495	0.450
.159	.386	.658	.833	.926	.969	1.56	sl75g(24)	3.975	3.783	2.720	0.875	0.465	0.215	0.155
.085	.230	.468	.727	.864	.936	1.40	sl50g(24)	2.125	2.417	2.380	1.295	0.685	0.360	0.320
.064	.164	.340	.647	.797	.902	1.27	sl25g(24)	1.600	1.667	1.760	1.535	0.750	0.525	0.490

winter short(2,4,6h) quartiles(global) all/noCork/Cork

.068	.192	.403	.680	.809	.907	1.32	ws75g(20)	1.700	2.067	2.110	1.385	0.645	0.490	0.465
.058	.150	.308	.607	.759	.883	1.22	ws50g(20)	1.450	1.533	1.580	1.495	0.760	0.620	0.585
.055	.137	.267	.536	.725	.873	1.16	ws25g(20)	1.375	1.367	1.300	1.345	0.945	0.740	0.635
.069	.199	.413	.678	.809	.909	1.32	ws75g(20)nc	1.725	2.167	2.140	1.325	0.655	0.500	0.455
.061	.157	.321	.621	.767	.886	1.24	ws50g(20)nc	1.525	1.600	1.640	1.500	0.730	0.595	0.570
.058	.139	.273	.557	.740	.879	1.18	ws25g(20)nc	1.450	1.350	1.340	1.420	0.915	0.695	0.605
.059	.165	.353	.640	.779	.889	1.26	ws75g(20)c	1.475	1.767	1.880	1.435	0.695	0.550	0.555
.052	.139	.281	.541	.725	.872	1.17	ws50g(20)c	1.300	1.450	1.420	1.300	0.920	0.735	0.640
.047	.125	.254	.498	.695	.859	1.12	ws25g(20)c	1.175	1.300	1.290	1.220	0.985	0.820	0.705

summer short(2,4,6h) quartiles(global) all/noCork/Cork

.168	.365	.602	.770	.860	.935	1.48	ss75g(36)	4.200	3.283	2.370	0.840	0.450	0.375	0.325
.084	.209	.407	.676	.805	.907	1.32	ss50g(36)	2.100	2.083	1.980	1.345	0.645	0.510	0.465
.051	.136	.282	.577	.749	.880	1.19	ss25g(36)	1.275	1.417	1.460	1.475	0.860	0.655	0.600
.177	.388	.632	.781	.864	.937	1.50	ss75g(36)nc	4.425	3.517	2.440	0.745	0.415	0.365	0.315
.088	.222	.434	.689	.804	.905	1.33	ss50g(36)nc	2.200	2.233	2.120	1.275	0.575	0.505	0.475
.054	.142	.293	.589	.752	.881	1.20	ss25g(36)nc	1.350	1.467	1.510	1.480	0.815	0.645	0.595
.127	.256	.460	.720	.850	.934	1.39	ss75g(36)c	3.175	2.150	2.040	1.300	0.650	0.420	0.330
.059	.147	.311	.623	.783	.901	1.24	ss50g(36)c	1.475	1.467	1.640	1.560	0.800	0.590	0.495
.047	.124	.261	.539	.728	.872	1.16	ss25g(36)c	1.175	1.283	1.370	1.390	0.945	0.720	0.640

Moving centre profiles

long(12,24h) quartiles(global) winter/summer

.172	.337	.546	.752	.848	.920	1.44	mwl75(12)	4.300	2.750	2.090	1.030	0.480	0.360	0.400
.127	.255	.424	.639	.807	.922	1.33	mwl50(12)	3.175	2.133	1.690	1.075	0.840	0.575	0.390
.104	.209	.348	.557	.751	.889	1.23	mwl25(12)	2.600	1.750	1.390	1.045	0.970	0.690	0.555
.250	.428	.647	.844	.925	.969	1.58	msl75(24)	6.250	2.967	2.190	0.985	0.405	0.220	0.155
.168	.308	.486	.720	.854	.938	1.42	msl50(24)	4.200	2.333	1.780	1.170	0.670	0.420	0.310
.132	.246	.388	.613	.783	.907	1.29	msl25(24)	3.300	1.900	1.420	1.125	0.850	0.620	0.465

winter short(2,4,6h) quartiles(global) all/noCork/Cork

.134	.261	.426	.637	.784	.898	1.31	mws75(20)	3.350	2.117	1.650	1.055	0.735	0.570	0.510
.097	.200	.343	.566	.737	.874	1.21	mws50(20)	2.425	1.717	1.430	1.115	0.855	0.685	0.630
.075	.161	.287	.511	.697	.853	1.14	mws25(20)	1.875	1.433	1.260	1.120	0.930	0.780	0.735
.140	.269	.434	.646	.792	.904	1.32	mws75(20)nc	3.500	2.150	1.650	1.060	0.730	0.560	0.480
.104	.209	.355	.572	.736	.872	1.22	mws50(20)nc	2.600	1.750	1.460	1.085	0.820	0.680	0.640
.082	.170	.299	.523	.703	.854	1.16	mws25(20)nc	2.050	1.467	1.290	1.120	0.900	0.755	0.730
.099	.213	.375	.588	.759	.884	1.25	mws75(20)c	2.475	1.900	1.620	1.065	0.855	0.625	0.580
.069	.158	.291	.520	.703	.861	1.15	mws50(20)c	1.725	1.483	1.330	1.145	0.915	0.790	0.695
.062	.139	.260	.478	.667	.838	1.10	mws25(20)c	1.550	1.283	1.210	1.090	0.945	0.855	0.810

summer short(2,4,6h) quartiles(global) all/noCork/Cork

.231	.400	.584	.754	.867	.940	1.48	mss75(36)	5.775	2.817	1.840	0.850	0.565	0.365	0.300
.156	.273	.422	.633	.788	.899	1.31	mss50(36)	3.900	1.950	1.490	1.055	0.775	0.555	0.505
.105	.198	.321	.535	.710	.863	1.18	mss25(36)	2.625	1.550	1.230	1.070	0.875	0.765	0.685
.247	.421	.604	.764	.870	.939	1.50	mss75(36)n	6.175	2.900	1.830	0.800	0.530	0.345	0.305
.170	.292	.443	.644	.794	.903	1.33	mss50(36)n	4.250	2.033	1.510	1.005	0.750	0.545	0.485
.113	.208	.334	.543	.718	.867	1.20	mss25(36)n	2.825	1.583	1.260	1.045	0.875	0.745	0.665
.163	.304	.479	.697	.839	.925	1.39	mss75(36)c	4.075	2.350	1.750	1.090	0.710	0.430	0.375
.109	.217	.353	.587	.757	.888	1.24	mss50(36)c	2.725	1.800	1.360	1.170	0.850	0.655	0.560
.080	.169	.294	.517	.696	.859	1.15	mss25(36)c	2.000	1.483	1.250	1.115	0.895	0.815	0.705

24h moving centre quartiles winter/summer

.177	.344	.550	.752	.844	.916	1.44	mw24h75	4.425	2.783	2.060	1.010	0.460	0.360	0.420
.139	.276	.452	.671	.816	.921	1.36	mw24h50	3.475	2.283	1.760	1.095	0.725	0.525	0.395
.110	.222	.376	.598	.787	.906	1.27	mw24h25	2.750	1.867	1.540	1.110	0.945	0.595	0.470
.264	.465	.700	.885	.946	.977	1.63	ms24h75	6.600	3.350	2.350	0.925	0.305	0.155	0.115
.189	.345	.542	.786	.894	.953	1.49	ms24h50	4.725	2.600	1.970	1.220	0.540	0.295	0.235
.161	.292	.442	.684	.825	.925	1.37	ms24h25	4.025	2.183	1.500	1.210	0.705	0.500	0.375

weighted average profiles, 0.75 of fixed (cork summer=.7, cork winter=.6)

average long winter/summer

.145	.325	.573	.802	.886	.944	1.49	awl75	3.625	3.000	2.480	1.143	0.420	0.292	0.280
.093	.215	.405	.676	.816	.917	1.33	awl50	2.313	2.046	1.900	1.353	0.701	0.504	0.416
.074	.166	.314	.598	.764	.887	1.23	awl25	1.850	1.525	1.487	1.416	0.831	0.615	0.566
.182	.397	.655	.836	.926	.969	1.57	asl75	4.544	3.579	2.587	0.903	0.450	0.216	0.155
.106	.250	.473	.725	.862	.937	1.40	asl50	2.644	2.396	2.230	1.264	0.681	0.375	0.317
.081	.185	.352	.639	.794	.903	1.28	asl25	2.025	1.725	1.675	1.433	0.775	0.549	0.484

average summer short noCork/Cork

.195	.396	.625	.777	.866	.938	1.50	assnc75	4.863	3.363	2.288	0.759	0.444	0.360	0.313
.109	.240	.436	.678	.802	.905	1.33	assnc50	2.713	2.183	1.968	1.208	0.619	0.515	0.478
.069	.159	.303	.578	.744	.878	1.20	assnc25	1.719	1.496	1.448	1.371	0.830	0.670	0.613
.138	.270	.466	.713	.847	.931	1.39	assc75	3.445	2.210	1.953	1.237	0.668	0.423	0.344
.074	.168	.324	.612	.775	.897	1.24	assc50	1.850	1.567	1.556	1.443	0.815	0.610	0.515
.057	.138	.271	.532	.718	.868	1.16	assc25	1.423	1.343	1.334	1.307	0.930	0.749	0.660

average winter short noCork/Cork

.087	.217	.418	.670	.805	.908	1.32	awsnc75	2.169	2.163	2.018	1.259	0.674	0.515	0.461
.072	.170	.330	.609	.759	.883	1.23	awsnc50	1.794	1.638	1.595	1.396	0.752	0.616	0.588
.064	.147	.280	.549	.731	.873	1.17	awsnc25	1.600	1.379	1.328	1.345	0.911	0.710	0.636
.075	.184	.362	.619	.771	.887	1.26	awsc75	1.875	1.820	1.776	1.287	0.759	0.580	0.565
.059	.147	.285	.533	.716	.868	1.16	awsc50	1.470	1.463	1.384	1.238	0.918	0.757	0.662
.053	.131	.256	.490	.684	.851	1.11	awsc25	1.325	1.293	1.258	1.168	0.969	0.834	0.747

average 24h winter/summer

.149	.329	.588	.800	.868	.936	1.48	aw24h75	3.713	3.008	2.585	1.063	0.340	0.337	0.323
.102	.238	.448	.706	.824	.920	1.36	aw24h50	2.556	2.258	2.098	1.294	0.586	0.480	0.403
.079	.176	.339	.632	.795	.907	1.27	aw24h25	1.981	1.617	1.630	1.462	0.814	0.561	0.466
.207	.445	.708	.877	.948	.979	1.62	as24h75	5.175	3.963	2.627	0.846	0.358	0.155	0.104
.123	.296	.548	.790	.907	.961	1.49	as24h50	3.075	2.875	2.525	1.209	0.585	0.273	0.194
.096	.214	.414	.709	.843	.929	1.36	as24h25	2.394	1.971	1.995	1.476	0.671	0.429	0.356

Key to profile labels

The profiles are basically labelled as:

(1) FSR profiles start 'fsr',
followed by 'w' or 's' for winter or summer,
then the quartile indicator 25,50 or 75.

(2) Irish profiles start 'w' or 's' for winter or summer,
then the storm duration/timestep (both minutes unless specified 'h'),
then (in brackets) the number of storms per gauge used in averaging,
then the gauge code (d=Dublin, k=Kilkenny, c=Cork, s=Shannon, g=Galway).

but

(a) Averages over durations 2,4,& 6h have 's' in place of duration/timestep, while averages over durations 12 & 24 hours have 'l'.

(b) Averages excluding Cork data end 'nc'

(c) Where 'l' follows a quartile indicator, individual gauge/durations were sorted into quartiles before averaging (otherwise all storms were taken together when sorting into quartiles).

(d) Moving centre profiles all start 'm'

(e) Weighted average of fixed/moving centre profiles all start 'a'