Appendix D

The Old and New UK PR Equations

Appendix D – Comparison between Old and New UK PR Equations

D1 Old UK PR Equation

The Old UK PR equation was derived by statistical analysis from data from 33 catchments. It should be noted that the equation is entirely statistical and takes no account of topography.

$$PR = 0.829\,PIMP + 25.0\,SOIL + 0.078\,UCWI - 20.7$$

where:

PR	*= percentage runoff*
PIMP	*= percentage impermeability*
SOIL	*= an index of the water holding capacity of the soil*
UCWI	*= Urban Catchment Wetness Index.*

A brief explanation of the meaning and derivation of these parameters follows.

PIMP
This parameter is the percentage imperviousness of the catchment obtained by dividing the total directly connected impervious area (both roofs and roads) by the total contributing area.

SOIL
The soil index SOIL is based on the Winter Rain Acceptance Parameter (WRAP) included in the Flood Studies Report. The index broadly describes infiltration potential and was derived by a consideration of soil permeability, topographic slope, and the likelihood of impermeable layers. Five classes of soils are recognised as shown in Table D1 below and Figure D2.

SOIL	WRAP	Runoff	SOIL Value	Soil Characteristics
1	Very high	Very low	0.15	Sandy, well drained
2	High	Low	0.30	Intermediate soils (sandy)
3	Moderate	Moderate	0.40	Intermediate soils (silty)
4	Low	High	0.45	Clayey, poorly drained
5	Very low	Very high	0.50	Steep, rocky areas

Table D1 Different Classes of Soil

UCWI
UCWI is the Urban Catchment Wetness Index, which is a composite of two antecedent wetness parameters and is given by:

$$UCWI = 125 + 8\,API5 - SMD$$

where:

API5	*= five day antecedent precipitation index (mm)*
SMD	*= soil moisture deficit.*

The value for UCWI is calculated from these parameters for specific events, but design values are provided by referring to a figure relating UCWI to the Standard Annual Average Rainfall (SAAR) for that location (Figure D1). Values are provided for both winter and summer conditions.

For specific events, API_5 is calculated using the following procedure. First determine the rainfall depths (in mm) for the five days prior to the event. The API_5 value at 0900 on the day of the event is then defined by

$$API5_9 = \Sigma_{n=1,5} P_{-n} C_p^{n-0.5}$$

where:

P_{-n} = *rainfall on day n before the event*
C_p = *decay coefficient = 0.5*

Finally the API_5 at the time of the event is given by

$$API_5 = API5_9\, C_p^{(t'-9)/24} + P_{t'-9}\, C_p^{(t'-9)/48}$$

where:

t' = *time (hours) of the beginning of the event*
$P_{t'-9}$ = *rainfall depth between time t' and 0900.*

The soil moisture deficit is calculated from a similar equation

$$SMD = SMD_9 - P_{t'-9}$$

where:

SMD_9 = *soil moisture deficit at 09:00 on the day of the event*

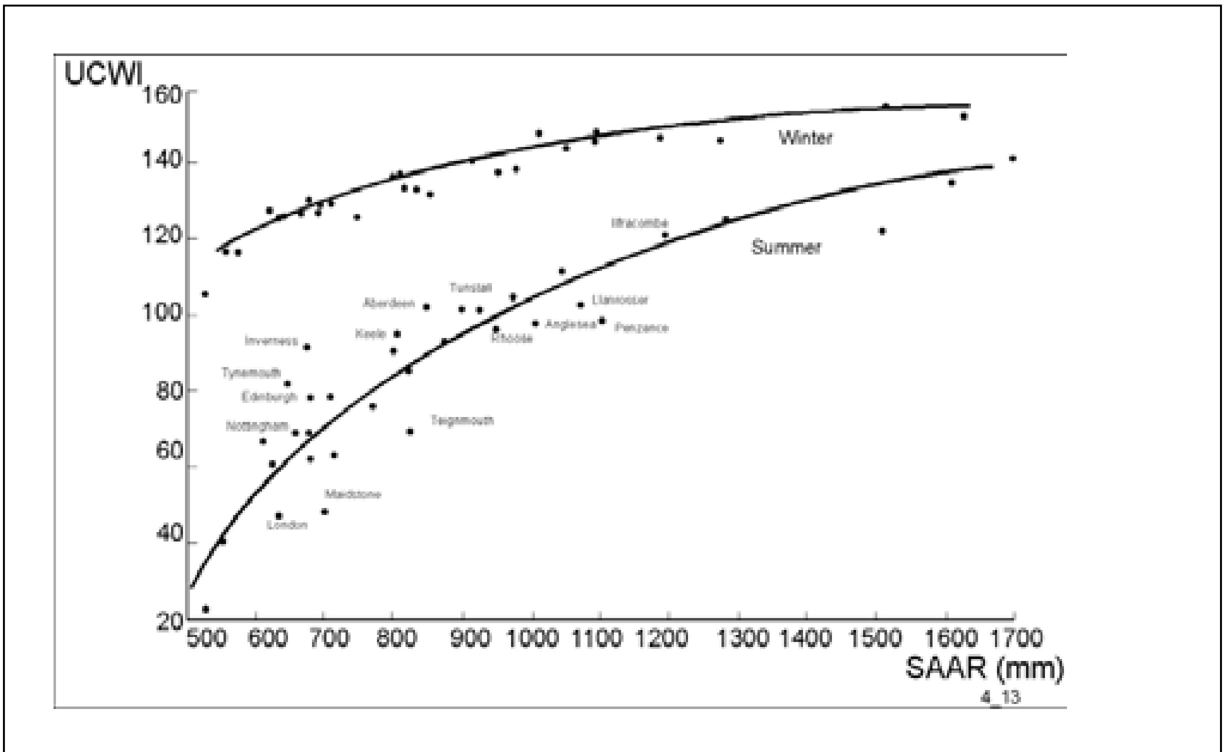

Figure D1 Seasonal UCWI Relationship with SAAR

The SMD_9 value (known as ESMD) was obtainable from the UK Meteorological Office until 1997. It was calculated from a water balance between daily rainfall and an estimate of evapotranspiration based on the use of Penman's equation, assuming a notional catchment under short rooted vegetation (50%), long rooted vegetation (30%) and riparian areas (20%). Since the development of the Wallingford Procedure, the Meteorological Office has ceased the routine issue of ESMD and issues a new SMD value based upon the use of a different calculating system (MORECS), which is a modification of the Penman equation by Monteith. This is further confused by the fact that the Irish calculation of SMD is again different. However there appears to be little practical difference between the use of the various methods, particularly as the PR equation is not significantly influenced by this parameter.

Inspection of the Old UK PR equation indicates that for low values of PIMP, SOIL and UCWI, low or even negative values of PR can be predicted. Consequently, a minimum value of PR_{paved} of 20% together with a maximum of 100% is specified. It should be appreciated that unrealistic PR values can be predicted with low values of SOIL (e.g. 0.15) in combination with both low values of PIMP (e.g. PIMP < 30%) and UCWI because the correlation equation was derived for catchments with reasonably high values of PIMP. Its application on sewers with partially separated systems or lightly urbanised areas is therefore generally inappropriate. Figure D2 illustrates how PR changes with PIMP and SOIL.

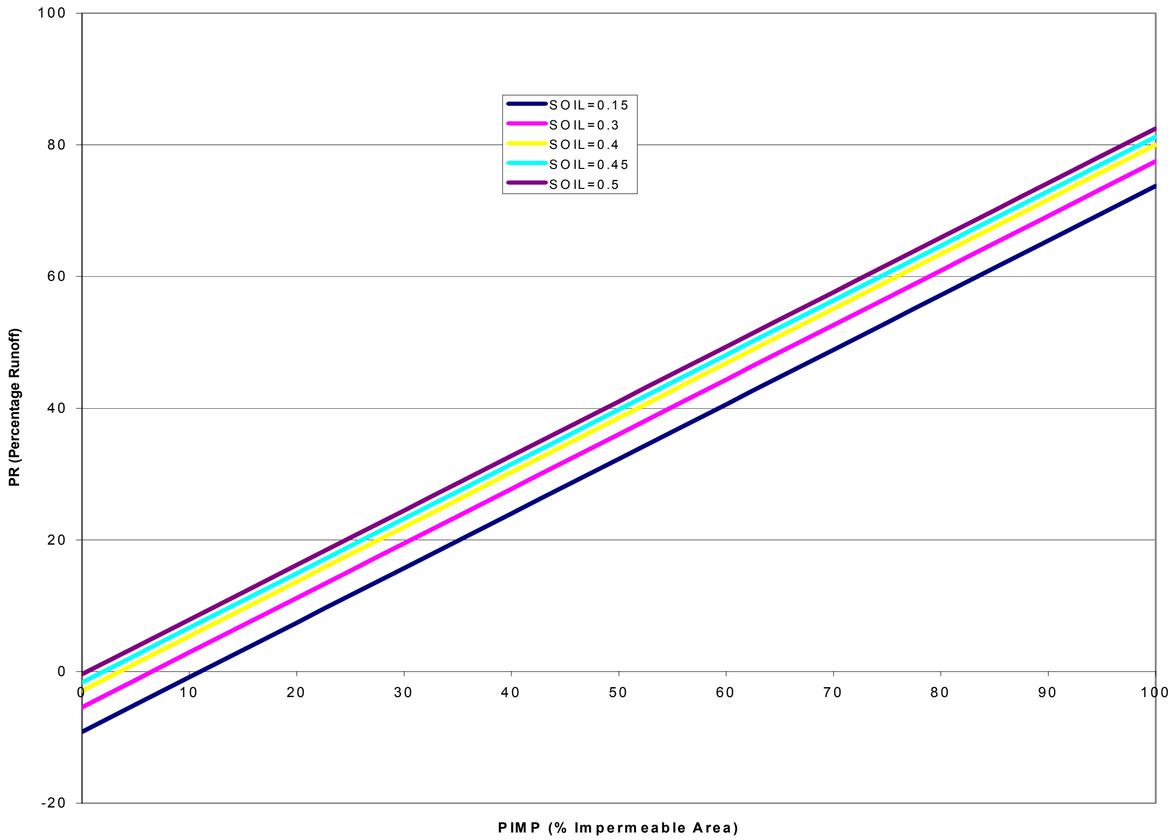

Figure D2 PR as a function of SOIL and PIMP (Old UK PR Equation)

D2 The New UK PR Equation

The new UK PR equation was developed jointly by HR Wallingford, the Water Research Centre and the Institute of Hydrology with support from NorthWest Water PLC. It has been designed as a replacement for the familiar Old PR equation described previously. It is now becoming more commonly used and is recommended for use in Ireland.

The new equation was designed primarily to overcome some of the difficulties experienced in practical application of the first equation, namely:

- The Old UK equation defines PR as being a constant throughout a rainfall event irrespective of catchment wetness. Clearly for long duration storms, losses towards the end of the event may be much reduced as the catchment becomes saturated;
- Problems have been encountered in applying the PR equation to partially separate catchments and to catchments with low PIMP and low SOIL values;
- The assumptions of the flow split between paved and pervious runoff is clearly inappropriate for catchments with significant rural components to the runoff.

To overcome these problems, various new model forms were investigated using a subset of the original data.

It should be noted here that the Old UK PR equation, although still used, is now less popular than the New UK PR equation. It is recommended that the New PR equation be adopted for the Dublin Region.

The dangers of applying the Old UK PR equation for low values of PIMP are graphically illustrated by Figures D3 and D4 where it is assumed that 1 ha of paved surface has a variable amount of pervious surface. The graphs show the effect of 10mm and 80mm of rainfall on SOIL types 1 and 4. The curves for the New UK PR equation graphically illustrate the effect of high runoff contributions from the pervious surfaces.

It also indicates that verifying models using the New UK PR equation against small storms does not draw attention to volumes of runoff from pervious areas, but with large events considerable runoff is predicted to take place. The figures are provided in log and normal scales to provide a clear understanding of the effects.

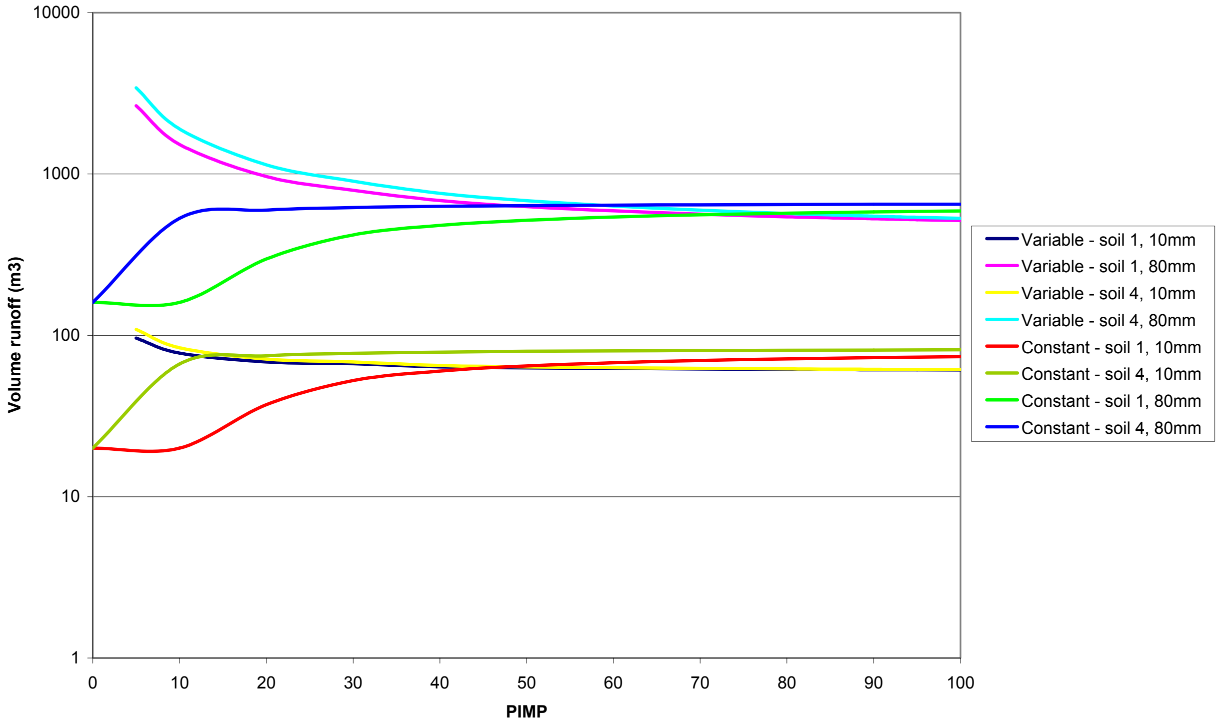

Figure D3 Volume of Runoff (log scale) – 1 ha paved, variable pervious area: (Old & New UK PR Equations)

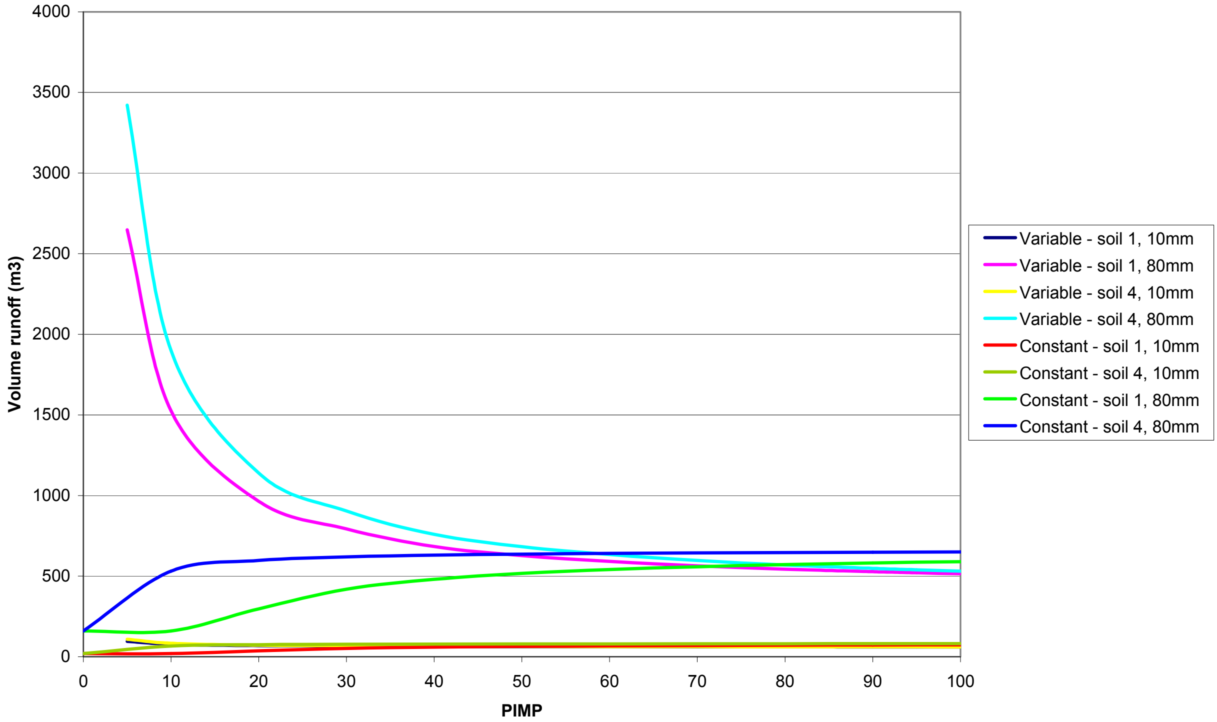

Figure D4 Volume of Runoff (linear scale) – 1ha paved, variable pervious area: (Old & New UK PR Equations)

The recommended model derived by this analysis is of the form:

$$PR = IF * PIMP + (100 - IF * PIMP) * \frac{NAPI}{PF}$$

where

IF	=	*effective impervious area factor*
PF	=	*moisture depth parameter (mm)*
NAPI	=	*30 day antecedent precipitation index*

This equation divides PR into two elements. First, the impervious area runoff is obtained by using an effective contributing area factor, IF. Therefore after initial losses on impervious surfaces, remaining losses are given as a constant fraction of rainfall volume. Recommended values of IF are indicated in table D2 and can be compared with the PR_{imp} values for the individual catchments derived using the Old PR equation. One of the principal features of this equation (and a possible drawback) is that engineers have to choose a value by using their judgement as to what is appropriate.

Surface Condition	Effective impervious area factor, IF
POOR	0.45
FAIR	0.60
GOOD	0.75

Table D2 Recommended Values of IF

The losses on pervious surfaces and also non-effective impervious areas are represented by the second term of the equation. The first part of this term represents the total percentage of the catchment occupied by pervious and non-effective impervious areas. The losses from this area are dependent on the function NAPI/PF.

NAPI is defined as a 30-day API with evapotranspiration and initial losses subtracted from rainfall. As for API_5, API_{30} is given by:

$$API_{30} = \sum_{n=1,30} P_{-n} C_p^{n-0.5}$$

The constant value C of the API has been made dependent on the soil type to reflect the faster reduction of soil moisture on lighter soils. The relationship between C and soil type is shown in Table D3.

Soil Type	C
1	0.1
2	0.5
3	0.7
4	0.9
5	0.99

Table D3 Relationship Between Soil Type and C

The moisture depth parameter, PF, was calibrated using the data described above. A value of 200 mm was obtained (which compares well with the available water capacity of soils with grass vegetation). It is dangerous to modify this value without careful consideration of the consequences.

Figure D5 illustrates the effect of increasing rainfall on percentage runoff using the New PR equation. This should be compared to Figure D4 above showing the difference between the Old and New UK PR equations. For information, the assumptions used in the figure are as follows:

Old PR
- PIMP = 50 percent
- SOIL = 1 - 5
- UCWI = 100

New PR
- PIMP = 50 percent
- SOIL = 1 - 5
- NAPI = 0mm at start of the event
- PF = 200mm
- IF = 70%

Rainfall
- $M_5 60$ = 20mm
- Rainfall ratio "r" = 0.4
- Depth = 50 year 18 hour summer event (78mm)

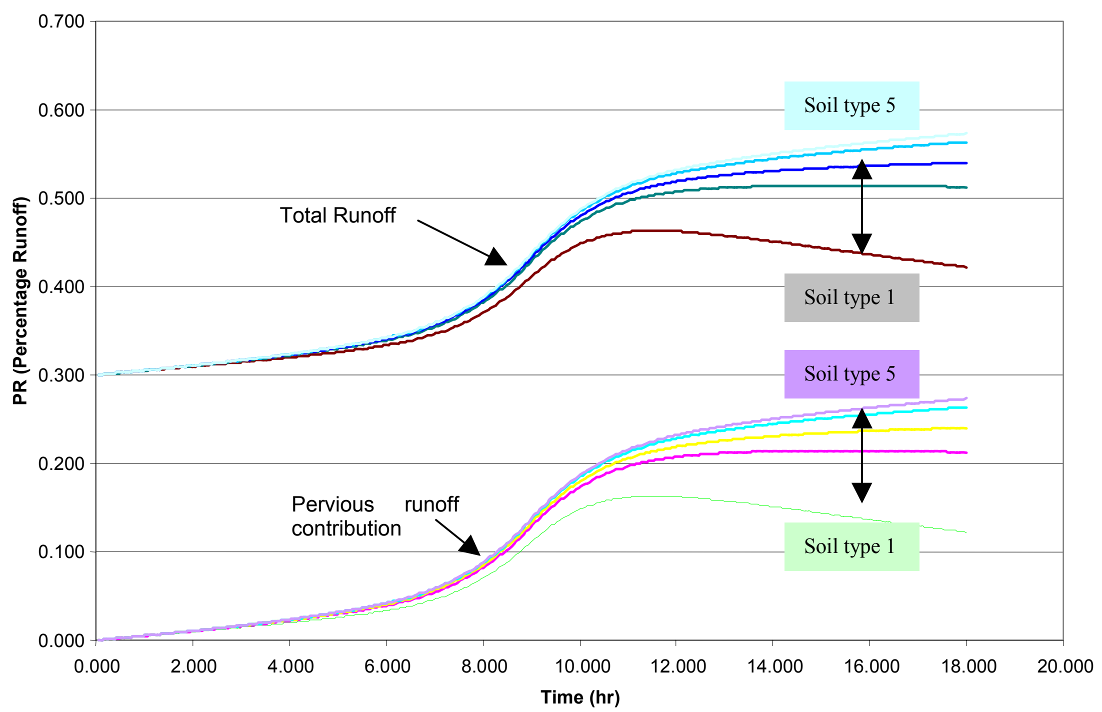

Figure D5 ***Percentage Runoff as a Function of Rainfall Depth using the New PR Equation***

Rainfall profiles exist in the form of summer or winter profiles. These are symmetric and are respectively defined as being 50 percentile and 75 percentile storms. The summer profile provides a maximum intensity, which 50 percent of real storms exceed for that specific return period and duration. Similarly this applies to the winter profile. The design rainfall profiles that are in current urban drainage software are derived from the Flood Studies Report, 1975.