THE WALLINGFORD PROCEDURE PERCENTAGE RUNOFF EQUATION

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1. INTRODUCTION

In 1974 the Institute of Hydrology began work on developing a mathematical model of the above ground phase of runoff to sewer networks as part of the development of the Wallingford Procedure (Refs 1, 2). The model developed is known as the Wallingford Subcatchment model and is incorporated in the Wallingford Procedure and most subsequent modelling packages. The model can be divided into three phases: determining the volume of runoffs, distributing it in time and space and finally routing the runoff. This note covers the derivation and application of the first phase of the model.

Anyone who has watched runoff occurring during a storm will appreciate just how complex the processes involved are. To model these processes in a deterministic manner would be impractical so a statistical approach was adopted. 510 storm events from 17 different catchments were analysed in a study of catchment average values of runoff coefficients. A regression analysis was carried out to find the equation that gave the best fit to the data set. The resulting equation, which explained 58% of the variance in the data with a standard error of 10.3%, is known as the Percentage Runoff or PR equation.

2. PR EQUATION

The equation is used to determine the volumes of runoff occurring in any storm as follows:

$$\text{Volume of runoff} = \text{Rainfall} \times \text{Total Catchment Area} \times \frac{PR}{100} \qquad - (1)$$

where the PR equation is

$$PR = 0.829 \times PIMP + 25 \times SOIL + 0.078 \times UCWI - 20.7 \qquad - (2)$$

The value of PR is not allowed to fall below 0.4 PIMP as this was the lower limit observed in the data set.

Examining the parameters in the equation in turn.

Percentage impervious area – PIMP

$$PIMP = 1\ 00 \times \text{Total Impervious Area/Total Catchment Area} \qquad - (3)$$

If the amount of pervious area included in a catchment is increased, then the PR equation predicts less runoff per unit of impervious area. This reflects the situation where, for example, a paved area is adjacent to a grassed area and some of the rainfall landing on the edge of the paved area will splash off or even drain onto the grass and be lost to the sewer system. Thus the equation recognises that the greater the pervious area is, the larger these losses. This highlights that only pervious areas which can interplay with the impervious area should be included in the total catchment area. Hence networks draining roofs only would have little or no pervious area included. Large grassed areas such as golf courses in the middle of a catchment which have their own separate drainage should not be included in the calculation of total area. Inclusion of such areas will lead to a serious underestimation of the runoff in the network. Detailed advice on which pervious areas to include is given in WaPUG User Note No 21.

In the earliest Wallingford Procedure modelling package (WASSP) the application of the PR equation was based on the overall catchment parameters. As the PIMP value will be different for each pipe length the model will over-predict runoff on pipe lengths with a PIMP value lower than the average and vice versa. If this problem is significant, for example, when a whole sub-catchment is markedly different from the rest of the catchment, then consideration should be given to modelling the sub-catchment separately. In more recent modelling packages this problem is overcome by calculating PR on a sub-catchment basis.

SOIL

The appropriate value for this is obtained by referring to the Winter Rain Acceptance Potential (WRAP) class map in Volume 3 of the Wallingford manuals (3). This map was originally derived for the Flood Studies Report (4) excluding the urban areas which were added at a later date on fairly sparse data. Most urban catchments in the UK fall into the high WRAP classes and changing from one WRAP class to the next does not usually cause a significant change in PR. This is less true of the catchments in the lower WRAP classes, especially during verification storm events, when the catchment is dry. If a change in the value SOIL will make a significant difference to PR then it may be necessary to check the local WRAP class by reference to any available data.

As the SOIL value rises so does PR and thus the heavier soils give a higher runoff as expected.

In most modern software SOIL can be specified for each sub-catchment. In earlier software PR was generally based on the overall catchment average and if SOIL varied across a catchment then an average value was used.

Urban Catchment Wetness Index – UCWI

$$UCWI = 125 + 8AP15 - SMD \qquad - (4)$$

and

$$AP15 = 0.5^{t/24}\,AP15_9 + 0.5^{t/24}\,P_{t'-9} \qquad - (5)$$

and

$$AP15_9 = 0.044P_{-5} + 0.088P_{-4} + 0.177P_{-3} + 0.354P_{-2} + 0.707P_{-1} \qquad - (6)$$

and

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

where

AP15 is the 5 Day antecedent precipitation index.

$AP15_9$ is the 5 Day antecedent precipitation index at 9am on the day of the storm.

t is the time in hours of the start of the event after gam. If start of the storm is before 9am then this must be related to 9am on the previous day which becomes the day of the storm.

$P_{t'-9}$ is the Rainfall between 9am on the day of the storm and the start of the storm.

P_{-n} is the Rainfall on day ‘n’ before the start of the day of the storm.
Note that this refers to rainfall days which run from gam to 9am.

SMD9 is the Soil moisture deficit at 9am. The original analysis used the ESMD value for composite land use. Since the development of the model the Meteorological Office has switched to the MORECS system which cannot be directly related to the ESMD value. The closest of the many different MORECS values available is the real land use value. WRc compared ESMD values with MORECS values on a study containing 17 independent catchments and the maximum difference found was 20 mm. In no case did this make a significant difference to PR. In most circumstances it will be sufficiently accurate to use the MORECS value. If the prediction of PR is particularly sensitive to SMD then it is still possible to obtain ESMD values but some delay may be caused.

The UCWI value represents the wetness of the catchment at the start of the storm event. AS UCWI rises so the PR rises which reflects the increased runoff to be expected from a wetter catchment.

During a storm event the catchment wetness will increase, however the PR value is kept constant. The derivation of the PR equation was based on the total volume of runoff in short events and so the equation will correctly predict this. Since the UCWI will change during an event the model will tend to under-predict the runoff at the end of a storm. This will be more marked in longer events, and, although not usually significant, users should be aware of this effect.

3. CONCLUSIONS

The PR equation has many limitations and users of the Wallingford Procedure must be aware of these if they wish to obtain realistic results. The derivation of the equation by statistical methods makes it harder to grasp the physical significance of the parameters used in the equation. However, if the equation is to be used correctly, then the user must take the effort required to understand the significant of the parameters used.

The fit of the equation to its data set is not very good. But much of the misfit could be explained by errors in the data set. In the early 1990s WRc verified over 50 major WASSP or WALLRUS models covering a wide range of catchments and in every case a satisfactory match between modelled and measured flows was achieved without force fitting the model. This must go some way to validating the PR equation although there will be catchments it cannot and should not be used on.

In such cases other run-off models should be considered.

4. REFERENCES

1. Institute of Hydrology, Report No 60, 1979.

2. Institute of Hydrology, Report No 61, 1980.

3. Wallingford Procedure, Volumes 1 & 3 DoE, National Water Council, Standing Technical Committee Reports, No. 28, 1981.

4. Flood Studies Report, NERC, 1975.

AMENDMENTS

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1.	First Published	October 1987
2.	Revision	September 1989
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