A NEW RUNOFF VOLUME MODEL

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1. INTRODUCTION

A new runoff volume model was developed some years ago as an alternative to the existing Wallingford Procedure Percentage Runoff equation. This note describes its use for predicting normal runoff from urban catchments. The use of models to predict slow response runoff and infiltration is described in a separate note.

2. LIMITATIONS OF THE WALLINGFORD PROCEDURE PR MODEL

The PR equation and some of its limitations were described in WaPUG user note 9. Methods of assessing the catchment data so as to avoid some of the limitations were described in WaPUG user note 21. These methods are not perfect and can be complex to apply. There is also one important limitation that cannot readily be avoided. This is that the PR equation does not show increasing runoff due to wetting of the catchment even in large or long duration storms. This can cause significant errors, particularly in calculating the volume of large detention tanks or the operation of treatment works storm tanks. It is also impossible to run the PR model for continuous simulation.

3. DEVELOPMENT HISTORY

A short project to develop a new model was set up in 1987 and John Packman from the Institute of Hydrology carried out the work. The initial results of this development were reported at the WaPUG spring meeting in 1988 (Ref 1). The first version of this User Note was produced in August 1993. One reason for the delay was to allow more testing of the model after the development projects. There was therefore some reluctance to encourage people to use it. Even though the procedures for using the model were not fully developed, its use has gradually increased since 1993 and the benefits are now clear. We have now reached the point where it should be considered as the preferred model for all studies.

4. BENEFITS OF THE MODEL

There are four main benefits of the new runoff model:

- It calculates the runoff from paved and permeable surfaces separately. This makes the calculations more robust as there is less interference between the two. It is therefore easier to use for separate or partially separate areas that would otherwise give anomalous results with the PR equation.
- It calculates the increase in runoff during an event as the catchment wetness increases.
- It gives the same results for simulating individual events as for continuous simulation.

It does not require Soil Moisture Deficit values and so is easier to use in verification. The new model also has benefits compared to some alternative methods of representing delayed runoff and rainfall induced infiltration.

5. DESCRIPTION OF MODEL

The model calculates the volume of runoff from a contributing area during a defined rainfall event. It has three components; initial loss to depression storage, runoff from impervious surfaces, runoff from pervious surfaces.

5.1 Initial losses

The first part of the rainfall is lost in wetting the surfaces and filling up depressions before runoff can start. Each surface has a characteristic depression storage. The depth to which this is filled by previous rainfall is defined by the antecedent rainfall depth in the rainfall data file. The depth of the depressions in the surface depends on the slope and the type of the surface but is typical 0.5 to 2 mm. If the model is run for continuous simulation then the depression storage is dried out by evaporation when the rainfall stops.

5.2 Impermeable surface runoff

After the subtraction of initial losses, the model deals with losses during the rest of the rainfall. Modelled impermeable surfaces are dealt with in two parts. A percentage of the surface is assumed to be directly connected to the drainage system and to give 100% runoff. The rest of the surface is assumed to be less effectively connected to the drainage system and to behave as if it was permeable surface. This part is therefore added to the permeable surface. The normal values for the percentage that is directly connected are shown below. In exceptional circumstances, the user can adjust these to calibrate the model for a particular catchment. This should be clearly documented.

Surface type	**% effective**
Normal urban paved surfaces	60
Roof surfaces	80
Well drained roads	80
Very high quality roads	100

(The figure for normal paved surfaces was calibrated during the model development, the others are based on the best available information.)

5.3 Permeable surface runoff

The modelled permeable surfaces and the non-effective parts of the modelled impermeable surfaces are then taken together and the runoff calculated using a soil moisture storage model. The model is defined as:

Runoff = P * API / S

Where Runoff runoff depth in a timestep

P	rainfall depth in a timestep
API	antecedent precipitation index
S	soil storage depth

The percentage of the rainfall that becomes runoff therefore increases as the antecedent precipitation index increases. Unlike the API5 term used in the old PR equation the value of API is updated continuously throughout the simulation so that as the storm goes on the catchment gets wetter and the percentage of runoff increases. API is defined in the following section.

The soil storage depth S represents a notional soil depth that is wetting and drying due to rainfall and evapotranspiration. The default value is 0.2 m and this should not normally be changed.

5.4 Antecedent precipitation index

All definitions of antecedent precipitation index are similar in structure in that the effect of the rainfall is reduced by a decay factor for each day that passes. This represents the drying out of the catchment. The definition of antecedent precipitation index used with the original PR equation ignored evaporation and used a decay factor of 0.5 per day. This meant that after 5 days the multiplying factor was so small that any rainfall before this could be ignored, hence API5, the five day API. The decay factor did not vary with the soil type as SOIL was a separate term in the equation.

The new equation uses an improved definition of API that gives a more realistic measure of how wet the soil is. It takes account of evaporation and varies the decay factor (k) to represent the different rates of drying out of different soil types. For the high values of k, rainfall more than five days previously does have an effect. It is therefore necessary to include a longer history of rainfall and 30 days of rainfall should be used to calculate the API value.

Soil index	K(1 /day)
1	0.1
2	0.5
3	0.7
4	0.9

There are two steps to calculating the API at the start of the event.

Using daily rainfall data, calculate API9 the API to 9:00 am on the morning before the start of the event.

$$API_9 = \sum_{n=30}^{n=1} [P - E]_n k^{n-0.5}$$

Where n number of days prior to the event
P_n Rainfall on day n
E_n Evaporation on day n
k Decay factor depending on the soil index
$[P - E]$ Net rainfall is not allowed to take negative values

The 0.5 constant corrects the API from the middle of the rainfall day to 9:00 am.

Then calculate the adjustment to give API_E the value at the start of the event.

$$API_E = API_9 k^{(t-9)/24} + [P - E]_{(t-9)} k^{(t-9)/48}$$

Where $(t\text{-}9)$ Time in hours from 9:00 am to event start
$[P - E]_{(t-9)}$ Net rainfall from 9:00 am to event start

The evaporation rate varies seasonally and with location, but if no detailed information is available then the following approximate values can be used for UK conditions.

Winter - 1 mm/day
Summer - 3 mm/day

5.5 USING THE MODEL

For information on using activating the model in a particular piece of software reference should be made to the software manual or help system.

6. DESIGN VALUES FOR API

The new runoff model can be used with real rainfall data for model verification or with rainfall time series by calculating the API from the rainfall data before the event. However it is also necessary to define standard design values for use with synthetic (design) storms. Unfortunately no-one has funded the development of maps or tables of these standard values so they have to be derived for each study. Fortunately this is fairly simple.

The values should be derived by analysing a long rainfall record from a nearby raingauge. The analysis can use daily rainfall data. The API at the start of each day (I+1) is calculated from the value the day before (I) using:

$$API_{(I-1)} = API_I k + [P - E]_I k^{0.5}$$

Where $[P\text{-}E]_I$ Net rainfall from 9:00 am day I to 9:00 am day I+1

Then select the values for the start of days with more than 5 mm of rainfall. The median of these values gives the design value for long duration storms. Shorter durations need an adjustment to allow for the likelihood of earlier rainfall. If a study of this has not been carried out then the indicative values given below can be used. It is probably appropriate to use an annual value of API rather than separate summer or winter values. However the appropriateness of the chosen values should be demonstrated by comparing the results of design storms with continuous simulation of the full rainfall record using a simplified model of the catchment.

Duration (hrs)	Adjustment
1	+4.5
2	+3.0
4	+1.5

7. CASE STUDY - HAVERING

The sewerage study of the London Borough of Havering (Ref 2) made use of the new runoff model. This was a predominately separate system but with significant storm inflow into the foul system leading to flooding. It was not found possible to get a good match to measured flows using the PR equation. If the model was adjusted to give a good fit on an event with dry antecedent conditions it underestimated the runoff for wet antecedent conditions.

The new runoff model was therefore used for verification and was found to give a good representation with more runoff in the wet conditions. Design values of API were derived by analysis of a five-year rainfall record for an adjacent catchment and these were used to assess system performance. The new runoff equation gave significantly higher flow volumes than the PR equation but seemed to match well with recorded flooding.

8. References

1. A new hydrology model for the Wallingford Procedure. M P Osborne and J A Packman. WaPUG Spring meeting, May 1988.
2. Havering drainage area plans - a case study. D Brend, J Raymond. WaPUG Spring meeting, May 1996.
3. Runoff models - lessons from study audits. M Osborne. WaPUG Spring meeting, May 2000.

AMENDMENTS

Ver	Description	Date
1.	First Published	August 1993
2.	Revision	May 2001
3.	Editorial Amendments	March 2009