UPDATE OF ARC TP108 RUN-OFF CALCULATION GUIDELINE

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ABSTRACT

This paper focuses on the update of the Guidelines for Stormwater Runoff Modelling in the Auckland Region Technical Publication (TP108) to provide technical procedures to calculate event based stormwater discharges to design stormwater drainage facilities, treatment/detention devices and delineate flood inundation within the Auckland region.

The guideline provides rainfall depths for design storms from 3-month to 500-year Average Recurrence Interval (ARI). Maps with spatial distribution of rainfall depths for the relevant recurrence intervals are provided. For both approaches to calculate runoff hydrographs (SCS and Initial Loss and Constant Infiltration) it is necessary to run the full 24 hour storm duration.

For various methods to calculate runoff (Rational Method, SCS method and Initial Loss and Constant Infiltration) rain losses are provided.

The empirical based parameters curve numbers for the SCS method and runoff coefficients for the Rational Method are provided in relation to initial loss and constant infiltration values

Two methods to calculate the transformation from rainfall excess to runoff are provided in this guideline. The first employs the unit hydrograph approach which is based on the assumption that a catchment, in converting rainfall excess to runoff, acts as a linear, time invariant system. To take the large diversity of flow characteristics in impervious-connected and pervious-unconnected catchments into consideration, two unit hydrographs are provided.

The alternative methodologies can be picked in accordance with there limitations (eg lag time not more than ten minutes for Rational Method) and the simulation purpose (eg peak flow for flood estimation).

KEYWORDS

Hydrology, rainfall, runoff, rainfall losses, catchment lag time, runoff transformation, flood simulation, stormwater mitigation

1 INTRODUCTION

In 1992 the Auckland Regional Council (ARC) published two guidelines: Flood Flows in the Auckland Region, Technical Publication 4 (TP4; ARC, 1992a) and Selection of Stormwater Treatment Volumes for Auckland, Technical Publication 19 (TP19; ARC, 1992b). The purpose of TP19 was to provide an analytical methodology to estimate catchment-wide flood runoff. The calculation of stormwater runoff to design treatment devices was covered by TP4 In both guidelines the calculation approach adopted was a simplified method with focus on hand calculations rather than computer simulations.

In 1999 Guideline for the Stormwater Modelling in the Auckland Region, Technical Publication 108 (TP108; ARC, 1999) replaced TP19 and the hydrological portion contained in TP4. TP108 provided rainfall depths for 24 hour duration events from 2 year to 100 years Annual Recurrence Interval (ARI) for the entire region. This approach differed markedly from TP19 which was limited to statistical rainfall data at selected raingauge sites. TP108 also contained guidance on use of the Hydrologic Engineering Centre's Hydrologic Modelling System, HEC-HMS (USACE, 2006) to calculate computer based runoff hydrographs and hydrological catchment simulations.

Ten years later Guideline for the Stormwater Modelling in the Auckland Region. Volume A. Methodology is being updated to replace TP108. The new guideline is henceforth known as Guideline Document 2010/002 (GD2010/002). A companion guideline of worked examples will be published alongside the methodology as Guideline for the Stormwater Modelling in the Auckland Region. Volume B. Worked Examples.

The principal topics reviewed and updated in the new guideline are:

- Rainfall depth and design storm shape;
- Estimation of rainfall losses and runoff calculation; and
- Runoff transformation.

The new guideline maintains the content of TP108 while updating and refining the data upon which rainfall-runoff is computed in the guideline.

An additional ten years of rainfall record provided the opportunity to update the rainfall depth-duration-frequencies (DDF), allowing for increased confidence in the derived rainfall statistics. New DDF rainfall maps for 3-month to 500 years are provided within this guideline. The design storm shape (i.e. nested design storm versus other shapes) was investigated. The nested design storm was retained.

Also, importantly, while maintaining the Soil Conservation Service (SCS) rainfall-runoff method, the new guideline now includes alternative rainfall run-off methods.

Three approaches to calculate rainfall losses are now included in the updated guideline: (1) rational method, (2) SCS method and (3) initial loss - constant infiltration approach. Guidance is provided in which method to use depending upon the particular study or design situation.

Two methods to simulate runoff transformation are recommended in this guideline: unit hydrographs (i.e. the SCS method) or the kinematic wave. Underpinning each approach is a number of worked examples.

The introduction of the kinematic wave method (in conjunction with initial and constant loss method) provides a more physically based approach. It provides an alternative method that may be more suitable to certain design situations. It can also provide consistency and linkage for use with continuous rainfall-runoff simulation which will become a more common simulation and design tool in the near future.

In this paper the above mentioned topics of review, rainfall, rainfall losses and runoff transformation, are presented in detail.

2 RAINFALL AND DESIGN STORM

2.1 GENERAL

This section provides the derivation and selection of a synthetic (design) storm shape and its use for the Auckland region. The relevant attributes to describe natural and synthetic storm events are:

- Average recurrence interval (ARI) (i.e. frequency),
- Rainfall depth for a period of time (i.e. depth-duration),
- Temporal pattern to describe the variation of rainfall intensity over the given time period, and
- Areal reduction factor (ARF) that addresses the spatial variation of the rainfall event.

The rainfall depth-duration is provided for ARIs from 3-months to 500 years. Care must be used when utilising design storms exceeding 100-year ARI as there is less confidence in the rainfall statistics for very extreme events.

2.2 RAINFALL DATA USED

2.2.1

Data from 147 rain gauge stations (manual and automatic) were analyzed to provide sound base for the statistical analysis. Thirty one automatic stations with individual record time more than 13 years and total record time of 619 years have been used for statistical analysis. Further 117 additional manual stations with minimum individual record time of 20 years have been used to prepare rainfall intensity contour maps (Shamseldin 2008).

STORM CHARACTERISTICS

In addition to the ARI, three features are required to describe a storm event:

- total rainfall depth,
- duration, and
- spatial pattern.

These are described in detail below.

RAINFALL DEPTH

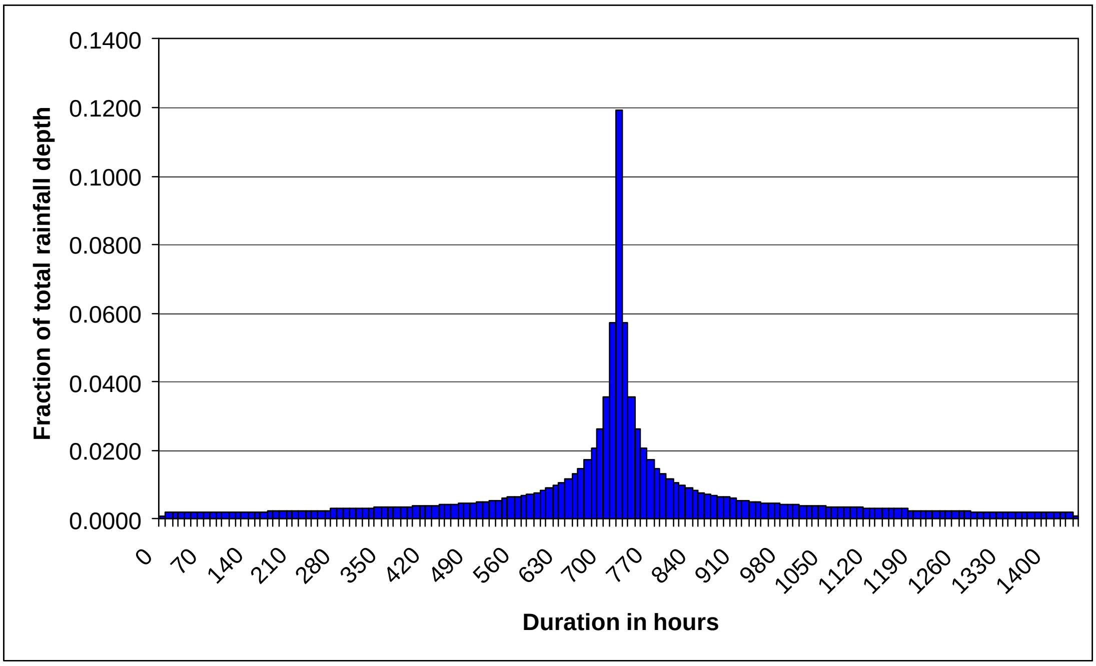
The total rainfall depth for a 24-hour design storm of various ARIs is provided and is also available in digital format. Rainfall depths for shorter durations can be computed by taking a subset of the 24-hour depth-duration from the centre of the 24 hour design storm hyetograph.

TEMPORAL PATTERN

The design storm is constructed in accordance with the Chicago Design Storm Hyetograph (Keifer and Chu 1957).

The design storm provided incorporates ten minute time intervals, consistent with the previous runoff guideline TP 108 (ARC 1999). Figure 1 shows the design storm temporal pattern.

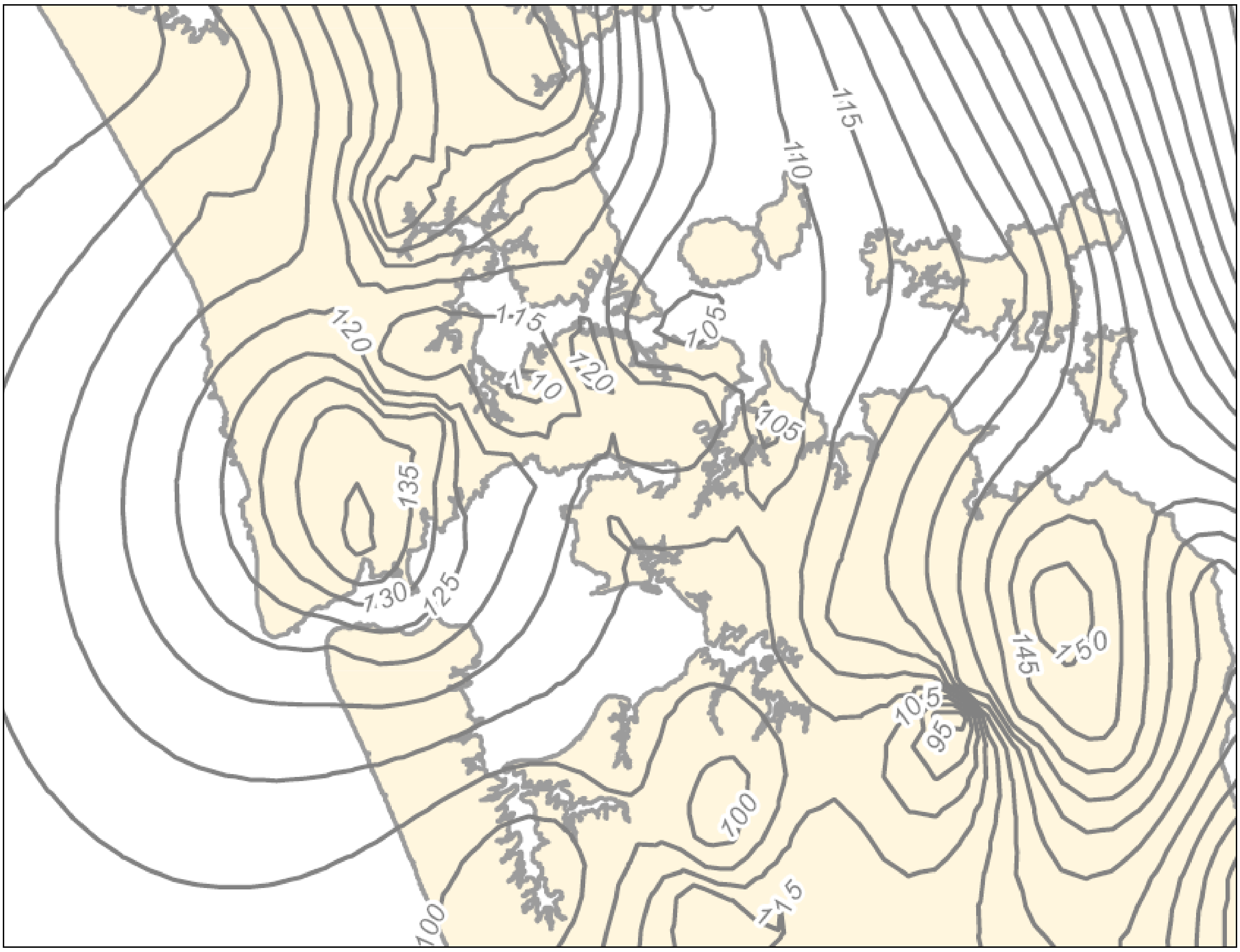
Figure 1: Chicago design storm shape based on rain gauges within the Auckland region (Shamseldin 2008). Time increment steps are ten minutes



SPATIAL PATTERN

Rainfall depth-durations are computed for points rather than catchment areas. These depth-duration relations were used to provide the rainfall intensity maps, as shown in Figure 2. This is because the data analysis is based on point gauging stations.

Figure 2: Extract of a rain intensity map of the Auckland Region. It shows the 24h rainfall depth for a 10 year ARI event



Areal Reduction Factors (ARF), as provided in Table 1, are used to convert the design storm rainfall depth from a point to an area. More information how the maps are produced and the ARF are derived, is provided in Shamseldin (2008).

Table 1: Areal Reduction Factors for the Auckland region (Shamseldin 2008).

Area (km2)	Duration of Storm (hours) / Lag time for catchment						
	0.5	1	2	3	6	12	24
<10	1	1	1	1	1	1	1
10	0.88	0.91	0.93	0.94	0.96	0.97	0.98
20	0.83	0.88	0.91	0.93	0.95	0.96	0.97
50	0.79	0.84	0.88	0.90	0.93	0.94	0.96
100	0.74	0.80	0.85	0.87	0.90	0.93	0.95
200	0.63	0.76	0.82	0.83	0.88	0.90	0.94
500	0.60	0.65	0.77	0.81	0.85	0.88	0.93

It is recommended to select a value in accordance to the study area time of concentration and size, and apply this to the 24-hour design storm.

FUTURE DEVELOPMENT AND CLIMATE CHANGE

Rainfall intensity increase will be taken into account in accordance with guidelines, provided by the Ministry for the Environment (MfE).

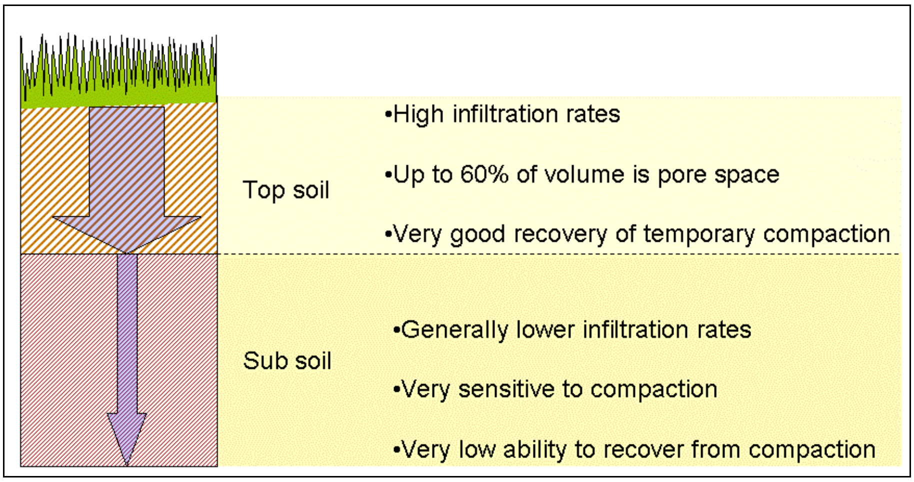
3 RAINFALL LOSSES

3.1 GENERAL

This section addresses how rainfall losses can be taken into account for hydrological simulations. Various methodologies are presented; runoff coefficients for the rational method, initial loss and constant infiltration rates, and curve numbers.

Undisturbed, natural soils in the Auckland region can be described as a composite of good draining top soils over sub soils with limited infiltration rates. A schematic sketch is shown in Figure 3.

Figure 3: Systematic composition of soils in Auckland region



3.2 SIMULATION APPROACHES

The way to define this in terms of hydrological modelling is the two parameter approach initial loss and constant infiltration rate. The initial loss represents the filling of surface depressions and top soil storage volume.

Previously the SCS curve number approach was the recommended methodology in the Auckland region. Curve numbers represent an empirical relationship between rainfall intensity and duration on the one hand and runoff volume on the other. The curve number approach is maintained in this guideline. However, curve numbers for the Auckland region have been refined to take into account initial loss and constant infiltration rates.

For small sites with a lag time less than ten minutes, and peak flow calculations, the Rational Method is presented as an alternative approach. The runoff coefficients were derived to fit constant infiltration rates.

3.2.1 PARAMETER EVALUATION

INITIAL LOSS AND CONSTANT INFILTRATION

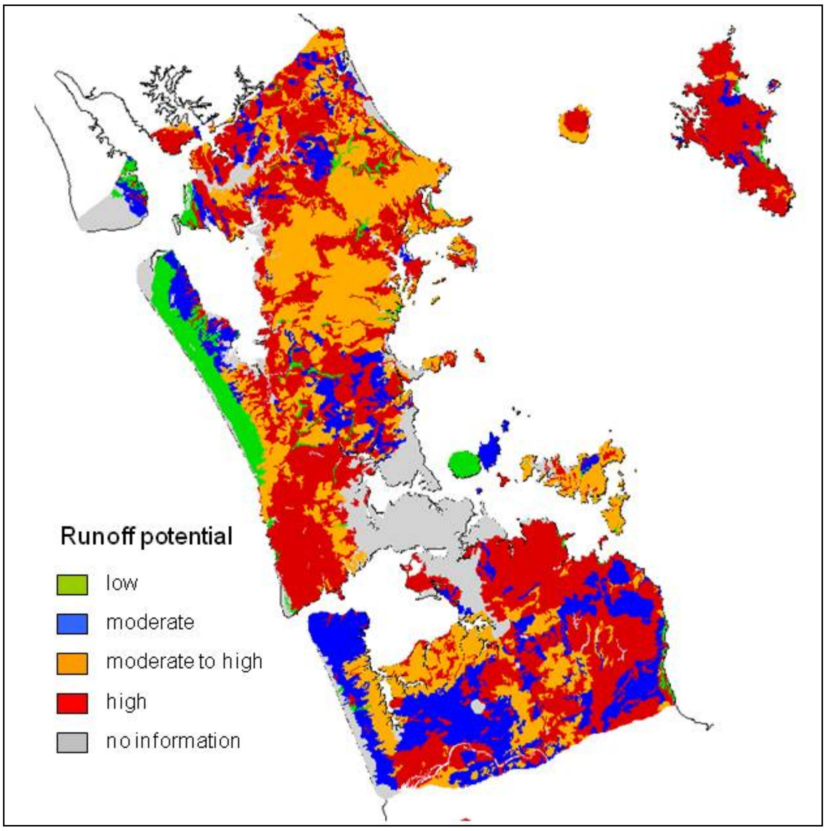
The maximum top soil storage volume can be estimated by measuring the top soil depth and assuming the available pore space of the total volume. The total volume is only available after a longer dry period and not particular relevant for flood or mitigation simulations.

The design of devices to mitigate the effects of land development and urbanisation on the catchment hydrology can be based on average moisture conditions in pre development situation. It is considered that the soil field capacity presents these average soil conditions. This means that all soil pores that can be drained by gravity are filled with air. Pores that are small enough to hold water by capillary forces are filled with water and are not available for initial losses in the case of a rainfall event.

Flood simulations were undertaken for rainfall events of an average recurrence interval (ARI) of 2 years and greater. It is assumed that rainfall events of these recurrence intervals are unlikely to occur on dry soils and without any previous precipitation. As the 24 hour event time is not long enough to estimate the soil moisture conditions in a larger storm event (Institute of Hydrology, 1999), this estimation must be undertaken in the first part of the simulation. For a conservative simulation it is assumed that a major rainfall event is based in a longer rainfall period than 24h. In this case the initial loss volume should be considered as filled. Therefore zero or very low initial losses should be applied.

Subsoil infiltration rates can be measured on site by using a double ring infiltrometer in accordance with the relevant ASTM guideline (ASTM, 2003). Alternatively the infiltration rate can be assumed from Figure 4.

Figure 4: Constant infiltration rates for subsoils within the Auckland region



Apart from very few areas in the north, the region is dominated by soils with high clay content. For this reason, sites which are earthworked with heavy machinery possess a very limited infiltration rate, limited to 2 mm h-1 (ARC 2009b).

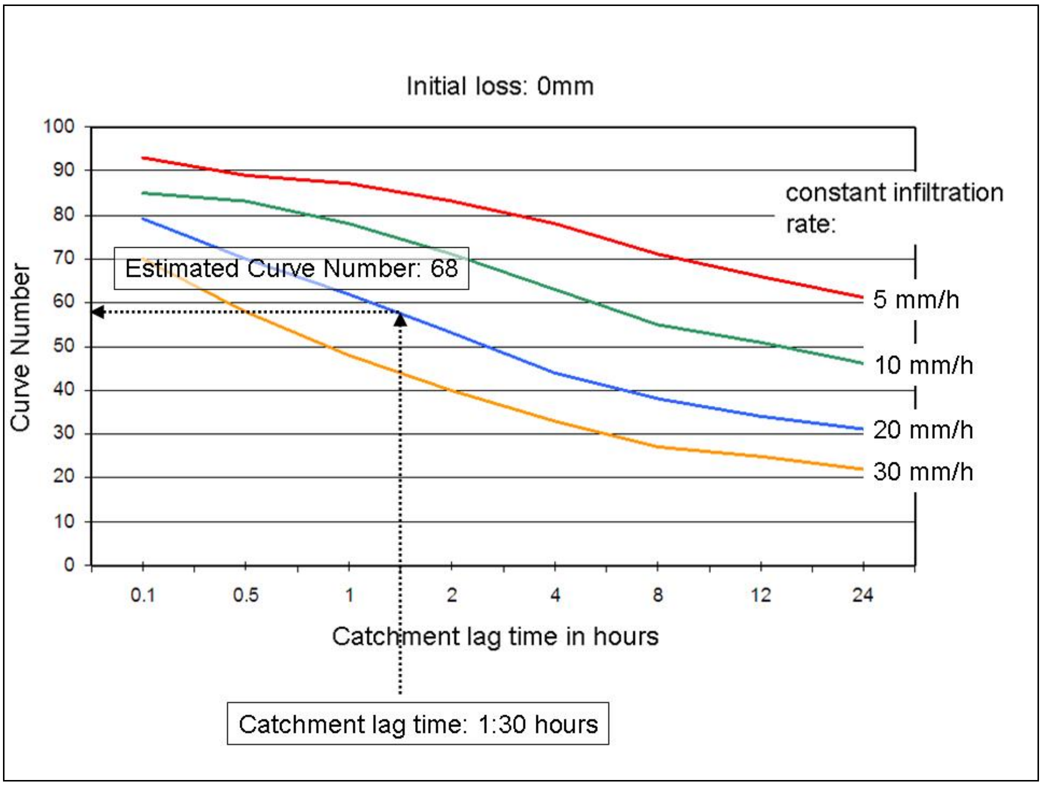
If not demonstrated through infiltration tests, disturbed soils in urban areas are considered to have an infiltration rate of 2 mm h-1 (marked grey in Figure 4.2).

SCS CURVE NUMBERS

The SCS Curve Number approach is strictly limited to peak flow rates.

Input parameters for the SCS Curve Number approach in this guideline are initial loss and constant infiltration. These parameters must be measured or estimated. The third input parameter is the catchment lag time, which must be estimated. Figure 5 shows the curve number table for an initial loss of 0 mm. Further tables for initial losses in 10 mm intervals, up to 40 mm, are provided. If initial loss values are between the intervals, the Curve Numbers can be interpolated.

Figure 5: Curve number derivation chart for 0 mm initial loss. Input parameters are constant infiltration rate and catchment lag time.



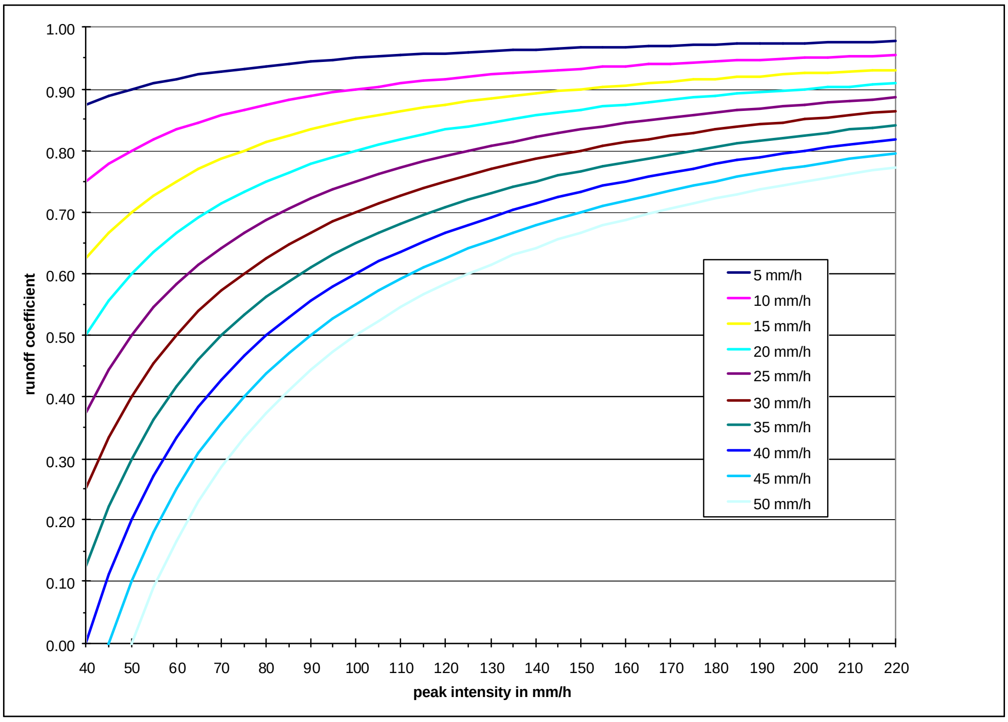
In the example, shown in Figure 5, the curve number is required for a flood simulation. As the simulation assumes a conservative result, the assumption is made that the initial loss volume is filled by antecedent rainfall. Therefore the initial loss is zero.

The constant infiltration rate is defined to be 20 mm/h. The catchment lag time is calculated to be 1:30 hours. The curve number for this catchment conditions is to 68.

RUNOFF COEFFICIENT

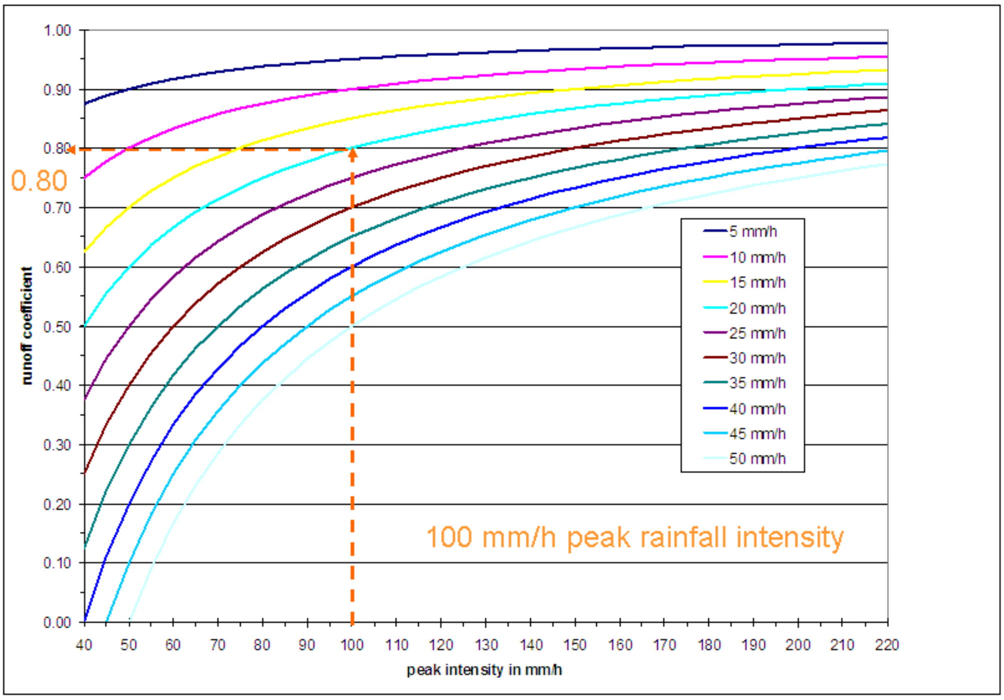
In the Rational Method, runoff coefficients are used as a percentage of loss. This makes it necessary to relate constant infiltration to rainfall intensities. In Figure 5 are constant loss rates and peak rainfall intensities related to runoff coefficients. Loss rates are provided in 5 mm intervals. If necessary, results for runoff coefficients can be interpolated or calculated with the equation provided below.

Figure 5: Curve number derivation chart. Input parameters are constant infiltration rate and catchment lag time.



An example how to derive this graphically is shown in Figure 6. For infiltration rate of 20 mm/h and a peak rainfall intensity of 100 mm/h the runoff coefficient results to 0.80.

Figure 6: Curve number derivation chart with worked example. Input parameters are peak rainfall intensity (100 mm) and constant infiltration rate (20 mm).



Alternatively the runoff coefficient can be calculated, using the following equation.

$$C = \frac{(I_P - L)}{I_P}$$

Where:

C Runoff coefficient

IP Peak rainfall intensity (mm/h)

L Constant infiltration rate (mm/h)

Using the same example from above again, the runoff confinement results to 0.80.

$$C = \frac{(100 - 20)}{100} = 0.80$$

4 RUNOFF TRANSFORMATION

4.1 GENERAL

Runoff transformation is the process of change from the temporal pattern of the rainfall event to the temporal pattern of the runoff event.

This section provides two methodologies to simulate this process. All input parameter to use these methodologies are provided.

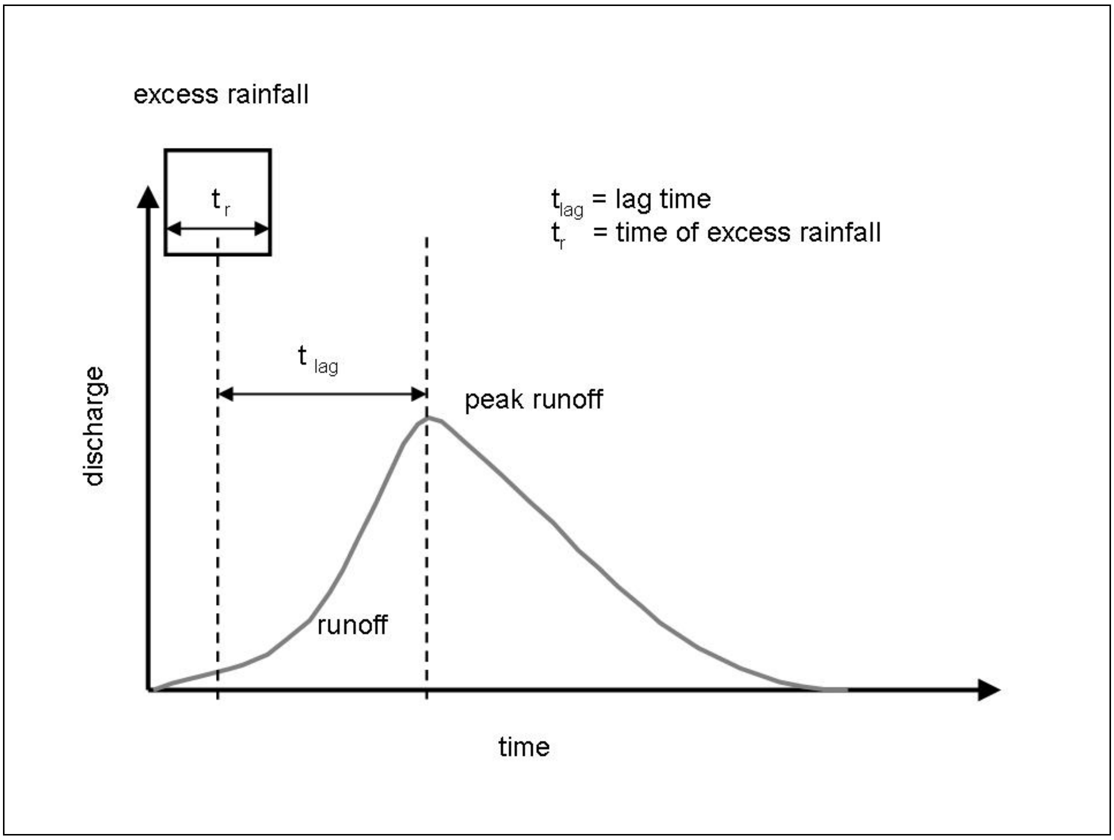
The first approach employs the unit hydrograph and is based on the assumption that a catchment, in converting precipitation excess to runoff, acts as a linear, time invariant system. The second is based on mathematical simulation of surface runoff using the kinematic wave. The kinematic wave takes into consideration that rainfall intensity and consequently the runoff volume varies over time. This variation effects the runoff transformation. Therefore the kinematic wave approach is suitable for continuous simulations, where rainfall intensity varies significantly.

4.2 UNIT HYDROGRAPH

The unit hydrograph represents the “response”, which means the concentration of runoff, for a given catchment resulting from a unit volume. In the metric system, the “unit volume” is that due to 1 cm of effective rainfall generated runoff. Unit hydrographs can be derived for gauged catchments from measured rainfall and runoff events. An alternative to site specific hydrographs are synthetic unit hydrographs. The synthetic unit hydrograph averages the runoff transformation.

The only input parameter besides the excess rainfall volume is the catchment lag time. For use in the guideline lag time is defined as the time between the centres of mass of the excess rainfall to the peak of the catchment runoff (Figure 7).

Figure 7: Illustration of lag time (t_{lag}) of a unit hydrograph (Bedient and Huber, 1992)



4.2.1 LAG TIME CALCULATION

Similar to the kinematic wave approach, the lag time calculation is broken down to overland and concentrated flow.

OVERLAND FLOW

The equation to calculate the overland flow time is based on the kinematic wave equations and is adjusted to provide best fit with the kinematic wave simulations in HEC HMS.

$$t_{lag} = 1.2 * \frac{9.2184 * L^{0.6} * n^{0.6}}{I^{0.4} * S^{0.33}} \qquad (5.1)$$

with:

t_{lag}	catchment lag time in hours
L	length of flow path in km
n	surface roughness
I	rainfall intensity in mm h^{-1}
S	slope in %

Input parameters for the equation are surface slope, length, roughness, and rainfall intensity. The lag time is given in hours.

CONCENTRATED FLOW

Concentrated flow can be calculated with hydraulic models or by a hand calculation, using the Manning's equation:

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

With:

V	flow velocity in m s^{-1}
R	hydraulic radius in m
S	slope in m m^{-1}
n	Manning's n in s $m^{-1/3}$

For post development scenario simulation, flow velocities are often available from design calculations.

For calculations of the level of subdivision size, concentrated flow has a very limited contribution to total lag time, due to its high flow velocities. For estimation purposes or if no design information is available, flow velocities for various channel and stream types is provided in Table 3.

4.3 KINEMATIC WAVE

4.3.1 GENERAL

The kinematic wave approach is based on a simplified hydraulic calculation of one dimensional flow. Surface or overland flow and concentrated or channelized flow are calculated separately as both kinds of flow are affected differently by surface roughness. Further information is available in textbooks and manuals (Bedient and Huber, 1992; USACE, 1994).

4.3.2 OVERLAND FLOW

The input parameter for the over land flow calculation are:

- surface slope
- length of flow path
- surface roughness
- rainfall

Surface slope and length can be estimated on site or by using plans and maps. The Manning's roughness coefficient in relation to the surface cover can be taken from Table 2.

Table 2: Roughness coefficients for surface runoff (Engman 1986)

Surface description	Manning's n
Smooth surfaces	0.011
(concrete, asphalt, gravel, bare soil)	
Grass	
Poor grass stroke	0.15
Dense grass stroke	0.24
Forest	
Light underbrush	0.40
Dense underbrush	0.80

If the catchment has particular inhomogeneous overland flow the parameter should be averaged by using a weighted average.

4.3.3 CONCENTRATED FLOW

An additional parameter for concentrated flow, as occurs in channels and pipes, is the channel/pipe geometry. The approximately geometry can be estimated on site or by using topographic maps and building plans. Concentrated flow has different Manning's n than overland flow. Table 3 shows typical Manning's n values for concentrated flow in channels and pipes.

Table 3: Typical roughness coefficients for channel flow (Chow el al 1988)

Surface description		Manning's n
Concrete		0.012
Gravel bottom with sides	- concrete	0.020
	- mortared stone	0.023
	- rip rap	0.033
Natural stream channels:		
Clean, straight stream		0.030
Clean, winding stream		0.040
Winding with weeds and pools		0.050
With heavy brush and timber		0.100
Flood Plains:		
Pasture		0.035
Field crops		0.040
Light brush and weeds		0.050
Dense brush		0.070
Dense trees		0.100

5 CONCLUSIONS

In a nutshell, the three essential elements of a hydrological simulation are:

- Rainfall (How much, how long, in what temporal and spatial distribution)
- Rainfall losses (how much of the rainfall contributes to surface runoff, how much is detained)
- Runoff transformation (how is the runoff affected by hydraulic factors as surface roughness)

All these simulation elements were subject of the TP108 review.

The new findings and methodologies, presented in this paper, will be published in the ARC GD2 (Guideline Document 2). The paper is expected to be released for discussion by mid 2010.

ACKNOWLEDGEMENTS

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