HYDROLOGY – PROVEN WAYS TO CHEAT

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ABSTRACT (200 WORDS MAXIMUM)

Contrary to the title, this presentation is not intended to provide a blueprint as to how to cheat. This paper is aimed at all stormwater professionals, on both sides of the consent application process.

Hydrologic applications in practice are still based on many assumptions and simplifications. Some of them are necessary and defendable, others are misleading and can be used to bias the model output in favour of the modeller.

This paper provides a collection of examples and errors that often occur in stormwater resource consent applications. Intentional or not, those errors can result in under or over sizing of stormwater infrastructure. In the interest, therefore of the receiving environment and the efficient use of (financial) resources, these errors should be avoided. This paper can only cover a small portion of the wide field of hydrology and concentrates on the use and abuse of the ARC guideline TP 108. The examples will show:

1. The significant influence of the catchment lag time on simulation results and how this is calculated correctly.

2. How changes to the proposed simulation approaches affect the results of runoff peak flow and volume calculations.

KEYWORDS

Initial loss, constant infiltration, kinematic wave, curve numbers, unit hydrograph, time of concentration, lag time, detention devices under sizing

PRESENTER PROFILE

Background: Hydrology, Hydraulic, Water Resource Management, Interaction of Ground and Surface Water. Current role: Research on stromwater quantity and quality treatment methodologies and their introduction into relevant guidelines.

1 INTRODUCTION

This paper is intended to show the effects that changes in simulation methodology and parameter can have on the sizing of treatment devices. It is not aiming to disqualify users that used similar simulation approaches in the past.

The focus is on the effect that small and often underestimated changes of simulation parameters or simulation approaches have to modelling results. A qualified engineer can use these effects to bias the simulation results and to make them more suitable to own or client expectations. The line between stretching the necessary assumptions and cheating is broad and vaguely defined. The reason for this is that hydrology is a rather complex science and is often simplified and adjusted to tasks and user capabilities.

For the purpose of this paper a fictitious calculation to size a storage volume to maintain natural peak flow conditions is utilised to demonstrate potential adjustments.

Calculations are not explained in detail as the targeted audience is expected to be familiar with those procedures. Instead the focus is set on the discussion of the results.

2 EXAMPLE BACKGROUND

In the Auckland region, land development above a certain threshold is required to provide storage volume for stream habitat protection and peak flow mitigation from the two and ten year ARI storm events.

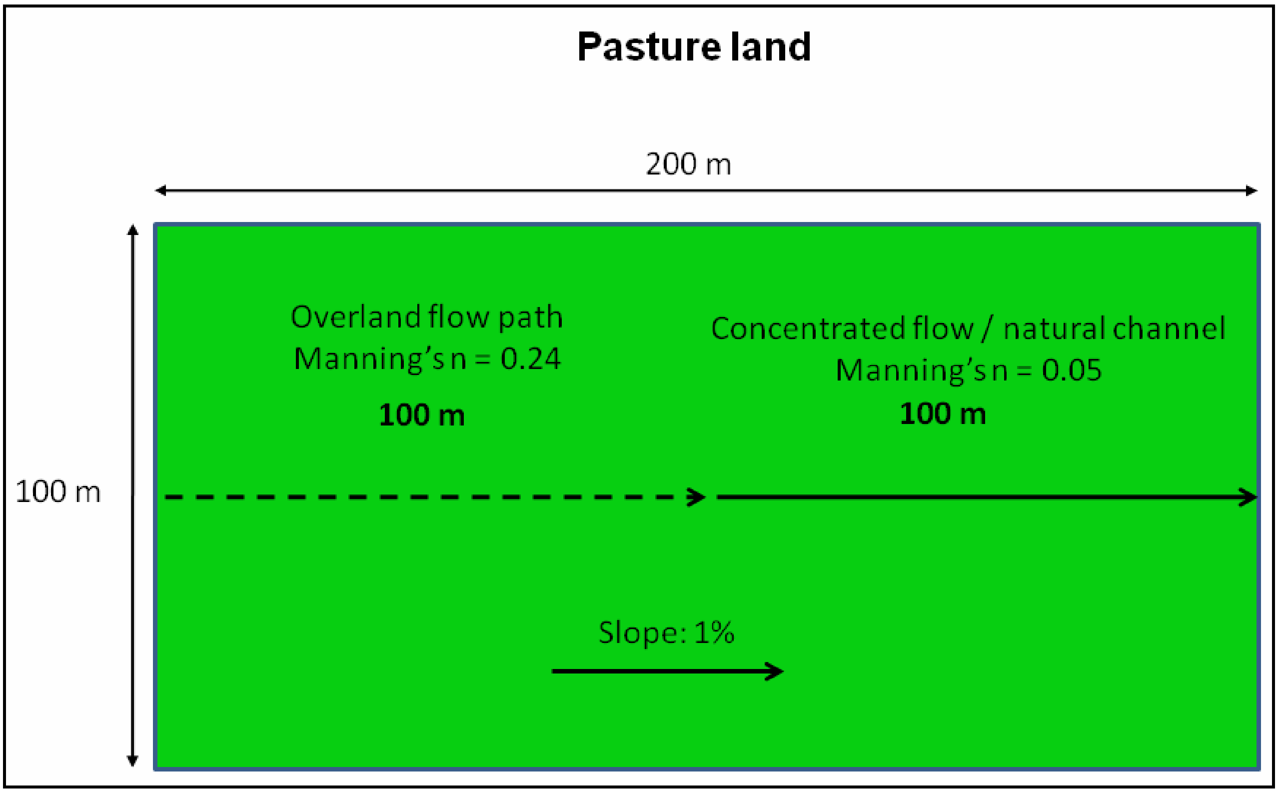
In this example the two year ARI storm was chosen.

To demonstrate the potential effects of the variation of parameters and methodologies, a benchmark was set up by using a detailed simulation. Physical based methodologies to simulate rainfall losses (initial loss, constant infiltration) and runoff transformation (kinematic wave) were chosen for this benchmark simulation. In further steps, the degree of detail was reduced and empirical simulation approaches were applied. The results (section 4) were then compared with the benchmark.

3 THE SITE

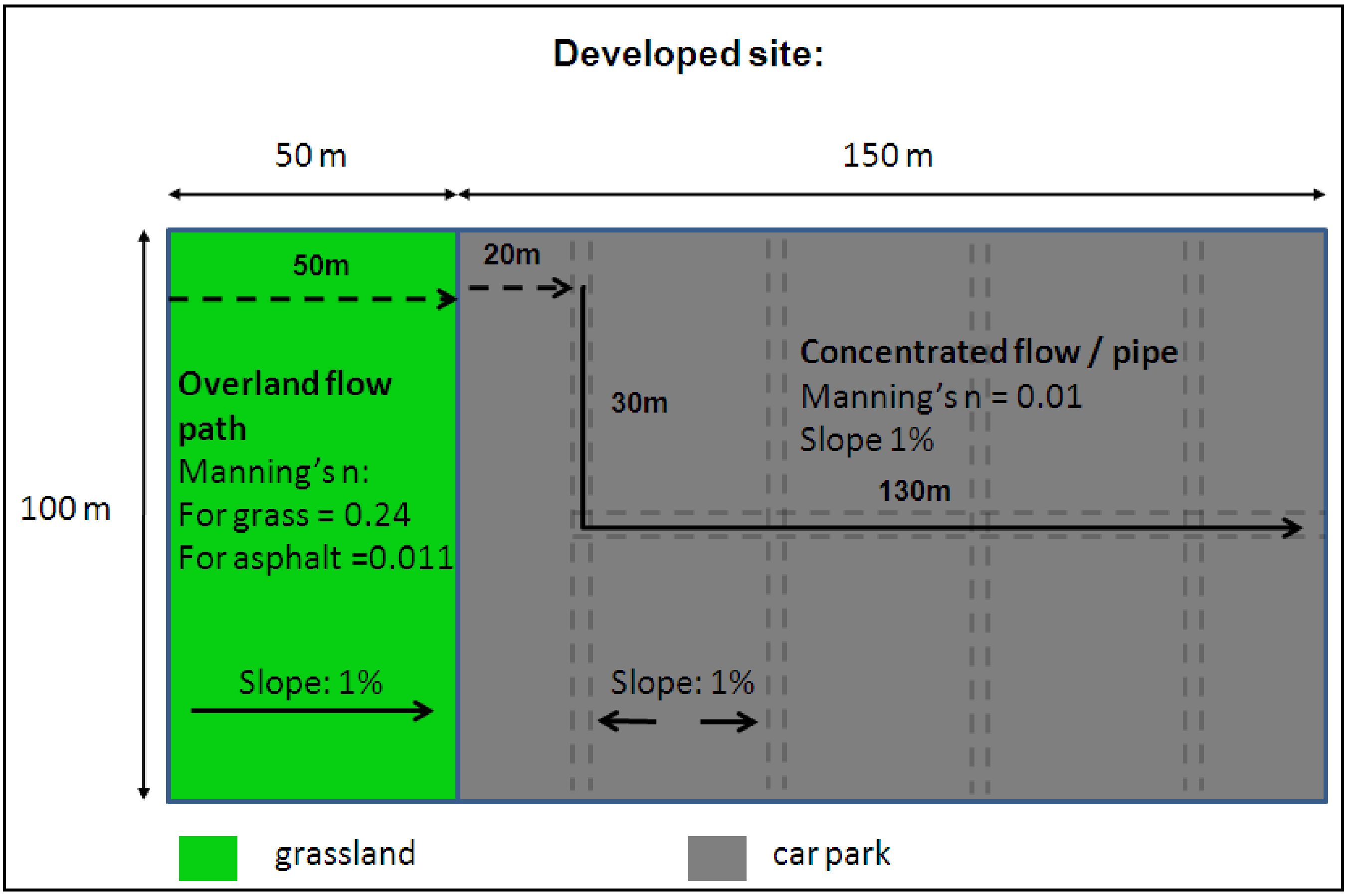
The example site is a two hectare pasture field. It is covered with dense grass vegetation. The subsoil is of clay nature as typically found in the Auckland region. Topsoil is well draining and has a depth of 0.2 meter. A sketch of the site is shown in Figure 1. The soil horizons are shown in Figure 3.

Figure 1: *Schematic sketch of the pasture field with runoff flow path, before development.*



The fictitious development of this site is the creation of a sports field with an adjacent car park. For this purpose the entire site requires earth working to provide a level area for the sports field and a compacted underground to build the car park. The car park area is drained with a catch pit/pipe system. A sketch of the developed land is shown in Figure 2.

Figure 2 *Schematic sketch of the cark park and grassland feature and the runoff flow path.*



4 DETAILED SIMULATION TO SET BENCHMARK

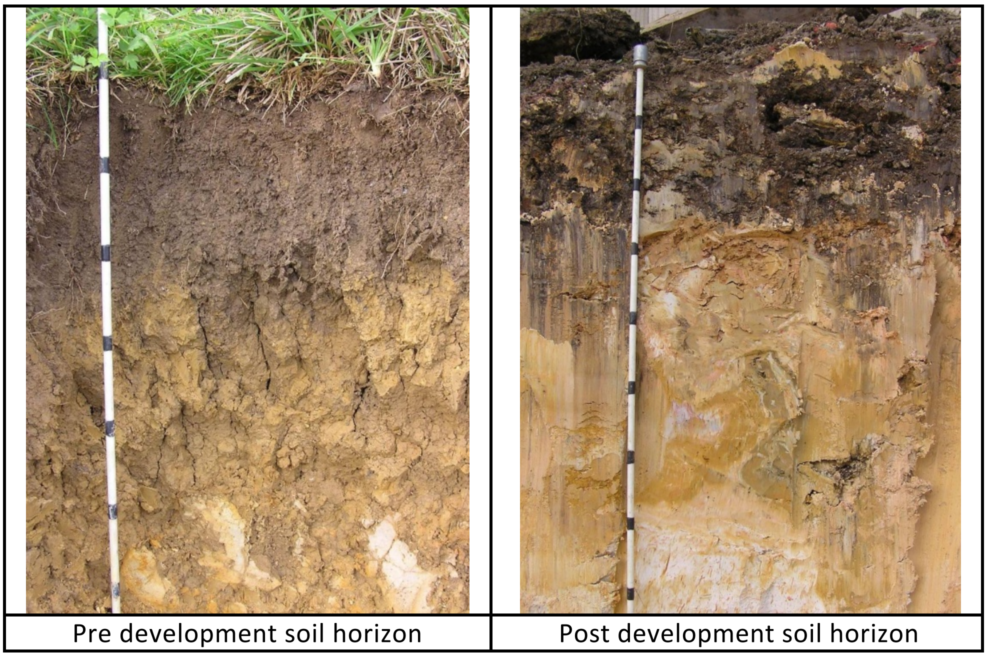
For this simulation, the initial loss and constant infiltration approach was applied for the loss calculation. Runoff transformation was calculated by applying the kinematic wave approach. The catchment was subdivided in areas with homogeneous hydrological characteristics. Runoffs from those areas are simulated separately as runoff is generated separately. The separation is between pervious and impervious surfaces for the developed area.

An overview of all relevant simulation parameters is provided in Table 1. It is important to note that the pre and post development infiltration losses for the pervious area differ significantly. Causal for this is the effect that earthwork and associated compaction have on the hydrological characteristics of soils and clay soils in particular. Figure 3 shows a typical Auckland soil composition and the effect earth work has. Measured loss rates for natural and developed sites within the Auckland region can be found in Technical Report TR 2009/73 (ARC 2009b).

Table 1: Simulation parameter for the benchmark simulation

Parameter		**Natural**	**Developed**		
			Pervious	Impervious	Combined
Rainfall		2 year ARI; 85 mm/24 h; GD02design storm distribution			
Area		20,000 m2	5,000 m2	15,000 m2	20,000 m2
Losses	Initial	20 mm	5 mm	0 mm	1.25 mm
	constant	20 mm/h	2 mm/h	0 mm/h	0.5 mm
Overland flow path	Slope	2 %	2 %	2 %	2 %
	Length	100 m	50 m grass + 20 m asphalt	20	50 m grass + 20 m asphalt + 180 pipe
	Manning’s n	0.24	0.24 for grass 0.01 for asphalt	0.011	0.24 for grass 0.01 for asphalt and pipe
Channelized flow path	Slope	2 %	2 %		
	Length	100 m	180 m		
	Manning’s n	0.01	0.01		

Figure 3: Pre and post development soil horizons from the Auckland region.(photos taken from TR 2009/74 (ARC, 2009), prepared by Landcare Research.



Pre development soil horizon

Post development soil horizon

4.1 BENCHMARK RESULTS:

Runoff from the natural site is reasonable low with a peak flow rate of 0.04 $m^3 s^{-1}$. The reasons for this are: the loss rate of 20 mm h^{-1} and even more important the long lag time of 30 minutes has extended the period of peak flow and consequently reduces the peak flow rate.

For the development conditions, the runoff volume and peak flow is much higher as shown in Figure 4. The peak flow rate is 0.30 $m^3 s^{-1}$. This is approximately ten times the peak flow rate for the undeveloped area. To maintain the natural peak flow rate, a storage volume of 465 m^3 is required.

5 CHEAT WITH INITIAL LOSS, CONSTANT INFILTRATION AND KINEMATIC WAVE

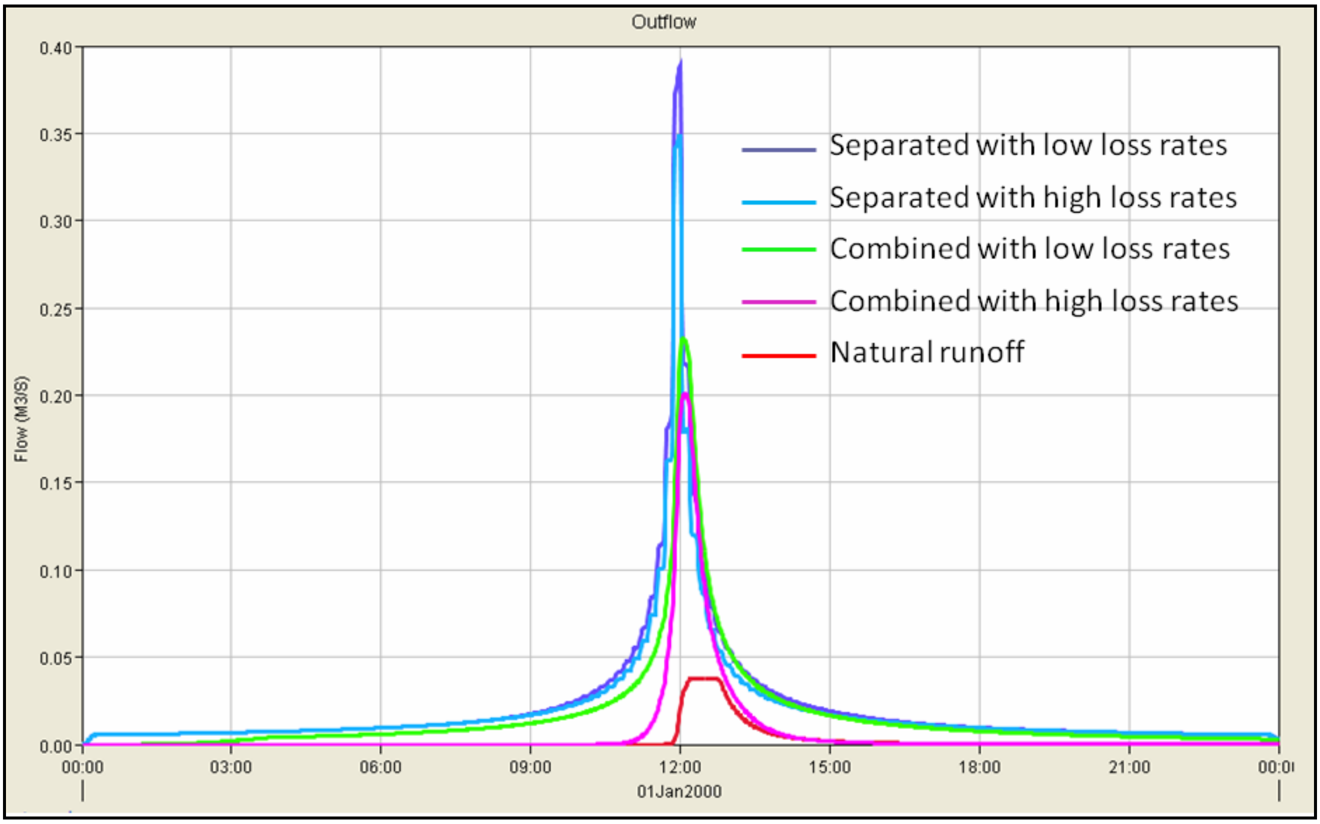
5.1 STEP 1: HIGHER INFILTRATION RATES

Often no difference is made between natural and earth worked soils. For undeveloped and developed scenarios the same loss rates are applied. If the same infiltration rate is applied for grass surfaces the peak runoff is reduced by 10 percent as shown in Figure 4. However, required storage volume can be reduced by approximately 25 percent. The required volume is 344 m^3.

5.2 STEP 2: COMBINING THE AREAS

This cheat aims to extend the flow path and consequently the flow time in the developed situation. It is often used and even recommended in some local guidelines. This cheat is particular effective when peaky design storms are used. As result the peak flow rate is reduced by approx 20%. However, there is no effect on the detention volume in the provided example.

Figure 4 Comparison of pre and post development runoff resulting from a two year ARI design storm with variations in loss rates flow path length.



5.3 CHEAT WITH CURVE NUMBERS (CN) AND KINEMATIC WAVE

When it comes to cheating, or adjustment of results, the curve number approach provides an additional benefit. The actual loss rate is very hard to determine. The loss rate in CN varies with storm intensity and simulation time. It becomes even more unclear if an additional initial loss is applied. This fact makes it very hard for any reviewer to check if the appropriate curve number has been chosen.

In this example, the curve number provided in TP 108 (ARC 1990), which comes closest, with still some difference to the 20 mm h^{-1} constant loss rate that is assumed for the pre development site is CN 61. However, CN 61 is the recommended CN for pasture in alluvial soils. For the more clayey soils in our example, which are shown in Figure 3, the recommended CN is 74. Peak runoff from simulations with constant infiltration rate 20 mm h^{-1}, Cn 61 and CN 74 are shown in Figure 5.

Figure 5 Site runoff from the pre development pasture land, applying CN 61 (blue line) and constant infiltration rate 20 mm h^{-1} (red line).

However, CN 61 is hardly used in the Auckland region, where pasture land usually is simulated by using CN 74. This CN provides a higher runoff rate as can be seen in Figure 5. An additional advantage, in regard to adjust the results, is that the CN 74 can be used for all grassed areas on silty or clay soils. No difference is made in TP 108 in regard to earth worked or natural soils. Consequently the same CN is applied for pre and post development simulations.

The use of CN 74 increases the pre development peak flow rate almost by factor two. The higher this pre development peak flow rate is, the higher the release rate from the detention device and the higher is the threshold, form which on onwards detention is necessary. Consequently less storage volume is needed.

To calculate the necessary storage volume, runoff from the development site was simulated by using CN 74 plus an additional initial loss of 5 mm for all pervious areas as recommended in TP 108. Impervious areas were simulated by applying CN 98 and no additional initial loss. As in the example above, the runoff was calculated in two ways: separated simulation of impervious and pervious areas and combination of both with averaged CN's. The results are shown in Figure 7.

Figure 6 Runoff simulation results for the pre and post development situations. The red line shows the pre development runoff. Runoff for the post development situation is shown in dark blue (impervious and pervious areas calculated separately) and light blue (pervious and impervious areas are combined).

The differences in the runoff hydrographs are significant. The peak runoff for the simulation of separated areas is quite similar to the benchmark simulation, which applied constant infiltration rates. This may surprise as the CN 74 has a lower loss rate. In this example the high runoff volume from the impervious area masks the effect that the lower loss rate of CN 74 has in this example. However, the difference is significant for the pasture land in the natural situation, as shown in Figure 6. This has a major effect on the storage volume required to maintain the pre development flow rate. The benchmark storage volume is 465 m^3.

Depending on the CN used to simulate the runoff for the pasture, the necessary detention volume is around 320 m^3 (CN 61), respectively 194 m^3 (CN 74).

Simulating the post development situation in a combined or separated area approach has a significant impact on the peak flow rates. However, as above, the detention volumes are not affected.

With some common modelling techniques, that most likely would pass the review, the volume is already reduced from 465 m^3 to 194 m^3. Is it possible to reduce this any further?

5.4 CHEAT WITH CURVE NUMBERS (CN) AND TP 108 TIME OF CONCENTRATION APPROACH

As shown in the examples above, variation to the catchment lag time makes a difference to the peak flow rate. The shorter the lag time in the natural catchment and the higher the peak flow rate consequently is, the smaller the required storage volume becomes. Cheating with the kinematic wave approach to manipulate the lag time is not impossible, however, the input parameter are transparent and can be easily checked.

Nonetheless, there are alternatives! In the Auckland region and other parts of New Zealand TP 108 (ARC 1999) is the relevant guideline to calculate runoff from rainfall. The guideline comes with a simple and easy to use approach to etimate the time of concentration and lag time (in TP 108: lag time = 2/3 times of concentration).

The TP 108 approach to calculate the lag time was used and results are shown in Table 2. The TP 108 equation is shown below as equation 1. Inputparameter can be taken from Table 1.

$$t_c = 0.14\, C\, L^{0.66} \left(\frac{CN}{200 - CN}\right)^{-0.55} S_c^{-0.30} \qquad \text{Eq: 1}$$

S: catchment slope
L: length of flow path
C: channelization factor (1 natural, 0.6 piped)

Table 2 Lag times for the example catchments calculated in accordance with TP 108

	Lag time (minutes)
Natural (CN 74)	6.67
Separate areas (CN 74 and 98)	6.67
Combined area (CN 92)	6.67

Surprisingly enough, the lag time for the natural and the developed situation are identical. Considering the above statement, the shorter the lag time in the natural catchment, the smaller the required storage volume becomes. This may have a significant effect on the necessary storage volume.

The runoff hydrographs for the pre and post development situation are shown in Figure 7. Obviously the difference in peak flow has reduced significantly compared to the benchmark and other simulations shown earlier. The post development peak flow only increases by 70 per cent compared to the pre development situation. Consequently the required storage volume results to very convenient 75 m^3. This is a reduction of more than factor 6 compared of the storage volume calculated in the benchmark simulation.

Figure 7 Pre and post development runoff hydrographs, resulting from TP 108 calculations.

6 CONCLUSIONS

The intention of this paper is not to function as blue print to cheat. However, it shows some weakness in methodology in existing guidelines. These weaknesses in combination with some daring assumption in regard to loss rates, can help the design engineer to reduce the required storage volume significantly.

Earlier work undertaken in the Auckland region, demonstrated that the infiltration rates of clay soils should not be neglected (ARC 2009b). The effects of earthwork are often understood but neglected in relevant guidelines.

The combination of catchments is an often seen technique, which should be handled with care. Pervious and impervious areas produce independent hydrographs, even if both draining to one outlet. This should be considered in all simulations.

The revised version of Auckland Councils rainfall runoff guideline will address these issues and provides clear guidance how to avoid those errors.

REFERENCES

ARC 1999: TP 108 - Guidelines for storm water runoff modelling in the Auckland region. Technical Publication TP 108

ARC 2009a: Technical Report TR 2009/074 – Identification of permeable soils within the Waitemata formation, Region, Auckland Regional Council

ARC 2009b: Technical Report TR 2009/073 - Hydrological effect of compaction associated with earthworks, Auckland Regional Council