TP108 – WHERE TO FROM HERE?

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ABSTRACT

Technical Publication 108 (TP108) was published by Auckland Regional Council (ARC) in 1999 and has been used as the primary flow estimation tool in the Auckland region since then. For the past ten years there has been consideration by ARC and then Auckland Council (AC) of updating the guideline, but a new version is yet to be adopted.

Similarly, there have been moves within the stormwater industry, supported and promoted by Water NZ, to develop a national standard similar to *Australian Rainfall and Runoff* to establish consistent and reliable flow estimation methods across NZ. In the absence of that guidance, many different flow estimation methods are in use, with variable reliability and suitability.

In the absence of national guidance, TP108 (or the NRCS (Natural Resources Conservation Service of the US Department of Agriculture) method on which it is based) has been adopted and adapted in part or in full for urban runoff estimation in other parts of New Zealand, and is widely used, but also in some respects misused. This misuse arises in part from a lack of understanding of the basis on which TP108 was adapted to the Auckland Region, and sometimes a lack of robust (or in some cases any) validation of the method to local conditions in new areas.

This paper sets out some underlying principles on which the application of the NRCS method to Auckland were based, and how it was adapted and validated to suit the particular requirements that ARC had defined. It discusses some examples where the method has been used inappropriately, or in new areas, resulting in poor estimation of runoff characteristics. From there the paper provides some guidance on factors that should be addressed, particularly in relation to validation, when transferring the method to other parts of New Zealand. There is also commentary on appropriate contexts in which to use the method, and where other tools might be more appropriate.

KEYWORDS

Floods, runoff, flow estimation, TP108, guideline

PRESENTER PROFILE

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1 INTRODUCTION

The Auckland Regional Council (ARC, now Auckland Council (AC)) Technical Publication 108 (TP108; ARC (1999)) was developed as a standard approach for designers and regulators for the calculation of stormwater flows for the Auckland Region. It had a particular focus on urban stormwater, and on understanding the effects on catchment hydrology of the change from rural to urban land use. It was developed from the US Soil Conservation Service (SCS, now Natural Resources Conservation Service (NRCS) of the US Department of Agriculture (USDA)) runoff method, originally developed in 1954 based on extensive field data collection over several decades, and uses curve numbers to characterize soil and land use hydrological response. A subsequent simplified calculation method for urban watersheds, TR-55 (USDA (1986)), provided background to the manual calculation approaches in TP108.

TP108 is a relatively simple approach that avoids direct modelling of the physics of the hydrological processes taking place, but is instead strongly based on reproducing what is actually observed in hydrological basins. The combination of this simplicity, and the connection to reality, that make it attractive. Therefore, when ARC was considering options for a guideline, and settled on the NRCS method, it was in the context of a significant effort to validate it to local Auckland conditions.

The attraction of the method, and the experience from Auckland use, has resulted in it being adapted and/or adopted in other parts of the country, sometimes with validation to local conditions, and sometimes not. Unfortunately, without that validation, as with any hydrological method, there is a risk of significant error in flow estimates.

This paper is intended as a thought piece to stimulate further discussion and action towards robust and standardised urban hydrological analysis in New Zealand, including the wider use of the TP108 approach, and is not intended to provide a comprehensive scientific analysis of methods or design parameters.

2 TP108 DEVELOPMENT

2.1 PERFORMANCE CRITERIA

It is important to recognise that the development of TP108 took place in a particular context, and if different performance criteria had been used, a different methodology might well have been adopted.

ARC was seeking a design tool that met the following principal criteria:

1. Provide a readily available and easily used tool for standardised stormwater management design.
2. Ensure consistent results for a given catchment analysis, which are able to be replicated by independent reviewers.
3. Allow for distributed analysis (i.e. identification and analysis of subcatchments).
4. Provide for calculation of runoff volume, and for the magnitude and timing of peak flows.
5. Show the effects of land use changes and development, and of stormwater management designs, on the magnitude, timing and volume of runoff.
6. Have a focus towards more frequent events, but be suitable for extreme events.

There are several elements of these criteria that had a strong influence on the selection of the NRCS method. In particular:

1. The need to address both frequent and extreme events. For a simple set of design parameters, this required a non-linear method, which reflected much lower runoff coefficients in frequent events than in large events.

2. The importance of being able to calculate volume of runoff in addition to peak flow rate.

These further criteria enabled the same parameters and methodology to be used for water quality design storms (typically in the 20 to 35 mm rainfall depth range) as for the 100 year average recurrence interval (ARI) storm (typically in the 200 mm range over 24 hours).

Notable omissions from the list of objectives, which might have influenced the choice for TP108 and might be pertinent in today's context, are:

1. Continuous simulation was not envisaged. While continuous simulation of a long time series (years or decades) is not widely used in New Zealand, it is overseas, and is of particular relevance to understanding the operation of treatment systems, stream erosion and waterway ecology.

2. While use for multi-catchment models was considered, the very detailed, highly discretised urban drainage system modelling commonly undertaken these days was not specifically envisaged at the time TP108 was developed – sub catchments were expected to be larger than just to one sump!

Therefore TP108 cannot be treated as a "one size fits all" approach, and other methods are needed in some circumstances.

2.2 SELECTION PROCESS

A wide range of methodologies and model packages (20 in total, varying from specific software packages to software-independent rainfall-runoff methodologies) was initially screened against a wide range of criteria, including cost, operational features, support, ease of use, suitability and track record. From these, three methodologies (NRCS TR55, ILSAX and further adaption of the previous ARC method, TP19) were selected for more rigorous testing against the required performance criteria.

2.3 VALIDATION

The approach to testing the methodologies was based on matching probability of occurrence of rainfall with calculated runoff, rather than validating against specific historical storm events. The intent was that, if 100 year ARI rainfall data was used, then 100 year ARI runoff would result, both in volume and peak flow rate.

Initially four sample Auckland catchments were selected that had reasonable flow records that were reliable and suitable for estimating flows out to 100 year ARI (taking confidence intervals into account). Two more were added later during the parameter development, to represent the volcanic soils in Franklin District. This gave coverage of clay, alluvial and volcanic catchments, suitable to cover much of the Auckland region.

Each methodology was used to generate design flows for events of 3 month, 2 year, 10 year and 100 year ARI storms for each test catchment, using the published methodology and parameters. Out of this, the NRCS method was found to give the most reliable outcome across a range of catchments and return periods, and to meet other ARC criteria.

While the subsequent development and validation, leading to publication of the TP108 method, has been based on real catchment data, there were only 6 catchments that were suitable, and this limited the statistical robustness and the ability to provide for separate calibration and verification cases. Therefore both the historical and any future development will still benefit from any new findings from external studies from across New Zealand and overseas.

2.4 KEY COMPONENTS

The method has been developed as a total package that should take a given rainfall and determine appropriate volume and peak rate of runoff for the Auckland context. Taking one part of the method, and mixing it with other methods (e.g. NRCS losses/net rainfall but another unit hydrograph, or a different hyetograph duration or pattern) will not necessarily yield reliable results, unless there has been local validation of this alternate mix of components.

2.4.1 RAINFALL - NESTED STORM

TP108 uses a nested storm, wherein for any of the specified durations from 10 minutes through to 24 hours, the maximum intensity of rainfall for each duration has the same ARI. This is an artificial construct for analysis purposes, and is not intended to represent any particular historical or expected storm. It is more common for a real storm event to have a range of return periods for different durations, and for this distribution to vary between storms. There is a common perception that this means the storm has greater overall depth than real storms. However, this is not so – the depths at each duration are correct, although the antecedent rainfall might differ from a real storm. By selecting the right time of concentration for the catchment, the catchment runoff analysis can operate on the relevant duration embedded within the nested storm.

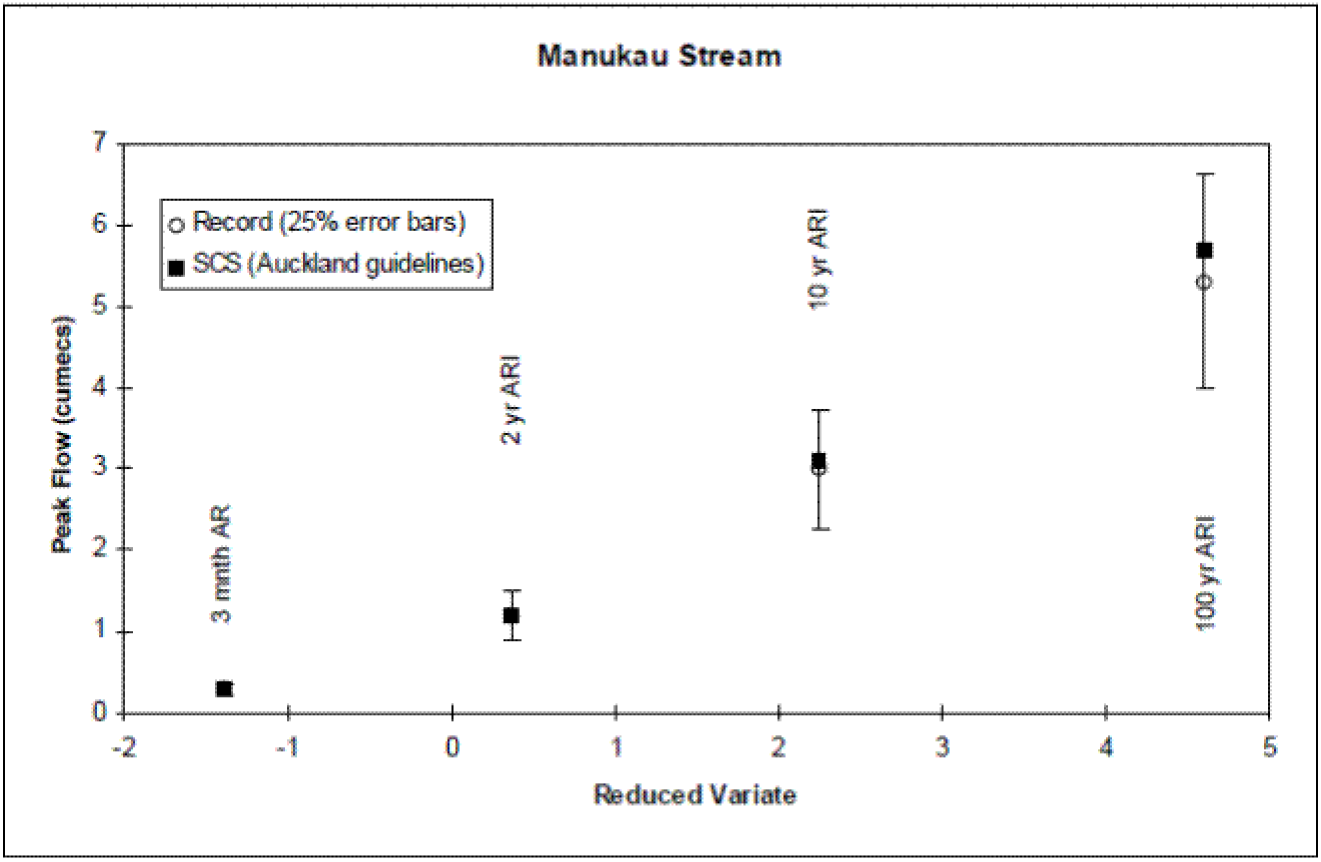
This difference is significant, and is one reason why a standardised storm, with central weighting and 24 hours duration, has been adopted. Use of a shorter duration design storm will affect the total runoff volume for a given CN/IA combination, and a different position for the storm peak will affect the peak flow rates. Any change to storm duration requires a recalibration of runoff volume, and for peak timing requires a recalibration of peak flow rates. Because peak rate is a combination of volume and timing, it is not appropriate to calibrate directly to peak rates. I have seen examples where parameters have been adjusted to get the peak rate right, but the volume has been significantly in error, which can be misleading when peak flow attenuation with storage needs to be assessed.

For the Auckland context, and for most urban areas, the 24 hour storm duration is adequate due to the typical catchment size and characteristics. TP108 explicitly states that it has been validated up to a catchment area of 12 km^2, with relatively steep catchments containing little storage, and for these the nested 24 hour storm is appropriate. For larger catchments, or where in-catchment or floodplain storage is significant, the nested storm and 24 hour duration might not be appropriate.

2.4.2 CN AND IA

The standard NRCS method involves determining a curve number based on soil hydrological group (reflecting infiltration characteristics) and land cover characteristics, calculating a notional "soil storage" parameter S, then assuming that initial abstraction IA is 0.2*S. Validation across a range of Auckland soils identified that this approach did not give a good fit through the range of ARIs and soil types, and that a fixed initial loss of 5 mm with a soil hydrological group one "step" lower (e.g. C rather than D) gave the best fit across the range. An example of the resulting validation fit is provided in Figure 1, copied from Beca 1999c.

Figure 1 – Example of validation from TP108

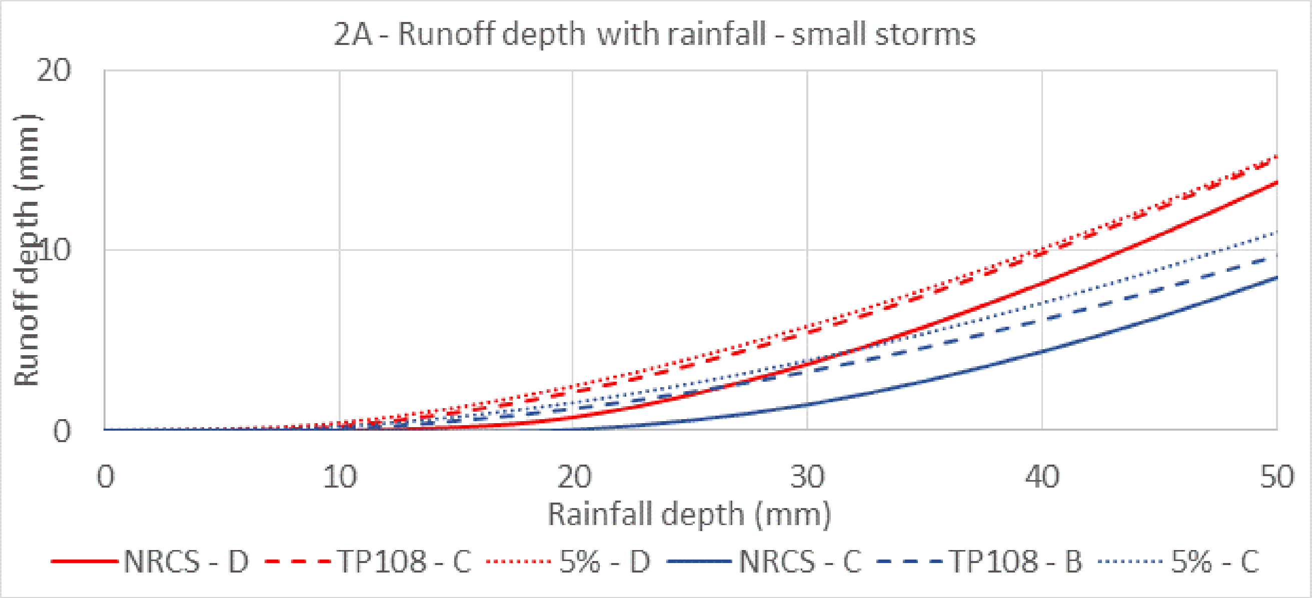


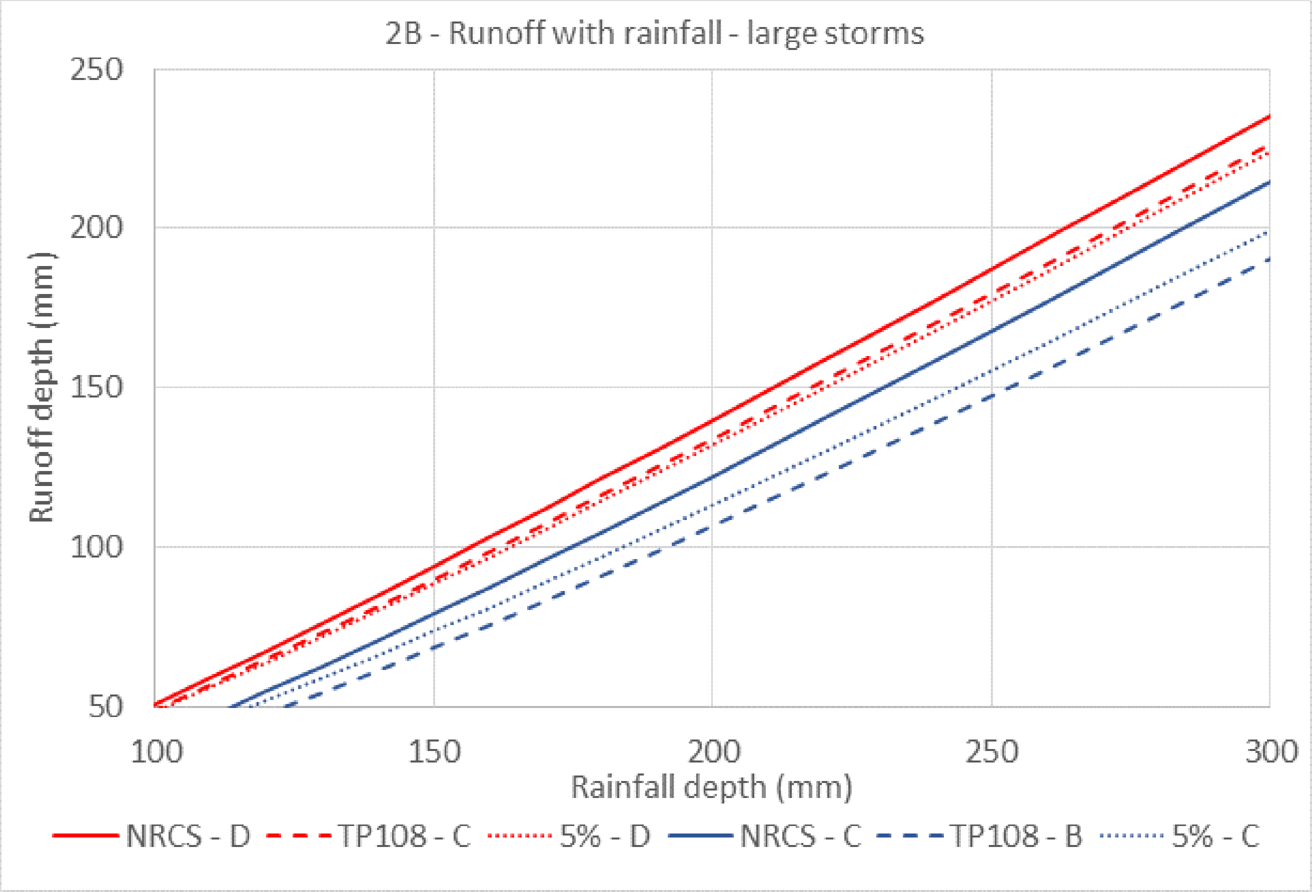
Notes:

- The solid squares represent TP108 modelling of the catchment.
- The circles represent the flow / return period data from analysis of the historical flow record, with 25% error bars shown.
- Other catchments had verification results further out on the error bars, some being above and some below the recorded flow values.

Alternate approaches, with reduced IA and similarly reduced CN, have been identified by other studies (e.g. Hawkins et al 2001). Based on field studies, Hawkins proposes that IA be 0.05*S (based on standard NRCS CN values), but that CN then be modified in line with the reduced IA. This results in runoff volumes similar to that derived using TP108. The differences are illustrated in Figure 2, and in Table 1. They become significant when in more permeable soils, and for smaller more frequent storms such as when calculating water quality volumes, whereas the relative effect in extreme storms is proportionally less significant.

Figures 2 – Comparisons of rainfall-runoff





Notes:

- NRCS refers to the original SCS/NRCS method, with IA = 0.2*S and CN as published.
- TP108 effectively uses a CN from one soil group lower than that soil would normally be classified, hence (for example) use of C compared to a D soil CN from the original NRCS method.
- 5% refers to IA calculated from 0.05*S, and the D soil classification has a CN that has been adjusted down for the original NRCS method, in accordance with a formula proposed by Hawkins.

Table 1 – Example IA and CN values based on different methods

Nominal NRCS Soil Group		A	B	C	D
NRCS	CN (pasture)	39	61	74	80
	IA	79.5	32.5	17.8	12.7
TP108	CN (pasture)	Volcanic loam over basalt - 17	Volcanic loam - 39	Alluvial - 61	Clay - 74
	IA	5.0	5.0	5.0	5.0
Hawkins 2001	CN (pasture)	24	47	64	72
	IA	19.9	8.1	4.5	3.2

Some software used for hydrological analysis appears to have the S value internally calculated from S rather than explicitly input, which can significantly alter the resultant runoff depth if used in the context of TP108. Further, I have seen reports that describe the CN values used for analysis, but do not mention IA, which is a significant omission in terms of understanding assumptions in the analysis.

As can be seen from some of the commentary above, the determination of CN and IA is the subject of ongoing research and validation, which is critical to achieving reliable predictions of runoff volume.

2.4.3 TIME OF CONCENTRATION

The development of TP108 included analysis by ARC of a number of historical storm hydrographs in the test catchments, and back calculation of time of concentration (Tc). These results were then correlated with parameters in the standard NRCS formula for time of concentration, and a new formula derived for Auckland. Using a different formula for calculating time of concentration can result in significantly different Tc values, which significantly affects the transformation of runoff volume to peak flow rate. This component is critical to ensuring that the calculated runoff volume (from CN and IA) is transformed into the correct hydrograph shape and peak rate.

The formula reflects the relatively steep catchments of the Auckland region. Work we have undertaken elsewhere (for instance parts of the Waikato and Bay of Plenty regions) suggest that catchment behaviour is much different to Auckland, and the formula appears to significantly underestimate catchment response time, resulting in a significant overestimate of peak flow rates. There is also a likelihood that the flat grades and limited drainage systems, particularly in some rural areas, result in much greater retention of rainfall and ponding within the catchment, leading to a reduced runoff volume. Transposing TP108 into such areas should only be done with reference to real flow data and catchment responses.

2.5 ADVANTAGES, DISADVANTAGES

The TP108 method should not be seen as a "one size fits all" approach. While it is suitable for the purpose for which it was originally developed, there are situations where it should not be used, or should only be adapted and used with caution. It is notable that while ARC and AC have sought to update and refine the method over the past decade, there does not appear to be a single agreed approach that they have been able to formally adopt and promulgate in place of TP108.

2.5.1 ADVANTAGES

Being a relatively simple method to apply, TP108 and its relatives will generally give a consistency of outcome no matter who uses it. This does depend on full adherence to the methodology, and not mixing inputs or method components from different sources, as has been observed to occur in practice.

The non-linearity of the rainfall runoff response reflects the reality of observed data and field experience – increasing rainfall depth results in an increasing volumetric runoff coefficient. The same effect occurs when using more physically oriented infiltration methods or catchment soil moisture modelling methods. This is important when a method needs to represent a wide range of storm severities and rainfall depths, something that is important with the increased awareness of the combined effects of a wide range of storm events on receiving environment quality.

The use of a nested storm means that one simulation event can represent a range of response times, including performance in different sub catchments as well as across the entire catchment. This means that fewer model runs are required when trying to map flood levels and performance across the entire catchment.

2.5.2 DISADVANTAGES

It is more clumsy that the rational formula, with little benefit when calculations are dominated by impervious surfaces and small catchments. Analysis for highway runoff, or for individual site piped stormwater design, can be undertaken more readily using rational formula-based guidelines such the E1 (MBIE 2017).

It uses a theoretical design storm, and therefore does not reflect any particular historical storm or likely hyetograph. Most storm events do not contain the same return period over the full range of durations within a storm. Nevertheless, it is still realistic to use an historical hyetograph to validate a model performance, so long as comparison with recorded runoff volume is part of the validation process, and the storms used are of a longer duration (i.e. not a short high intensity burst of rainfall).

The method specified in TP108 (particularly the adjustment of CN, and setting of IA) may be difficult to apply correctly in the case where the 0.2S values are embedded into some software and cannot be adjusted.

There is potential for confusion in using the TP108 approach, where the change of IA and consequent need to also adjust CN (by shifting by one soil group) is not applied, and the published hydrological soil group CN values are used instead (particularly if the resulting higher CN value is combined with the 5.0 mm IA value).

3 ADOPTION OF “TP108” ELSEWHERE

3.1 WHERE IS THE METHOD BEING USED

In addition to use of the NRCS methodology for TP108 in Auckland, I am aware of the general NRCS method (or elements of it) being used elsewhere in New Zealand. Some examples are listed below, and there are likely to be other examples.

Kāpiti Coast

The Kāpiti Coast District Council adopted the NRCS method when developing stormwater runoff guidelines around 2003. The guideline was developed based on local rainfall and flow data, has been peer reviewed, and was used to generate flow for flood mapping that has been defended through the Environment Court. It has been reviewed and republished in the updated guideline SKM (2011). The approach was developed in a similar manner to TP108, although the validation data from Wharemauku Stream recorder was not as reliable at moderate to high flows as would normally be considered desirable for such a context. One difference from TP108 is the use of the Clark Unit Hydrograph rather than SCS Unit Hydrograph to transform net rainfall to runoff, as the Clark UH has a storage component that assists in attenuating flows more in flatter catchments.

Hamilton City

Hamilton City's stormwater modelling guideline makes use of an NRCS based approach, and references directly back to TP108. There are some specific criteria where local conditions are addressed, particularly with a requirement that any significant storage areas (in-channel or within the flood plain) be explicitly modelled in the hydraulic model. This will at least in part address one of the issues with transfer of an Auckland-based methodology into a flatter Waikato terrain. However, the Tc equation remains the same as TP108, and this may not be appropriate without local validation. Similarly, CN is to be based on national soils maps, with the potential for the CN value being too high relative to the use of a small fixed initial loss rather than 0.2*S, and over-predicting runoff volume. Unfortunately Hamilton seems to have a paucity of urban and small rural flow records, which makes validation difficult.

Waikato Regional

Waikato Regional Council is in the process of developing a local version of TP108, on the understanding that the AC version might no longer be available. At the time of writing this paper the draft of the "Waikato TP108" was not available to this author.

Wellington

Wellington Water is currently developing a guideline similar to TP108, based on the NRCS method. My understanding is that it is being calibrated to local conditions, although it does differ from TP108 in aspects of the methodology, particularly around design storm duration, and validation of runoff volume.

3.2 WHAT ISSUES HAVE ARISEN

There is detailed soil mapping covering many parts of New Zealand (Landcare S-mapOnline), and the mapped soil types are linked to Hydrological soil group being used for the NRCS method (e.g. for TP108 modelling). If the soil classifications and resulting CN values are adopted, without consideration of the need to shift CN to accommodate the small fixed value of IA, then modelling will over-predict runoff volumes and peak flow rates. This is important in the more severe storms, but even more significant in a relative sense with more frequent storms.

The use of shorter model rain storm durations (e.g. to shorten model run times for smaller catchments) will affect the assumed basis of initial loss and the point on the rainfall/runoff curve at which peak intensities occur. This will affect peak runoff flow rates. Any proposal to use shorter storms should be based on a standardised approach (e.g. adopting 12 hours or 6 hours as standard) and a specific validation process to confirm the accuracy of the method.

The author has encountered a number of situations where use of TP108 un-validated has resulted in significantly higher peak flow rates than local flow records or the NIWA regional method (which is record-based) would suggest, particularly for rural areas and flatter drainage system with significant storage.

These matters could all be addressed if there are reliable long duration flow records against which the combination of parameters could be reliably validated. Unfortunately, there are many part of New Zealand, particularly in urban or small rural catchments, where there are few or no local records against which the method can be calibrated.

3.3 WIDER CONTEXT

One key issue that the stormwater industry in New Zealand has been grappling with over many years is the standardisation and reliability of methods for estimating runoff. The last comprehensive New Zealand-wide method was McKerchar and Pearson (1989), which was developed from recorded site data, is a reasonable guide for rural catchments, and is available as a tool on NIWA's Stream Explorer website. This tool has limitations due to being primarily catchment area linked, and does not reflect the very different context of urban hydrology, or the variation of runoff and drainage characteristics where these differ locally (e.g. hill catchments versus nearby flat-grade drainage scheme catchments. While the online tool can provide answers easily for any point in the country, it is worth going back to original publication to understand where the example catchments are and what their size and drainage characteristics are in the area of interest.

Since then, there has been a lack of national-level leadership. Local methods have been developed, often with limited funding and considerable differences in concept and reliability / validation. TP108 was developed in this context by a well-resourced ARC, as was Christchurch's Waterways Wetlands and Drainage Guide (rational formula runoff coefficients for manual calculations, and Hortonian loss rates for computer modelling). This individualised approach has not only been relatively inefficient, it has left gaps with no local, validated guidance, and some confusion where there is overlap or differences of approach in adjacent regions. Further, it leaves smaller, less well funded councils at a disadvantage in resourcing their own guidelines.

Australia has "ARR" which is being updated and was the subject a number of papers at the NZHS conference in Queenstown in 2016. From reports, it appears to be quite theoretical and sophisticated, and may be challenging and time-consuming for day-to-day engineering practitioners to apply.

It remains important for the New Zealand stormwater community to improve its performance in this area, including development of guidelines that meet the following criteria:

- Nationwide coverage and consistency of approach;
- A variety of consistent approaches that provide for the needs of simple site-level calculation of design flows through to sophisticated catchment-wide and urban drainage hydrological and hydraulic modelling;

- Robustly representative of real rainfall and runoff characteristics in different geographies and hydrological contexts, including guidance on input parameters for each context;

- Validated to real, reliable data; and

- Potential to be used for continuous simulations (possibly with further effort on validation compared to that needed for reliable flood estimation).

A factor that is potentially missing across New Zealand is the limited availability of long term reliable urban and small rural catchment runoff data that can be used to validate methods and models. Historically the flow monitoring focus appears to have been on larger rural catchments, with some limited exceptions. The significant amount of capital expenditure that occurs in urban drainage systems (both for greenfield growth, and to improve performance in existing systems) would justify a much greater level of expenditure on flow monitoring for calibration purposes, perhaps with a series of representative catchments being identified across a range of urban contexts. Such investment (in flow monitoring) would be a strategic move for future generations, as it takes many years to build the record length that would allow robust prediction of major flood flow rates and calibration of models or methodologies for those events.

4 CONCLUSIONS

TP108 or related methods based on NRCS are being used more widely, but are not necessarily reliable or validated for the particular context where they are being used. The NRCS method is often misunderstood or misapplied, leading to reduced reliability. If the method is to be used in a new area, there should be a focus on validation to local conditions, including specific consideration of both volume and peak flow rate.

The NRCS method in not suited to all situations – other tools are better in some contexts. In particular, it is not ideal for high definition detailed urban models. It is perhaps more complex than necessary for simple site-level runoff calculations where rational formula is simpler and potentially adequate. Neither is it ideal for a continuous simulation context that is needed for understanding lifecycle performance of urban drainage systems and devices.

The ideal would be a nationwide consistency of approach to rainfall runoff estimation that gave the industry and the public greater confidence in reliability. This approach would include different methods for different design / analysis contexts, but would be based on real flow data and appropriate validation in different contexts across the country.

Consideration should be given to methods that allow for continuous simulation, to better reflect the importance of environmental effects and everyday flows, rather than just for flood estimation.

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