CONTINUOUS SIMULATION MODELLING TO SUPPORT HEALTHY WATERWAYS

Jahangir Islam (AECOM), Josh Irvine (WSP Opus), Nick Brown and Nadia Nitsche (Auckland Council)

ABSTRACT

Frequent storm events contribute to the majority of the stream erosive effects compared to larger, rare events. Developing appropriate solutions to manage erosion requires a good understanding of the associated flows for frequent storm events. Long-term continuous simulation modelling is suited to represent the complex hydrological processes and to predict low magnitude stream flows.

Continuous simulation hydrological models for five gauged catchments in the Auckland Regions were developed using EPA-SWMM modelling software. Three infiltration models were used – Horton's method, Green-Ampt method and the Curve Number (SCS) method. Each of the models were calibrated against the stream flow gauge in the catchment. Calibration of the hydrological models considered methods other than just matching peak flows and the receding limb of individual events. This included calculation of the Nash-Sutcliffe model efficiency coefficient, matching of the peak flow frequency and flow duration curves from the gauge and the model. This ensures better overall flow replication and thus allows for better prediction of frequent events.

Calibration resulted in a good match for >99.5% of the stream flows. Four out of the five catchments calibrated provided at least a satisfactory match, based on the Nash-Sutcliffe results, with the Whau catchment providing a very good calibration and the Hoteo catchment providing a good calibration.

The analysis undertaken across the five gauged catchments enables a suitable set of continuous hydrological modelling parameters to be established. These parameters could be adopted for ungauged catchments across the Auckland Region and used to better understand stream erosion processes in lieu of observed data. The understanding of the stream flows can then be used to calculate stream flow velocities and shear stress acting on the stream bank to predict which streams may erode and where, and to estimate the quantity of streambank erosion and sediment in the receiving environment. The resultant models can also be used to assess the effects of future development and the benefits of potential erosion mitigation interventions. This is critical in protecting and restoring stream health and attaining healthy waterways.

KEYWORDS

Continuous Simulation, EPA-SWMM, Stream Flows, Horton, Green-Ampt, Curve Number, Model Calibration, Flow Duration Curve, Peak Flow Frequency Curve.

PRESENTER PROFILE

Josh Irvine is a Chartered Professional Engineer and a Senior Water Resources Engineer at WSP Opus, with over 10 years of experience in water resources and stormwater management. He has experience in a wide variety of areas including hydrological and hydraulic modelling, project management, construction monitoring and stormwater design.

Jahangir Islam is an Associate Director at AECOM in New Zealand. Jahangir has over 25 years of experience working for local authorities and as a consulting engineer. He has been involved with a wide variety of environmental management projects including stormwater catchment planning, hydrological and hydraulic modelling, stormwater quality improvement and remedial options investigations.

1 INTRODUCTION

The National Policy Statement for Freshwater Management (NPSFM) directs regional councils and communities to set objectives and limits to better manage freshwater quality. Sediment is one of the key 'matters' identified in the NPSFM, for regional councils to take into account for a healthy freshwater body, and is included in both compulsory values of ecosystem and human health (MfE, 2017).

Auckland is currently experiencing unprecedented urban development, with more than half of New Zealand's population growth in the next 30 years predicted to occur in the region. Many streams in the region are currently assessed as degraded, experiencing significant erosion from the hydrological effects of existing development. Without further intervention, future growth is likely to significantly exacerbate the issue. Conventional development increases runoff volumes and the duration of elevated peak flows which consequently degrade the morphological and ecological functions of streams. The observed increase in stream erosion in the region is a major concern for Auckland Council, Iwi and the general public.

Frequent storm events contribute to the majority of the stream erosive effects compared to larger, rare events. Research indicates that most of the sediment in streams is from streambank erosion processes rather than from slips and exposed soils in the catchment. Developing appropriate solutions to manage streambank erosion requires a good understanding of the associated flows for frequent storm events. The current event-based modelling practices adopted in the Auckland region (e.g. TP108) are not suitable for predicting stream flows for frequent storm events. This is because variations in the long-term pattern of rainfall intensity and duration, antecedent soil and storage conditions, and inter-arrival times between storms can have a significant impact on the frequency and duration of flows. Long-term continuous simulation modelling is best suited to represent these processes and to predict low magnitude stream flows.

In the Auckland region, of the 233 catchments only 18% have flow gauge information (the average catchment area is 2,000ha). Due to the limited number of stream flow gauges, continuous simulation modelling is required to simulate the hydrological processes. The purpose of this study is to develop a continuous hydrological modelling methodology using EPA-SWMM software, to predict stream flows in un-gauged catchments. By analysing gauged catchments, a suitable set of continuous hydrological modelling parameters can be established. Where ungauged catchments have similar characteristics, these parameters can be adopted, enabling a prediction of stream flows, and in turn an assessment of the stability of streambanks, considering critical shear stresses, can be undertaken. This is critical to achieving healthy waterways - not only to mitigate the impacts of further development, but to begin a process of restoring stream health across the region.

This study helps to enable the assessment of erosion mitigation interventions and to demonstrate meeting sediment targets under the National Policy Statement for Freshwater Management (NPSFM).

2 MODELLING APPROACH

2.1 OVERALL APPROACH

A long-term continuous simulation modelling approach has been used for five gauged catchments in the Auckland Region to model the hydrological processes in the catchment. Continuous simulation allows a quantifiable assessment of changes in hydrological regime due to urban development over the full spectrum of flow conditions. The advantage of continuous simulation is its ability to account for antecedent soil conditions as an implicit component of the modelling. Continuous simulation modelling is most useful for long-term stream erosion and contaminant loading assessment.

Continuous simulation modelling was carried out using 5 years of continuous 5 minute interval rainfall data. It is expected that a calibration period of 5 years captures most of the temporal hydrological variability so that a reasonable predictive model performance is achieved. This can then be used to identify representative hydrological modelling parameters for comparative ungauged catchments in the Auckland Region. As the impervious surface layer in the Auckland Region is based on 2007-2008 aerial photos, a continuous simulation period from 2007 to 2011 was selected. Monthly average potential evapotranspiration (PET) data were used based on a NIWA climate report (Chappell, 2010). A full year (2006) of simulation was carried out before the calibration period (2007-2011) to 'warmup' the hydrological model in order to obtain appropriate initial hydrological conditions at the start of the calibration.

The approach undertaken is to achieve a good overall calibration over a range of events with no one event calibrated perfectly. The hydrological models were calibrated across the full spectrum of flows that occurred during the 2007-2011 simulation period. Calibration of the hydrological model considered methods other than just matching the peak flows and receding limb of individual events. This included calculation of the Nash-Sutcliffe model efficiency coefficient, matching the peak flow frequency and flow duration curves from the gauge and the model for the 5-year simulation period by adjusting model parameters. This allows better prediction of the frequency and duration of medium to low magnitude flows.

2.2 HYDROLOGICAL MODEL

The EPA-SWMM modelling software was used for the continuous simulation modelling. EPA-SWMM is a dynamic rainfall-runoff simulation model widely used for single event or long-term continuous simulation of runoff quantity and quality from a catchment. The groundwater aquifer routing module available in the EPA-SWMM software was used for better representation of runoff responses and time-delayed base flow recession limbs from pervious areas. Three infiltration models were tested – the Modified Curve Number (SCS), Horton and Green-Ampt methods.

EPA-SWMM uses a nonlinear reservoir routing model to estimate surface runoff produced by rainfall over a catchment (Rossman & Huber, 2016). In the non-linear reservoir method the catchment is conceptualised as a shallow reservoir with rainfall as inflow and losses from evaporation and infiltration. Ponded water above the depression storage depth can become surface runoff. Depression storage accounts for initial rainfall abstractions such as surface ponding, interception by flat roofs and vegetation, and surface wetting. The discharge from this hypothetical reservoir is assumed to be a non-linear function of the depth of water in the reservoir.

2.3 GAUGE CATCHMENT CHARACTERISTICS

Three urban and two rural flow monitoring gauge catchments in the Auckland Region were used for continuous simulation modelling. A simple lumped catchment modelling approach was used i.e. the physical characteristics of the catchment are assumed to be spatially constant. ArcGIS software was used to aggregate the soil and land use characteristics to estimate area-weighted catchment depression storage and surface roughness. The gauge catchment slopes were computed as weighted slope along the pathway of overland flow to the gauge using a path-length weighted average. The catchment width was initially calculated using Equation 1 given below as recommended in SWMM reference manual (Rossman et al, 2016) for an irregular catchment shape. During model calibration the computed width was adjusted for a couple of gauge catchments to get a better match with the measured flow data.

$$W = L + 2L(1 - Z)\ and\ where\ Z = \frac{A_m}{A} \qquad (1)$$

where:

L = length of main drainage channel

A = catchment area

A_m = catchment area of the larger of the two areas on each side of the channel (refer to Figure 1)

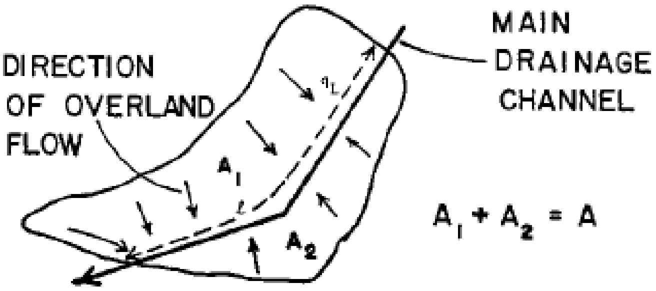

Figure 1: Width calculations for irregular catchment shape (Rossman, 2016)

For each flow gauge catchment model, 5 years of continuous 5 minute interval rainfall data was used from a nearby rainfall gauge. The rainfall gauges were located outside of three of the gauged catchments. Table 1 below summarises the characteristics of the gauged catchments.

Table 1: Summary of flow gauging catchments

Gauge Catchment Name	Lucas	Chartwell	Whau	Hoteo	West Hoe
Flow Gauge/ Parameters	Lucas @ Gills Road	Wairau @ Chartwell	Whau @ Blockhouse	Hoteo @ Gubbs	West Hoe @ Halls
Urban/Rural	Urban	Urban	Urban	Rural	Rural
Area (ha)	614	138	467	26,780	52.8
Imperviousness	29.8%	51.8%	43.1%	12.0%	0.0%
Slope	2.8%	4.6%	2.7%	0.49%	7.4%

Width (m) (Horton & Green Ampt)	1,345	2,590	1,160 & 1,250	82,800	1,430 & 900
Manning's n Pervious Area	0.21	0.20	0.19	0.25	0.31
Depression Storage (mm)	4.5	3.2	3.4	6.4	6.6
Soil Type	Waitemata/ Alluvial	Waitemata	Waitemata	Waitemata	Waitemata
Mean Annual Flood (m^3/s)	19.7	13.4	12.1	163.8	1.7
Rainfall Gauge Name	Torbay @ Glamorgan	Wairau @ Testing Station	Whau @ Mt Roskill	Hoteo @ Oldfields	Orewa @ Treatment
Mean Annual Rainfall (mm)	1,115	1,166	1,229	1,338	1,177
Location of Rainfall Gauge	1.1km from Catchment Boundary	0.65km from Catchment Boundary	Within the Catchment	Within the Catchment	3km from Catchment Boundary

2.4 INFILTRATION METHODS AND PARAMETERS

Three infiltration methods were tested in the development of this work, including Modified Curve Number, Horton and Green Ampt.

The Curve Number method, also known as the Soil Conservation Service (SCS) method, is widely used in Auckland with TP108 (AC, 1999) and in other areas of New Zealand. It was implemented in EPA-SWMM to match the observed flows. However, there are issues with EPA-SWMM's implementation of the Curve Number method. It does not replicate the Curve Number runoff peak flows and volumes. The error is greatest for lower curve numbers in pervious areas, where subcatchments with a CN of 74 and 39 produce runoff depths and volumes 10% and 79% lower respectively than the Curve Number method. Another issue was found using depression storage with long time-series modelling in SWMM software. Using a depression storage value, the infiltration rate does not recover post event and infiltration losses cease after a certain period (approximately a year's simulation). Due to these reasons, the Curve Number method in EPA-SWMM was not considered appropriate for continuous simulation modelling.

Horton's infiltration method is empirical in nature and is perhaps the best known of the infiltration equations. Horton (Horton, 1933 & 1940) proposed the following exponential equation to predict the reduction in infiltration capacity over time as observed from field measurements:

$$f_p = f_\infty + (f_0 - f_\infty)\, e^{-k_d t} \qquad (2)$$

where:

f_p = infiltration capacity into soil (mm/hr)

f_∞ = minimum or equilibrium value of f_p (at $t = \infty$) (mm/hr)

f_0 = maximum or initial value of f_p (at $t = 0$) (mm/hr)

t = time from beginning of storm (sec)

k_d = decay coefficient (1/hr).

The Green-Ampt infiltration equation (Green and Ampt, 1911) has received considerable attention in recent years. The Green-Ampt approach assumes that the infiltrating wetting front forms a sharp jump from a constant initial moisture content ahead of the front to saturation at the front. The water velocity within the wetted zone is given by Darcy's Law (equation 3) as a function of the saturated hydraulic conductivity K_s (mm/hr), the capillary suction head along the wetting front ψ_s (m), the depth of ponded water at the surface d (m), and the depth of the saturated layer below the surface L_s (m):

$$f_p = K_s \left[\frac{d + L_s + \psi_s}{L_s}\right] \qquad (3)$$

Both methods were found to be suitable for use and appropriate parameters were derived for the catchment areas based on the soil types. The Horton and Green-Ampt infiltration model parameter values were estimated from soil characteristics table given by Horton (1940) and Rawls et al (1983). The infiltration parameter values were found to have minor effects on model results. The infiltration model parameter values for the five gauge catchments are summarised in Table 2.

Table 2: Horton and Green-Ampt infiltration model parameter values

Gauge Catchment Name	Lucas	Chartwell	Whau	Hoteo	West Hoe
Flow Gauge/ Parameters	Lucas @ Gills Road	Wairau @ Chartwell	Whau @ Blockhouse	Hoteo @ Gubbs	West Hoe @ Halls
Horton's Infiltration Model Calibrated Parameter Values					
Max. Infiltration Rate (mm/hr)	85	61	71	61	51
Min. Infiltration Rate (mm/hr)	4.0	3.0	4.0	3.0	0.5
Decay Constant (1/hr)	2.0	2.0	2.0	2.0	2.0
Drying Time (day)	8.5	9.3	9.0	9.3	9.7
Max. Volume (mm)	0 (not used)	0 (not used)	0 (not used)	0 (not used)	0 (not used)
Green-Ampt Model Calibrated Parameter Values					
Suction Head (mm)	195	205	195	205	220
Saturated Hydraulic Conductivity (mm/hr)	4.0	3.0	4.0	3.0	1.5
Initial Deficit (fraction)	0.18	0.17	0.18	0.15	0.15

2.5 GROUNDWATER/AQUIFER PARAMETERS

EPA-SWMM analyses groundwater flow for each catchment independently. It represents the subsurface region beneath a catchment as consisting of an unsaturated upper zone that lies above a lower saturated zone. The height of the water table (i.e., the boundary between the two zones) changes with time depending on the rates of inflow and outflow of the saturated lower zone. The upper zone receives vertical inflow from infiltrating rainfall. Losses and outflow from the lower zone consist of deep percolation, saturated zone evapotranspiration, and lateral groundwater flow. The aquifer routing module improves the stream flow responses and improves representation of the recession limbs of the flow hydrographs. As the majority of the flow events being calibrated are small, the contribution of groundwater aquifer flow plays a vital role matching the observed flow duration curves and representing volumes correctly.

The groundwater aquifer model calibrated parameters for the five gauge catchments are summarised in Table 3. The aquifer soil parameter values (porosity, wilting point, field capacity, conductivity) were estimated from the soil characteristics table given by Rawls et al (1983).

Table 3: Groundwater Aquifer model calibrated parameter values

Gauge Catchment Name	Lucas	Chartwell	Whau	Hoteo	West Hoe
Flow Gauge/ Parameters	Lucas @ Gills Road	Wairau @ Chartwell	Whau @ Blockhouse	Hoteo @ Gubbs	West Hoe @ Halls
Porosity (m^3/m^3)	0.45	0.43	0.45	0.43	0.40
Wilting Point	0.14	0.14	0.14	0.14	0.14
Field Capacity	0.26	0.26	0.26	0.26	0.24
Conductivity (mm/hr)	4.0	3.0	4.0	3.0	1.5
Conductivity Slope	5	10	10	10	10
Tension Slope (mm)	350	350	350	350	350
Upper Evap. Fraction	0.3	0.3	0.3	0.3	0.3
Lower Evap. Depth (m)	3.0	3.0	3.0	3.0	3.0
Lower GW Loss Rate (mm/hr)	1.0	0.1	1.0	0.1	0.1
Bottom Elevation (m)	5.0	5.0	5.0	5.0	5.0
Water Table Elevation (m)	5.1	5.1	5.1	5.1	5.1
Unsat. Zone Moisture	0.26	0.26	0.26	0.26	0.24
Groundwater Depth (m)	1.0	2.0	2.0	2.0	2.0
Groundwater Flow Coefficient (A1)	0.10	0.01	0.01	0.03	0.03

3 MODELLING RESULTS AND DISCUSSION

3.1 PARAMETER SENSITIVITY AND EFFECTS

Table 4 outlines the sensitivity of runoff volume and peak flow to groundwater and aquifer parameters experienced during the work. The most sensitive parameters for flow, aside from the catchment parameters (area, imperviousness), were the groundwater parameters Surface Elevation (groundwater depth), the A1 Coefficient (groundwater influence multiplier) and the Conductivity Slope.

Table 4: Parameters used in the model and their sensitivity and effect on the runoff volume and peak

Parameters	Sensitivity	Effect of increase on runoff volume	Effect of increase on runoff peak	Comments
Subcatchment Parameters				
Area	Major	Increase	Increase	Less effect for a highly porous catchment*
Width**	Major	Decrease	Increase	Affects the shape of the hydrograph. For storms of varying intensity, increasing the width tends to produce higher and earlier hydrograph peaks, a generally faster response.*
Slope	Major	Decrease	Increase	Same as for width, but less sensitive, since flow is proportional to square root of slope.*
Impervious	Major	Increase	Increase	Less effect when pervious areas have low infiltration capacity.*
Roughness (Impervious and Pervious)	Moderate	Increase	Decrease	Inverse effect as for width.*
Depression Storage (Impervious and Pervious)	Moderate	Decrease	Decrease	Significant effect only for low-depth storms.*
Groundwater Parameters				
Surface Elevation**	Major	Decrease	Decrease	Coupled with the Bottom Elevation, it is effectively the available 'groundwater depth'. Increasing this parameter shifts the whole hydrograph down.
A1 Coefficient**	Major	Increase	Increase	Very sensitive. Higher A1 has a steeper receding limb
Aquifer Parameters				
Conductivity**	Moderate	Not assessed	Not assessed	Increasing the conductivity can eliminate runoff with two peaks.
Conductivity Slope**	Major	Decrease	Decrease	Flattens the hydrograph and increases the receding limb and peak
Tension Slope**	Minor	Minimal change	Increase	More effect for catchments where groundwater has more of an influence (e.g. rural areas).
Lower GW Loss Rate**	Moderate	Decrease	Minimal change	Shifts the hydrograph up or down, especially the receding limb.

*Comments taken from the SWMM reference manual (Rossman & Huber, 2016)
**Used as a calibration parameter

Parameters not mentioned in Table 4 were either considered to have a minor effect, or were a calculated parameter and not varied. These parameters include the infiltration parameters (refer to Table 2), the groundwater and aquifer parameters (refer to Table 3).

The only parameters that weren't calculated from some form of data were the parameters Surface Elevation, A1 Coefficient, Conductivity Slope, Tension Slope and the Lower GW Loss Rate. These parameters were derived in the model through testing. The Width parameter was initially calculated using equation 1, but was calibrated for the Lucas, Whau and West Hoe catchments. Of the parameters used in calibration, the Width, Surface Elevation, A1 Coefficient are the most sensitive.

3.2 NASH-SUTCLIFFE EFFICIENCY COEFFICIENT

The Nash-Sutcliffe model efficiency coefficient (Nash & Sutcliffe, 1970) is a quantitative indication of how well the model predicts the observed time-series data, in this case stream flow. A Nash-Sutcliffe coefficient of 1 represents a perfect prediction and a result of less than 0 corresponds to the model predicting worse than the mean of the observed data.

$$E = 1 - \frac{\sum_{t=1}^{T}(Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T}(Q_0^t - \overline{Q_o})^2} \qquad (4)$$

where:

$\overline{Q_o}$ = mean of observed discharges

Q_m^t= modelled discharge at time t

Q_o^t = observed discharge at time t

Moriasi considered >0.5 a satisfactory calibrated model, >0.65 a good calibrated model and >0.75 a very good calibrated model (Moriasi et al, 2007). However, how satisfactory the calibrated model is depends on the context and how and what the model will be used for. Table 5 shows the Nash-Sutcliffe model efficiency coefficient (NSE) results for the gauge catchments.

Table 5: Nash-Sutcliffe results for the Horton and Green Ampt methods

Gauge Catchment Name	Lucas	Chartwell	Whau	Hoteo	West Hoe
NSE result for 2007-2011	**Horton method**				
Mean	0.51	0.61	0.80	0.72	0.37
Median (of the years)	0.69	0.48	0.75	0.73	0.47
Maximum (of the years)	0.71 (2007)	0.68 (2007)	0.92 (2011)	0.82 (2007)	0.54 (2008)
Minimum (of the years)	0.26 (2011)	0.40 (2010)	0.61 (2007)	0.28 (2010)	-0.25 (2007)
NSE result for 2007-2011	**Green Ampt method**				

Mean	0.51	0.68	0.80	0.71	0.48
Median (of the years)	0.68	0.60	0.77	0.72	0.43
Maximum (of the years)	0.71 (2007)	0.73 (2011)	0.88 (2011)	0.83 (2007)	0.68 (2011)
Minimum (of the years)	0.26 (2011)	0.49 (2010)	0.73 (2008)	0.20 (2010)	0.22 (2007)

Horton and Green Ampt infiltration methods provided very similar NSE results.

The Whau catchment provided a very good calibration with NSE values of between 0.61-0.92 for Horton and 0.73-0.88 for Green Ampt and overall a median NSE of 0.75 and 0.77 for Horton and Green Ampt respectively was calculated. The Hoteo catchment provided a good calibration and the Lucas and Chartwell catchments provided a satisfactory calibration. The Westhoe catchment provided the worst calibration with a median NSE result of 0.37 and 0.43 for Horton and Green Ampt methods respectively.

The difference in NSE scores for the assessed catchments is considered predominately due to the proximity of the respective rainfall gauge. The Whau and Hoteo models provided the best calibration and their respective rainfall gauges were located in the catchment. The Chartwell, Lucas and Westhoe models used rainfall gauges outside of the catchments (refer to Table 1). The Westhoe model provided the worst calibration and used a rainfall gauge with the greatest distance from the catchment (3km away). The NSE scores would improve significantly if the uncertainty over the spatial variability of rainfall, especially in short-duration rainfall events, was minimised. Due to this reason, the models and parameter values used are likely to be a much better representation of reality than what the results are showing.

Although the NSE provided an efficient way of assessing the performance of the model, it was observed that in some cases a slight increase in the NSE score resulted in a visually poorer match to the observed flows and vice versa. The NSE score is a very good way of assessing model performance but should not be relied upon entirely.

3.3 FLOW HYDROGRAPHS

Flow hydrographs were developed to assess the ability of the model to predict stream flows based on the rainfall data. Graphing the flow hydrographs helps in the matching of the hydrograph shape, peak flows, receding limb, timing and response. Figure 2 and Figure 3 show the comparison of measured and simulated hydrographs for the Hoteo and Whau catchment respectively. They show are good prediction of the stream flows over a selected period.

Although the Horton and Green Ampt infiltration methods provided similar Nash-Sutcliffe scores, the methods produce a slightly different shape hydrograph. The Horton infiltration method produces a peakier hydrograph with a steeper receding limb compared with Green Ampt. Although they produce a similar result with equivalent parameters, the different infiltration methods need slightly different parameter values to yield a closer match, e.g. the catchment Width parameter and Lower Groundwater Loss Rate should be smaller when using the Horton's method or larger when using the Green Ampt method to ensure an equivalent hydrograph.

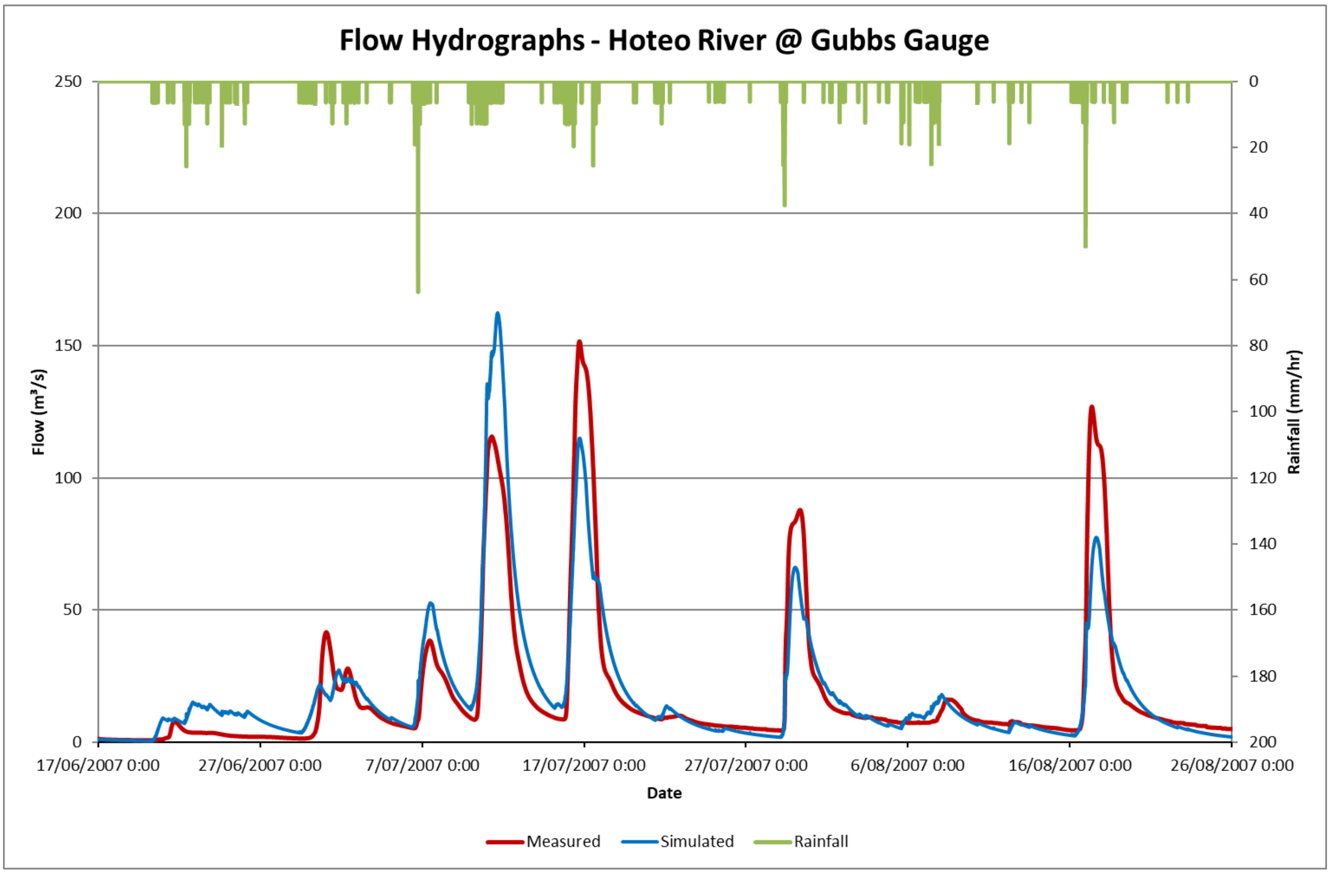

Figure 2: Flow hydrographs for the Hoteo catchment using Horton method

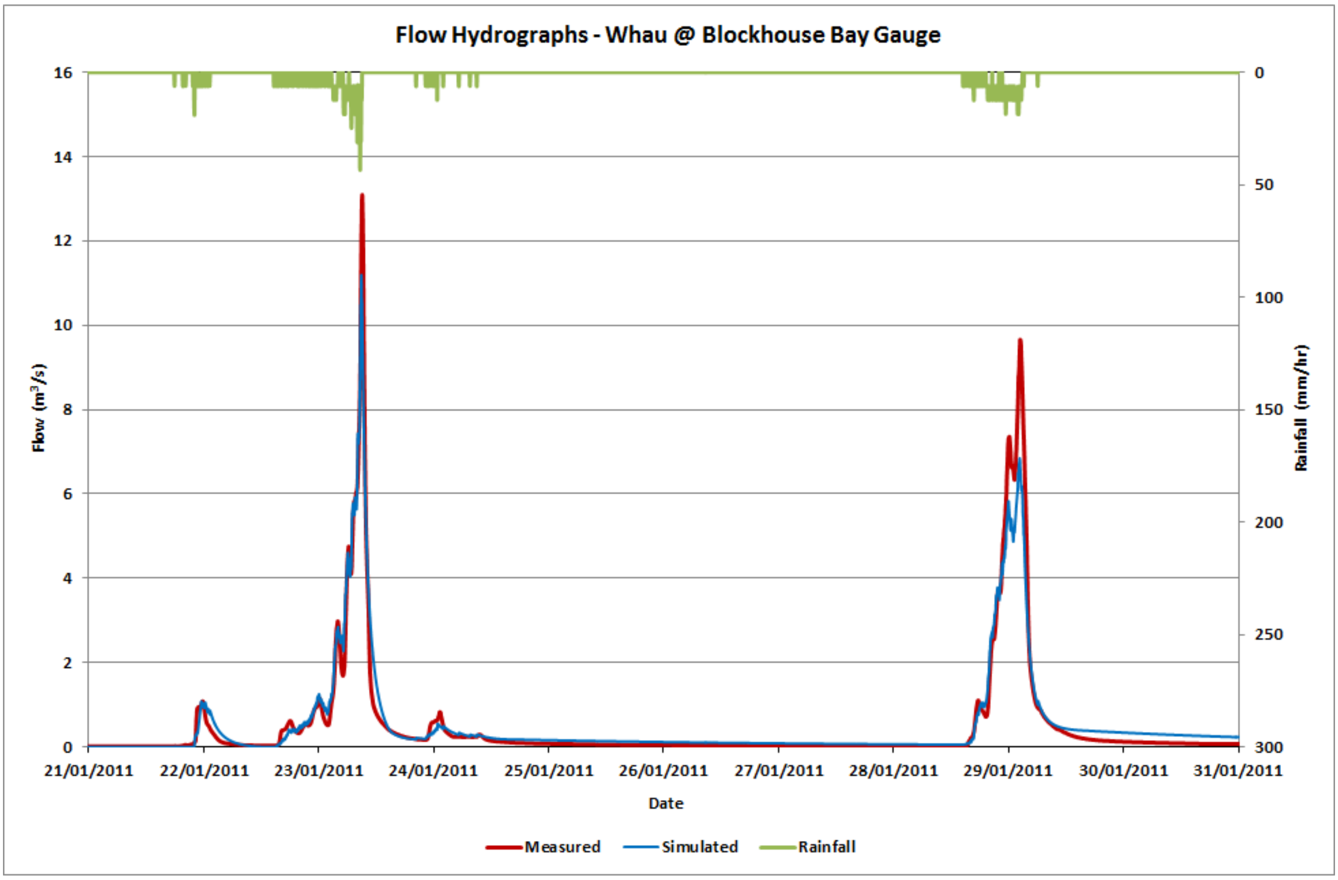

Figure 3: Flow hydrographs for the Whau catchment using Green Ampt method

3.4 FLOW DURATION CURVES

The flow duration curve is a graph of all the flows during a continuous record and their cumulative exceedances, or the percent of time each flow occurs during the period of record. Flow duration curves are primarily used for calibration in the mid to low flow range.

Flow duration curves were developed to compare the measured flows to the model generated flows (refer to Figure 4 and Figure 5). Figure 4 and Figure 5 shows a good match of flows 99.9% of the time for the Whau and Hoteo catchments.

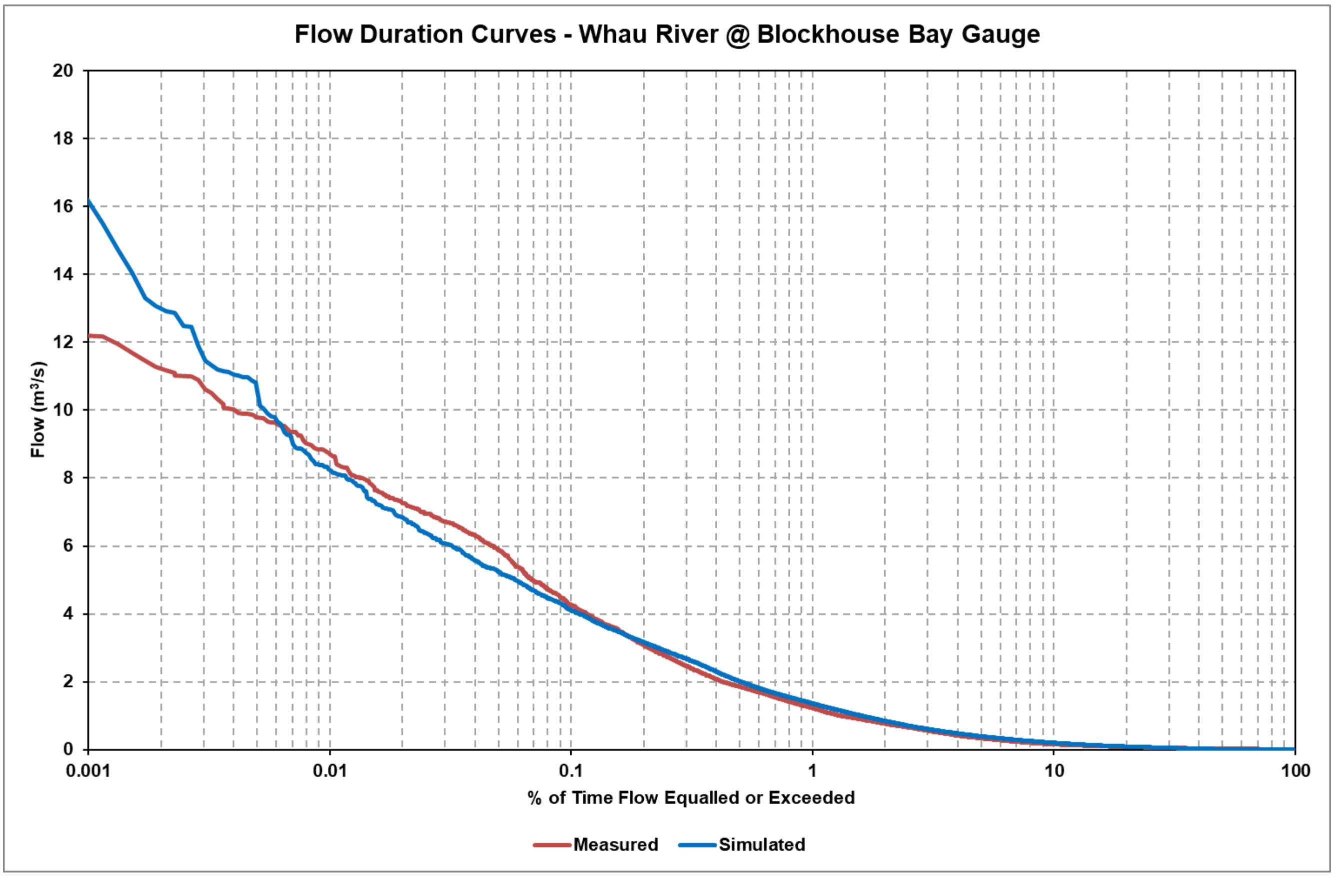

Figure 4: Flow duration curve for Whau catchment using the Horton method

Figure 5 shows the model and flow data match well up until the Mean Annual Flood (MAF) (164m^3/s), which is considered to be approximately the channel forming flow.

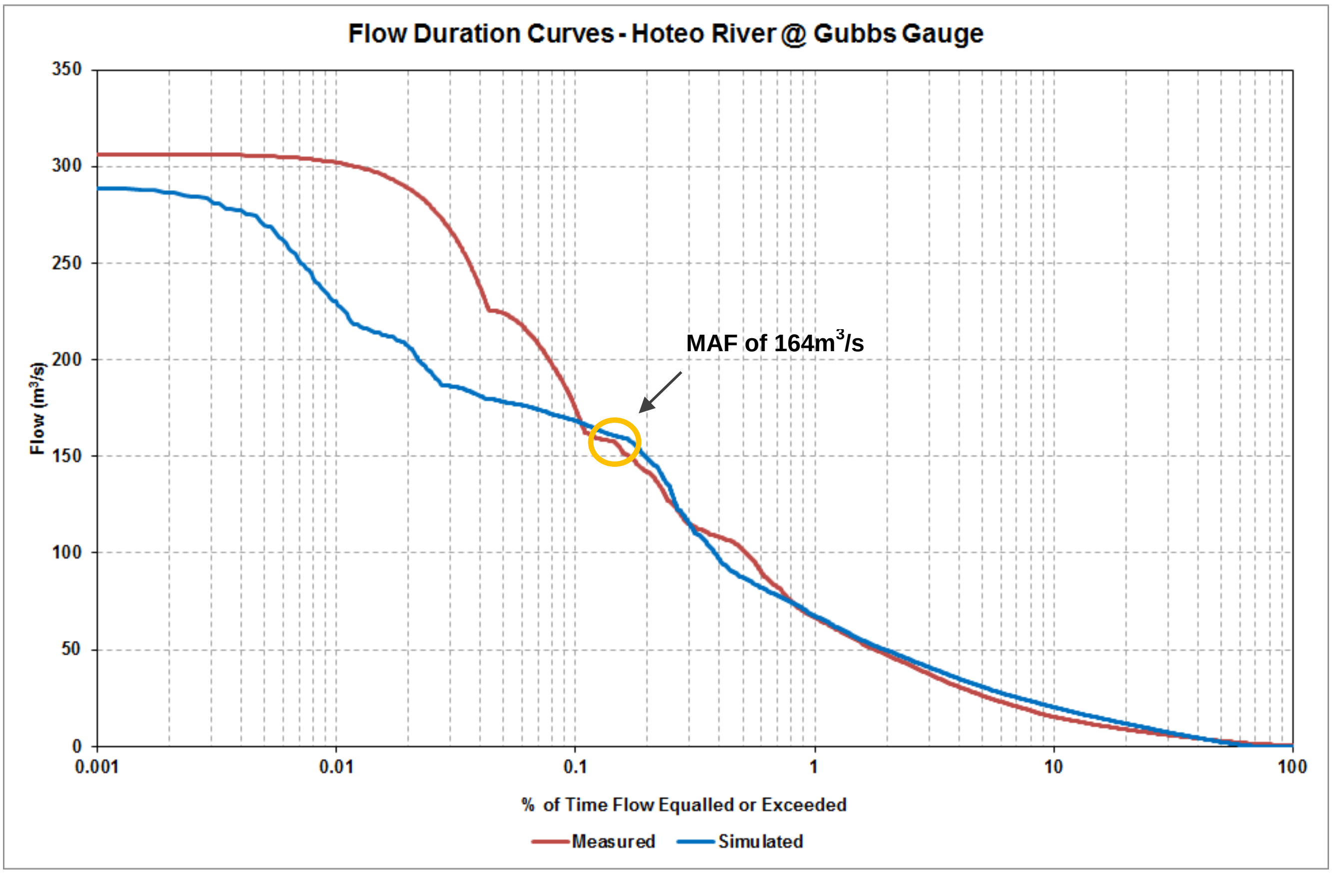

Figure 5: Flow duration curve for Hoteo catchment using the Green Ampt method

3.5 PEAK FLOW FREQUENCY CURVES

Peak flow frequency curves were developed from the partial series analysis using gauged and model generated continuous flow records. A 6-hour inter-event time interval was specified to separate the flow data into individual events. The frequency (average recurrence interval, ARI) of an event's peak flow was then estimated using a frequency distribution formula for a partial series, as recommended by Australian Rainfall and Runoff (1987), given below:

$$ARI_{(Years)} = \frac{n+0.2}{m-0.4} \qquad (3)$$

where:

n = number of years in simulation

m = rank of particular event

The peak flow frequency curves are used for calibration of the magnitude of runoff event peaks. Figure 6 and Figure 7 show the peak flow frequency curves for the measured and simulated flows for the Whau and Hoteo catchments. Results show that <1yr ARI flow events are well matched and >1yr ARI flow events provide a reasonable match.

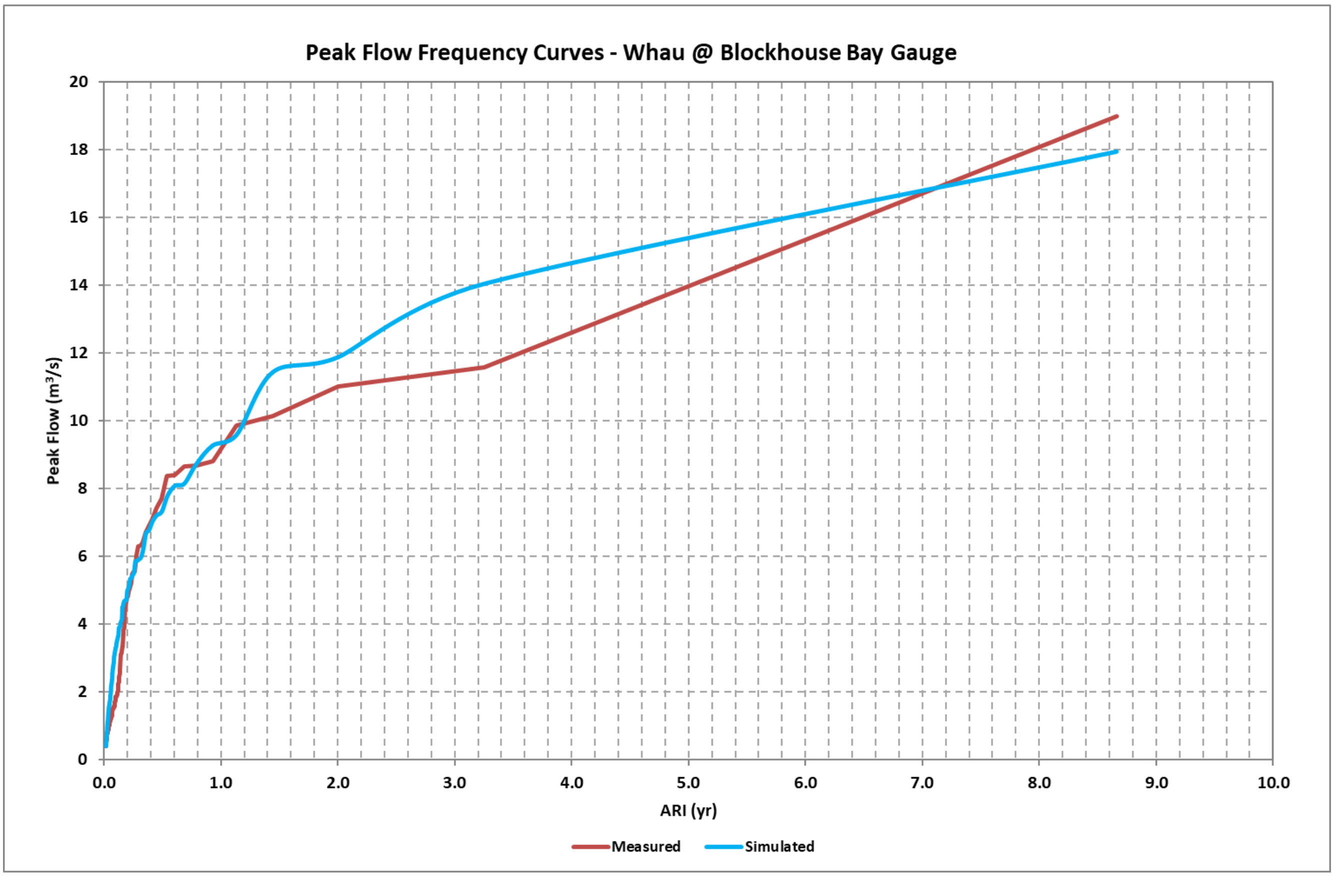

Figure 6: Peak flow frequency curve comparison for the measured and simulated flow for the Whau catchment using the Horton method

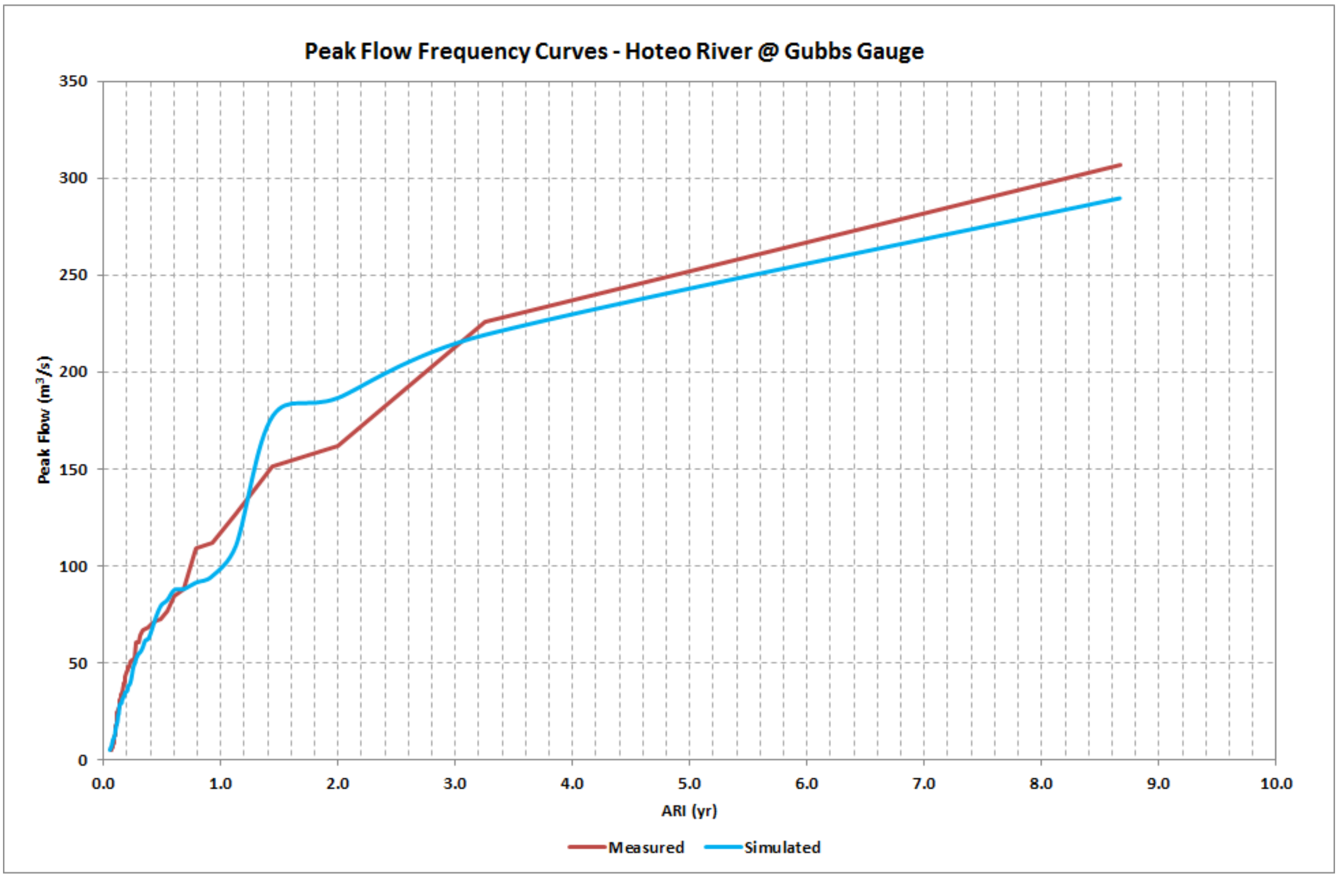

Figure 7: Peak flow frequency curve comparison for the measured and simulated flow for the Hoteo catchment using the Green Ampt method

3.6 LIMITATIONS AND ISSUES EXPERIENCED

The differences between the model results and measured data found in this study could be due to several issues or missing features that are not accounted for within the model as summarised below:

- Lack of data on spatial variability of rainfall data over the catchment.
- Lack of data on variability of rainfall patterns and catchment wetness.
- Flow gauging issues/uncertainties
    - Accuracy of rating at the flow gauge site.
    - Extrapolation of rating curves for extreme flows.
    - Change in flow gauge rating during the course of the 5yr simulation period.
    - Gaps in flow gauging data.
    - Lack of suitable rainfall and flow gauging locations.
    - Extreme flow variation between base flow and flood flow.
    - Shallow base flow depths.
- Exclusion of storage volume within the catchment.
- Lack of data on land use characteristics during the historical storm events.
- Lack of data on spatial variability of soil saturated hydraulic conductivity (heterogeneity) and groundwater table.
- Lack of catchment specific groundwater/aquifer information.
- Lack of detail catchment discretisation and schematisation (i.e. dividing the catchment into several sub-catchments) in non-linear reservoir routing method.
- Uncertainty and ambiguous sub-catchment width parameter estimates in the non-linear reservoir routing method.

4 FURTHER WORK

Further work to establish the continuous simulation modelling methodology and representative modelling parameters that can be used in ungauged catchments in the Auckland Region are summarised below:

- Develop semi-distributed hydrological model i.e. dividing the catchment into several irregularly shaped sub-catchments based on spatial variability in topography, drainage pathways, land cover, and soil characteristics. Inclusion of main drainage channel in the hydraulic routing model.
- Application of the semi-distributed hydrological and hydraulic modelling method in other catchments with different soil types (e.g. alluvial/greywacke/sandy/volcanic), to identify representative modelling

parameters that can be used in ungauged catchments for various climatic, topographic and hydrogeological conditions.

- Calibration could be undertaken utilising rain radar information for some catchments to reduce the uncertainty with the spatial variability of rainfall.

The intent, after a continuous simulation modelling methodology is developed and an appropriate set of parameter values for un-gauged catchments are confirmed, is to undertake further work to utilise the flows from the model to:

- Route flows through the main channel to calculate stream flow velocities and shear stress acting on the stream bank. This is to ultimately predict which streams will erode and where, estimate the quantity of streambank erosion (and sediment transported downstream) and the effect increased impervious development and mitigation will have on increasing or reducing the erodibility of the streams.

5 CONCLUSIONS

The following conclusions can be made from this study:

- Continuous simulation modelling is suited to predict frequent stream flows, as it can represent variations in the long-term pattern of rainfall intensity and duration, antecedent soil and storage conditions, and inter-arrival times between storms that can have a significant impact on the frequency, magnitude and duration of flows.
- The Curve Number (SCS) method implemented in EPA-SWMM is only an approximation of the method and does not replicate the Curve Number runoff peak flows and volumes. The error is greatest for lower curve numbers in pervious areas. Another error was found with the EPA-SWMM software, when the depression storage parameter is used along with the Curve Number infiltration method for continuous simulation. Infiltration losses cease after approximately a year (depending on parameters). This has been acknowledged by EPA-SWMM software developers. Considering these reasons, the Curve Number method implemented in EPA-SWMM software should not be currently used for single event or continuous simulation modelling.
- The spatial variability of rainfall is a key issue when matching flows. The Whau and Hoteo catchments provided the best match and were the catchments with rainfall gauges located in the catchment. The un-satisfactory match for the Westhoe catchment is likely due to the distance to the rainfall gauge. The Westhoe rainfall gauge was located 3km away from the catchment.
- Calibration was undertaken and assessed by comparing observed and predicted hydrographs, the calculated Nash-Sutcliffe model efficiency, flow duration curves and peak flow frequency curves. It was found that no one comparison method provides certainty over calibration.
- Calibration resulted in a good match for 99.9% of all stream flows for the Whau and Hoteo catchments and 99.5% for the Lucas and Chartwell catchments.
- Peak flow frequency results show that <1yr ARI flow events are well matched and >1yr ARI flow events provide a reasonable match for the Whau and Hoteo catchments.

- From the Nash-Sutcliffe results, four out of the five catchments calibrated provided at least a satisfactory match, with the Whau catchment providing a very good calibration and the Hoteo providing a good calibration.
- Of the parameters used in calibration, the catchment Width, groundwater Surface Elevation and groundwater A1 Coefficient were the most sensitive. To reduce uncertainty with these parameters, it is important to understand the catchment width parameter and catchment specific groundwater parameters.
- An accurate representation of the groundwater in the catchment is key in representing frequent stream flows. A good understanding of the catchments specific groundwater conditions is important to achieve this.
- The Horton and Green Ampt infiltration methods provided similar results, in terms of the Nash-Sutcliffe result, hydrographs, and the flow duration and peak flow frequency curves.

This study is leading to the development of a long-term continuous simulation modelling methodology in Auckland Region. The methodology and parameters will be further refined through experimentation with other catchments using the knowledge and issues gained in this study, to reduce uncertainty in model results and thereby gain a level of confidence in establishing the hydrological modelling parameter values. These parameter values can be adopted for ungauged catchments across the Auckland Region and used to predict whether a stream will erode and can be utilised in contaminant loading assessments.

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