IMPACT OF CATCHMENT SIZE FOR STORMWATER MODELLING IN THE AUCKLAND REGION

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Abstract
Stormwater management design in the Auckland Region is currently based on Guidelines for stormwater runoff modelling in the Auckland Region, Technical Publication No. 108 (TP108). These guidelines were produced based on Technical Release No.55 (TR55) prepared by the U.S. Soil Conservation Services (SCS) and the U.S. SCS rainfall-runoff model was applied to catchments in the Auckland Region. It has been used as a standard design tool in catchment modelling by different users. These guidelines were prepared for the Auckland Regional Council (ARC) by Beca Carter Hollings & Ferner Ltd. BCHF selected, calibrated and validated the SCS rainfall-runoff model for these guidelines based on the evaluation of gauged catchments in Auckland. However, there are a number of limitations associated with the use of these guidelines and the SCS model. One of the major concerns of these limitations is the maximum catchment size to be used in conjunction with the rainfall-runoff model. Once the maximum catchment size is determined, large catchments can be subdivided into smaller subcatchments in order to calculate the generated runoff. Flows generated from subcatchments routed to the catchment outlet using an unsteady hydraulic model, and an estimation of accuracy would be essential. The purpose of this study is to review the TP108 guidelines; and to investigate the impacts of catchment size in stormwater runoff modelling in the Auckland Region by carrying out desktop modelling simulation of the Papakura Stream Catchment.

Key Words : Catchment size, Stormwater modelling

1. INTRODUCTION
Stormwater management design in the Auckland Region is currently based on Guidelines for stormwater runoff modelling in the Auckland Region, Technical Publication No. 108 (TP108) (Auckland Regional Council, 1999). These guidelines were produced based on Technical Release No.55 (TR55) prepared by the U.S. Soil Conservation Services (SCS) and the U.S. SCS rainfall-runoff model was applied to catchments in the Auckland Region (U.S Soil Conservation Service, 1986). These guidelines were prepared for the Auckland Regional Council (ARC) by Beca Carter Hollings & Ferner Ltd (Beca, 1999a-d).

There are a number of limitations associated with the use of these guidelines and the SCS model. One of the major concerns of these limitations is the maximum catchment size to be used in conjunction with the rainfall-runoff model. Once the maximum catchment size is determined, large catchments can be subdivided into smaller subcatchments in order to calculate the generated runoff. Flows generated from subcatchments routed to the catchment outlet using an unsteady hydraulic model, and an estimation of accuracy would be essential.

2. MODELLING BACKGROUND
HEC-HMS and HEC-RAS software packages are currently being used worldwide in hydrological and/or hydraulic modelling of various catchments. These two software packages have been selected for modelling in this study. HEC-HMS is a hydrological modelling system designed to simulate the precipitation-runoff processes of dendritic catchment systems. This

modelling system was developed by U.S. Army Corps of Engineers. This system is capable of estimating runoff using the SCS method, and has been adopted in TP108. HEC-HMS provides a number of different approaches to calculate runoff concentration and conveyance. The accuracy and suitability of these approaches used in the model need to be investigated. HEC-RAS was developed to allow river flow analysis for a network of natural and constructed channels.

The current study will incorporate the use of HEC-HMS and HEC-RAS to perform both hydrological and hydraulic analysis of the assigned Papakura Stream Catchment in the region.

3. HYDROLOGICAL AND HYDRAULIC MODELLING OF PAPAKURA STREAM

3.1 Hydrological Modelling Using HEC-HMS

The hydrological models developed for the Papakura Stream Catchment using HEC-HMS are lumped, rainfall-runoff models. These models represent the rainfall-runoff processes with the catchment and generate catchment outflows for use as input to the hydraulic model for the stream channel. In general, TP108 guidelines were followed in the modelling process.

The entire catchment with a total area of 56 km^2 was divided into 37 subcatchments. These 37 subcatchments range from 0.07 to 13.24 km^2. A graphical representation of the subcatchment delineation is illustrated in Figure 1.

In order to investigate the impacts of catchment size on the modelling outcomes, four models were built to represent different scenarios. Model A has adopted the division of 37 subcatchments. Model B has combined two of the previous adjacent subcatchments to form 19 subcatchments. Similarly, Model C has combined four of the previous adjacent subcatchments to form 10 subcatchments. Subcatchment 25 has been considered as a single subcatchment in all three models due to its relatively large catchment size (13.24 km^2). Model D has also been developed, where the entire catchment has been considered as a single catchment without subcatchment division.

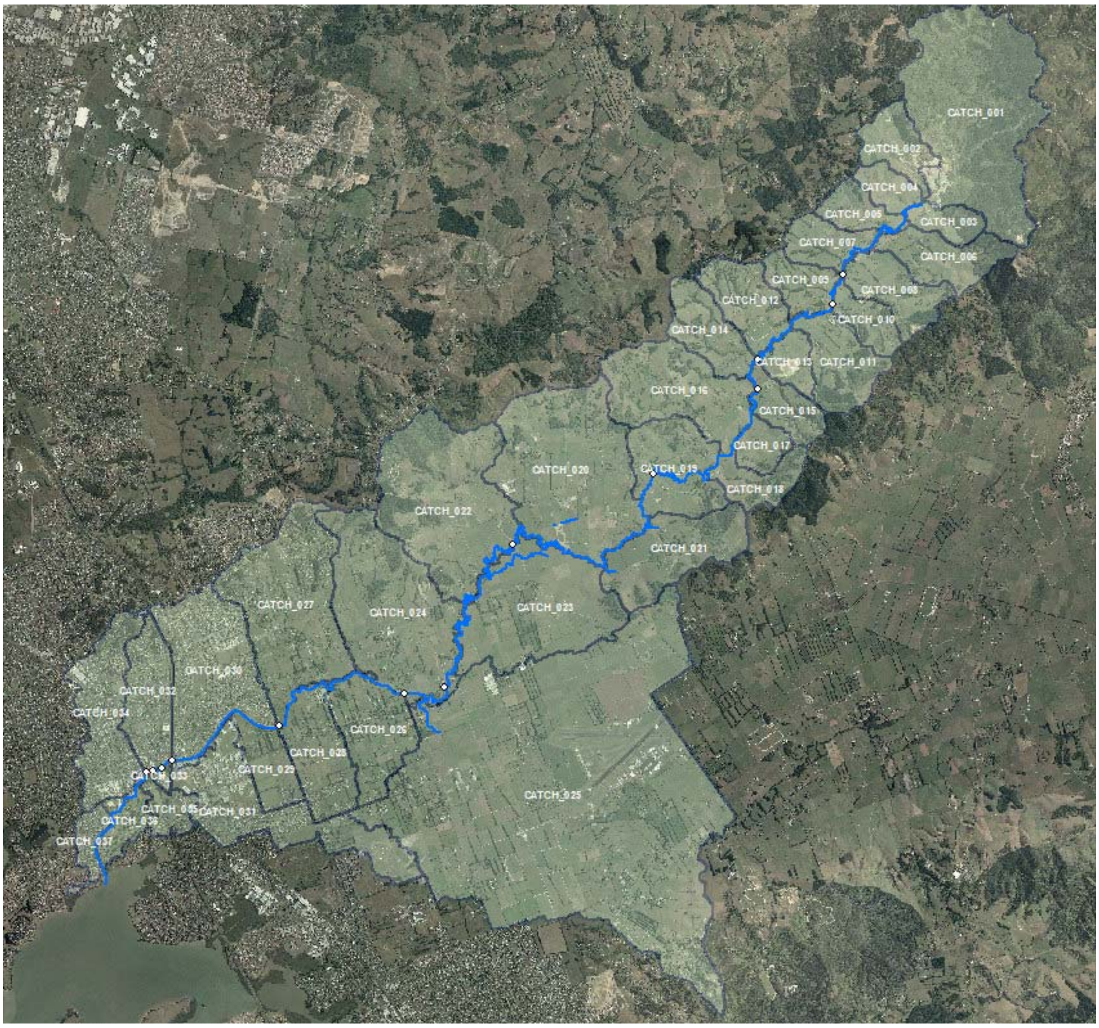

Fig 1. Subcatchment Delineation of the Papakura Stream Catchment

A flow chart is included in Figure 2 to show the overall hydrological modelling approach.

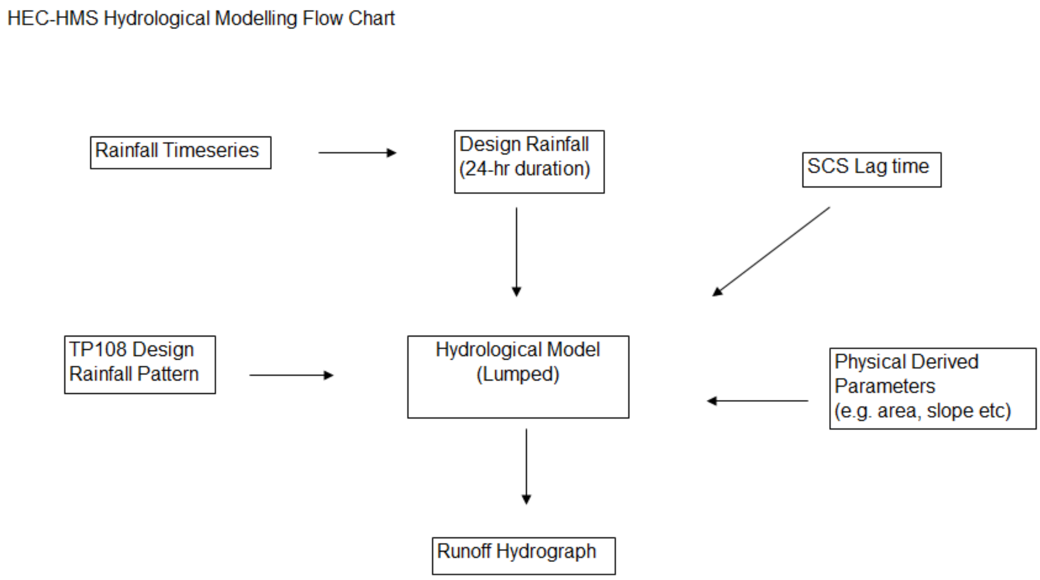

Fig 2. HEC-HMS Hydrological Modelling Flow Chart

3.2 Hydraulic Modelling Using HEC-RAS

The HEC-RAS software has been used as the tool for the hydraulic routing of the Papakura Stream. Three one-dimensional hydraulic models have been developed in HEC-RAS. Each of these hydraulic models incorporates the hydrological output from one of the three models (Model A, B and C) developed in HEC-HMS. No hydraulic model is needed for Model D since the entire catchment has been treated as one single catchment in the hydrological model. A flow chart is included in Figure 3 to show the overall hydraulic modelling approach.

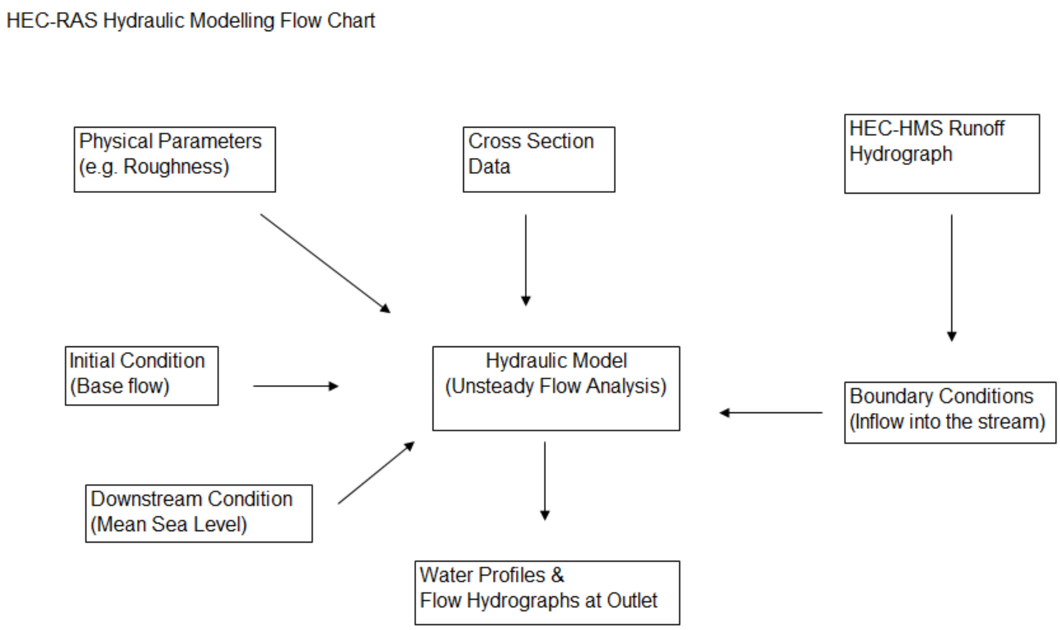

Fig 3. HEC-RAS Hydraulic Modelling Flow Chart

4. Results Discussion

4.1 Comparison between Models A, B and C

Figures 4, 5 and 6 show the runoff hydrograph at catchment outlet generated by three models for the 2, 10 and 100 yr events respectively.

For the 2 yr average recurrence interval (ARI) storm event, the differences in peak flows produced by Model A, B and C tend to be small to moderate. The peak flow at the catchment outlet generated in Model B (88.2 m^3/s) is lower than the one from Model A (90.3 m^3/s) by 2.3%, while the one produced by Model C (100.2 m^3/s) is 11.0% higher than Model A. The time to peak for Model B and C are 17:15hrs and 14:30hrs respectively, which varies by 1 to 15% from the one for Model A (17:05hrs). From inspecting the hydrographs produced by these three models, it was observed that Model B and C tend to show a “double peak” in the hydrograph, while it is indicative in Model A as a “single peak”. This indication of “double peak” is much clearer in Model C than Model B. Furthermore, the first peak (100.2 m^3/s) tends to be higher than the second peak (84.6 m^3/s) in Model C, while the two peaks in Model C have relatively similar values (86.3 and 88.2 m^3/s).

For the 10 yr ARI storm event, the differences in peak flows generated by Mode B and A is negative, while it is positive between Model C and A. Model B has produced a peak flow of 116.5 m^3/s, which is only 0.4% lower than 117.0 m^3/s generated from Model A. The difference between the peak flows produced by Model C (132.8 m^3/s) and A is 13.5%. The time to peak in Model B and C is 13:55hrs and 13:30hrs, which take place at 40 and 55 minutes before the peak in Model A. Similar to the 2 yr ARI storm event, the hydrograph of Model C tends to produce a “double peak”, while this is vaguely indicated in Model B, and only a “single peak” is observed in Model A. And the first peak (132.8 m^3/s) tends to be higher than the second peak (103.9 m^3/s) in Model C, while the two peaks in Model B are similar in magnitude (116.5 and 108.8 m^3/s).

For the 100 yr ARI storm event, the peak flows generated in Model B and C tend to be higher than the one in Model A. The variation between the peak flows generated from different models tends to be larger. The peak occurs at an earlier time step by 3 hours in Model C than it does in Model A, while Model A and B have similar time to peak. However, unlike the observations in the 2 and 10 yr events, the peak for Model B (168.6 m^3/s) is higher than the one produced by Model A (163.3 m^3/s); while peak flow from Model B is lower than the one for Model A in the other events. The variation of peak flows in Model B is 3.3% compared to Model A, while it is only 7.4% in Model C. Although the variation in peak flows and time to peak observed in the 100 yr event is larger than the one found in the 2 and 10 yr events, similar trend regarding to the shape of the hydrograph has been observed. Despite the fact that Model B produces a higher peak than Model C, the "double peak" picture is still vague in Model B.

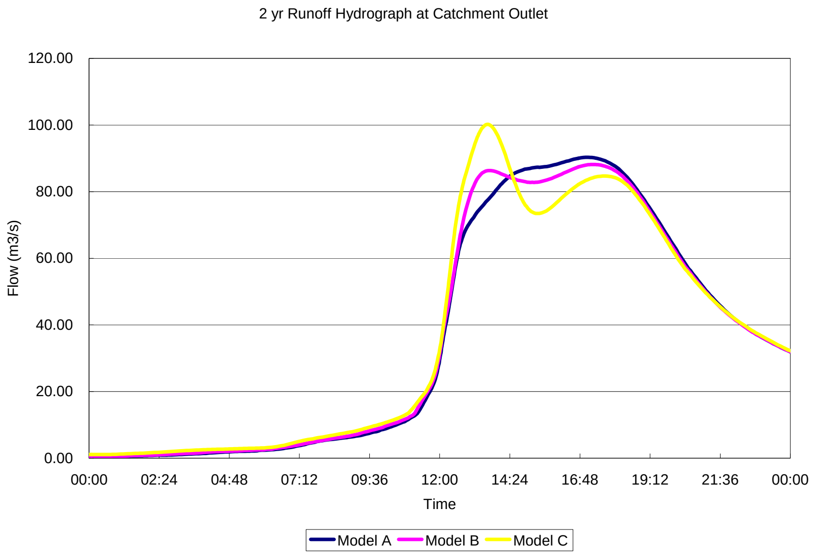

Fig 4. 2 yr Runoff Hydrograph at Catchment Outlet Produced by Model A, B and C.

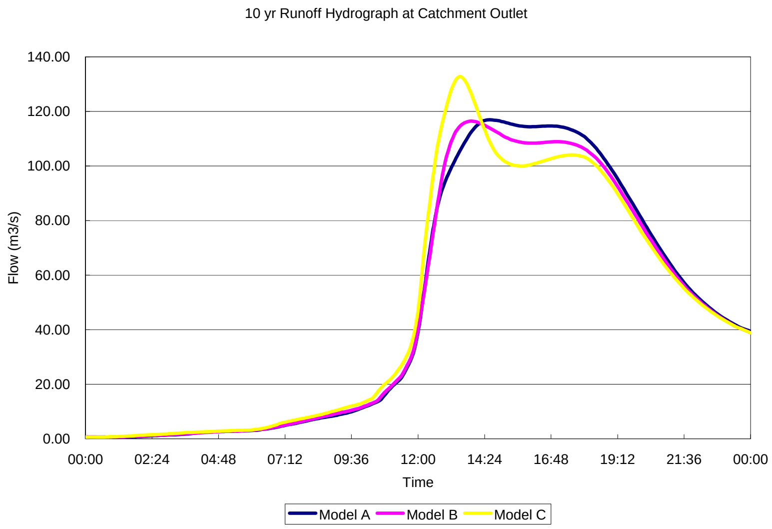

Fig 5. 10 yr Runoff Hydrograph at Catchment Outlet Produced by Model A, B and C.

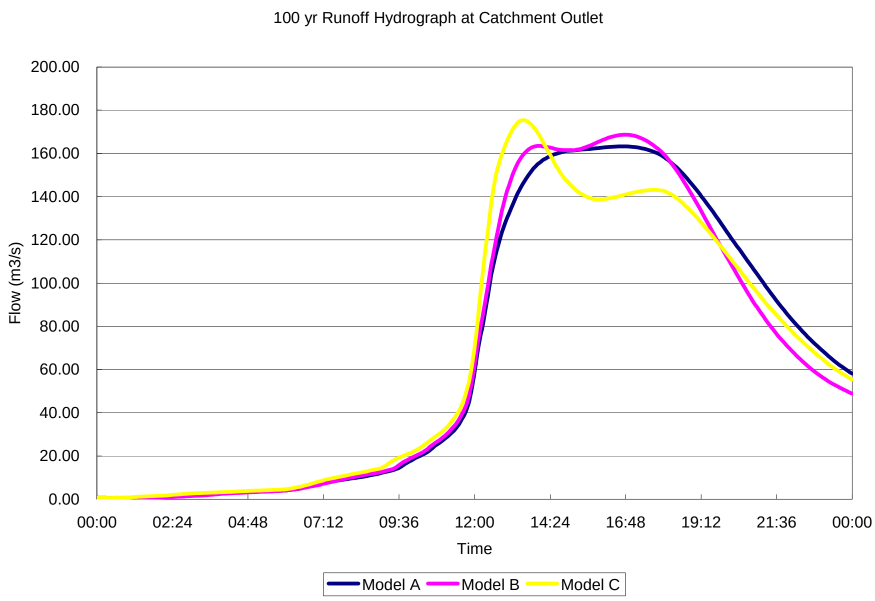

Fig 6. 100 yr Runoff Hydrograph at Catchment Outlet Produced by Model A, B and C.

Table 1 and 2 list the comparison between the output from Model A, B and C, in terms of peak flows and time to peak.

In general, by increasing the size of the subcatchments in hydraulic simulation (i.e. by combining subcatchment in Model B and C in this study), there is no obvious trend observed in the magnitude of the peak flows generated from different models. The effects are considered relatively small, within 14% for all scenarios analysed. However, by inspection of the hydrographs produced from Model A, B and C, there is a clear shift of the curve by going from Model A to Model B and C. From all design rainfall events simulated, it was observed that Model B and C tend to show a "double peak" in the hydrograph, while it is indicative in Model A as a "single peak". This indication of "double peak" is much clearer in Model C than Model B. Furthermore, the first peak tends to be higher than the second peak in Model C, while the two peaks in Model C have relatively similar values.

Peak Flow Comparison (m^3/s)			
Event ARI	Peak Runoff (m^3/s)		
	Model A	Model B	Model C
2yr	90.3	88.2	100.2
10yr	117.0	116.5	132.8
100yr	163.3	168.6	175.3

Table 1. Peak Flow Output from Model A, B and C.

Time to Peak (hh:mm)			
Event ARI	Time to Peak (hh:mm)		
	Model A	Model B	Model C
2yr	17:05	17:15	14:30
10yr	14:35	13:55	13:30
100yr	16:40	16:45	13:35

Table 2. Time to Peak Output from Model A, B and C.

4.2 Comparison with Model D

A lumped model has been developed for the Papakura Stream Catchment by treating the entire catchment as one single catchment. No hydraulic simulation has been carried out for this model. The hydrological output of this model (Model D) has been compared with the hydraulic output of the other three models (Model A, B and C). Table 3 shows the output from Model D simulation compared with results from hydraulic simulation of Model A. Only peak flows are compared due to the simulation time for Model A is not comparable to Model D, hence the runoff volume cannot be compared.

The peak flows generated from Model D are higher than the ones produced by Model A by 64 to 69% for all design rainfall events considered.

The lumped model (Model D) tends to produce higher peak flows because no hydraulic channel routing has been allowed in the model. Furthermore, no attenuation has been considered in the form of floodplain and channel roughness. It is considered inaccurate to model a catchment with such size by a lump model without any subcatchment division.

	Peak Flow (m^3/s)		
	Model D	**Model A**	**% Variation**
2yr	148.2	90.3	64.1
10yr	191.1	117.0	63.4
100yr	275.6	163.3	68.8

Table 3. Comparison between Outputs from Hydrological Model D and Hydraulic Model A.

4.3 Comparison with Flow Gauge

A flood analysis has been carried out on the records from the flow gauge at 90% downstream of the catchment. The results of this flood analysis have been compared with the output of the HEC-RAS simulation output in the following section.

Table 4 lists the results from the flood analysis from the flow gauged records against the HEC-RAS peak flows output.

	Flow Gauge (m^3/s)	**HEC-RAS Peak Flows (m^3/s)**					
		A	% Variation	B	% Variation	C	% Variation
2yr	25.9	90.3	248.6	88.2	240.4	100.2	286.8
10yr	56.7	117.0	106.3	116.5	105.5	132.8	134.2
100yr	81.4	163.3	100.6	168.6	107.2	175.3	115.4

Table 4. Comparison between Flow Gauge and HEC-RAS Peak Flows (m3/s)

The simulated peak flow from all three models is higher than the flow gauge design flow (25.9 m^3/s) by 249 to 286% for the 2 yr event, and around 100 to 115% for the 10 and 100 yr events. As discussed previously, the impacts of variation in roughness and catchment size used are considered relatively small, in the extent of up to around 10% difference in peak flows. The impacts of the selection of roughness and catchment size are considered small relative to difference between the simulated results from the models and the flow gauge output. The main contributing factors which could lead to such difference are as follow:

Storage Area or Floodplain

No storage area or floodplain has been included in the modelling. However, from local experience, there are various locations within the catchment which have considerable storage ability and could be treated as floodplain in hydraulic modelling. The exclusion of floodplain in the model could lead to a higher peak flow due to lack of attenuation.

Cross Drainage Structures
No bridges or culverts have been included in the models. There is a considerable amount of these structures exist along the stream which provide flow obstruction and attenuation along the stream.

Curve Number
Within each subcatchment, the area has been divided into two parts, impervious and pervious, each having a curve number associated. Then the curve number of the catchment has been calculated by weighting the curve numbers of these two parts, which is used to calculate the critical input parameter, time to peak, in the modelling. The curve number used in the simulations of this study was adopted using the values recommended in TP108. As discussed previously, the curve numbers suggested in TP108 adopted the values derived from U.S catchments. Although they have been examined against the data from a few catchments within Auckland, it is considered insufficient to justify whether these curve numbers are representative to the catchments in Auckland. Since curve numbers play an important role in stormwater runoff modelling and directly affects the outcome of the simulations, these curve numbers are recommended to be reviewed further to give values which are representative to the characteristics of the catchment in Auckland.

TP108 Design Rainfall Pattern
The TP108 24-hr design rainfall pattern has been adopted in the simulation, which has also been widely used throughout the region for stormwater modelling. As discussed previously, this 24-hr design storm has been derived from the method developed in the U.S. and examined against the rainfall records from four areas within the region. There was lack of justifications on whether the data used in the examination provides adequate coverage and representation of the area. This design storm pattern is a critical parameter used in the simulation and it is recommended that further studies should be carried out in regards to the use of this 24-hr standard storm pattern.

It was claimed that the models generated for the Auckland Region guided by TP108 generally produce peak flows, which have a factor 1.5 to the observed flows. The models developed by this study generate peak flows which are around 2 times the observed flow for the 10 and 100 yr ARI storm events, which is considered reasonable given the level of complexity of the models.

5. CONCLUSIONS

Both hydrological and hydraulic models have been developed for the Papakura Stream Catchment in order to investigate the impacts of catchment size for stormwater modelling in the Auckland Region. There are four models developed, Model A, B, C and D, which have divided the catchment into 37, 19, 10 and 1 subcatchments. Hence, the results from these simulations can be compared; consequently, the impacts of increasing the size of the subcatchments in stormwater modelling can be investigated. The following findings have been concluded from the current study.

In general, by increasing the size of the subcatchments in hydraulic simulation (i.e. by combining subcatchments in Model B and C in this study), there is no obvious trend observed in the magnitude of the peak flows generated from different models. The effects are considered relatively small, within 14% for all scenarios analysed. Furthermore, the water surface elevation produced by models with larger subcatchment size tend to be similar to the one generated by smaller subcatchment size model. However, the % of variation in water surface elevation between three models is up to 2.1, 2.5 and 4.0% for the 2, 10 and 100 yr ARI storm events. However, by inspection of the hydrographs produced from Model A, B and C, there is a clear shift of the curve by going from Model A to Model B and C. For all design rainfall events simulated, it was observed that Model B and C tend to show a “double peak” in the hydrograph, while it is indicative in Model A as a “single peak”. This indication of “double peak” is much clearer in Model C than Model B. Furthermore, the first peak tends to be higher than the second peak in Model C, while the two peaks in Model C have relatively similar values.

A lumped model has been developed for the Papakura Stream Catchment by treating the entire catchment as one single catchment. No hydraulic simulation has been carried out for this model. The hydrological output of this model (Model D) has been compared with the hydraulic output of the other three models (Model A, B and C). The peak flows generated from Model D are higher than the ones produced by Model A by 64 to 69% for all design rainfall events considered. The lumped model (Model D) tends to produce higher peak flows because no hydraulic channel routing has been allowed in the model. Furthermore, no attenuation has been considered in the form of floodplain and channel roughness.

The model output from this study has also been compared with the results from the flood analysis carried out on the records of the flow gauge in the catchment. The simulated peak flow from all three models is higher than the flow gauge design flow (25.9 m^3/s) by 249 to 286% for the 2 yr event, and around 100 to 115% for the 10 and 100 yr events. The impacts of variation in roughness and catchment size used are considered relatively small, in the extent of up to around 10% difference in peak flows. The effects of the selection of roughness and catchment size are considered small relative to difference between the simulated results from the models and the flow gauge output. The main contributing factors which could lead to such difference between the simulated peak and the observed flows are considered as: the level of complexity of the model (no floodplain attenuation of cross drainage structures are included); the curve number values and the 24-hr design rainfall pattern recommended by TP108 and used in this model need to be tested and justified further to give representations of the Auckland Region.

6. ACKNOWLEDGEMENTS

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