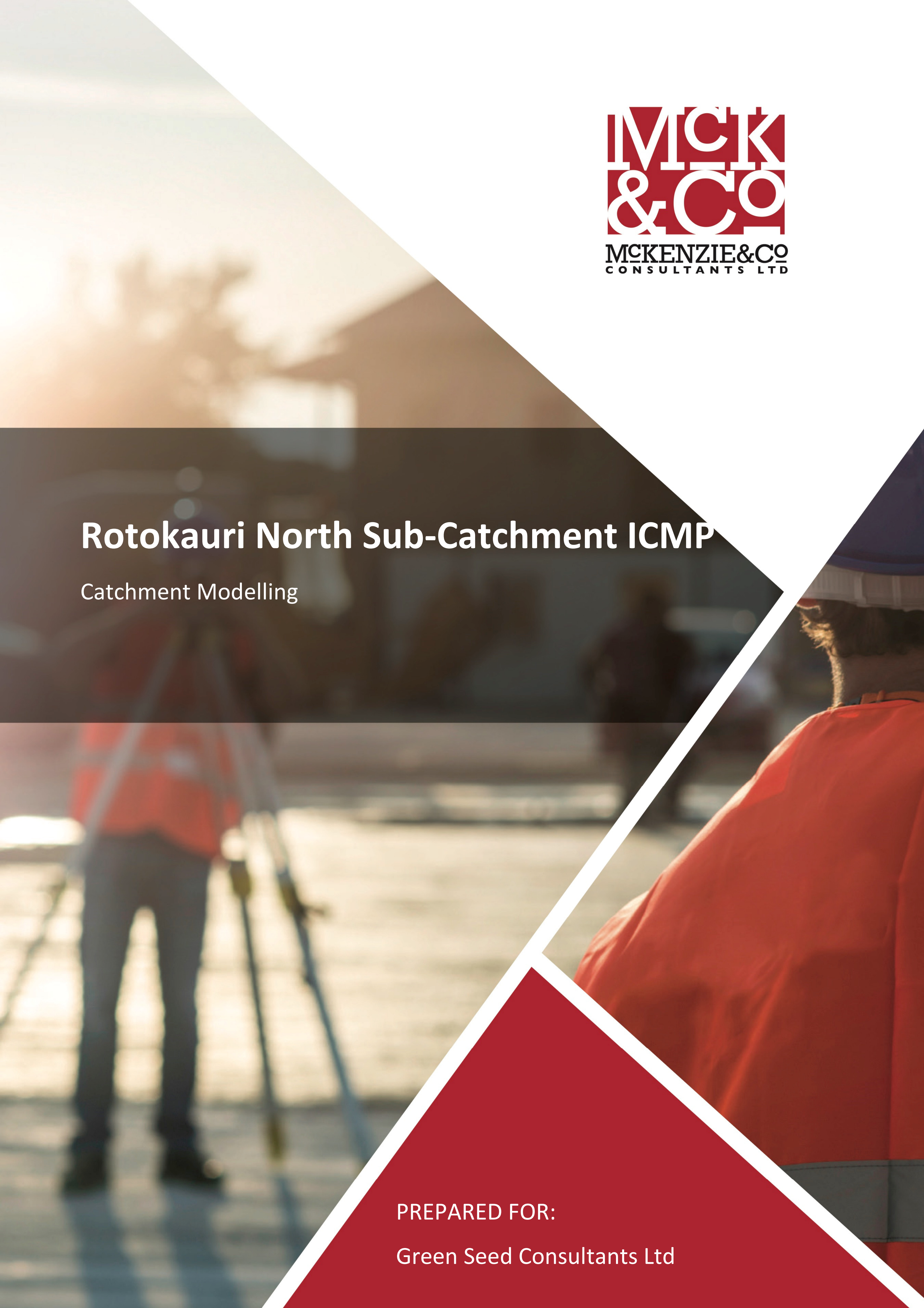

Rotokauri North Sub-Catchment ICMP

Catchment Modelling

PREPARED FOR:

Green Seed Consultants Ltd

DOCUMENT CONTROL RECORD

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CLIENT:	Green Seed Consultants Ltd
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Revision	Date	Originator	Checker	Approver	Description
Draft	10/18	BJR/BH	AJSH	AJSH	Client Review
1	12/18	BJR	AJSH	AJSH	Draft PPC
2	04/19	BJR/BH	AJSH	AJSH	ICMP Version

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1.0 INTRODUCTION

McKenzie & Co Consultants have been engaged by Green Seed Consultants Ltd (GSCL) to prepare a stormwater modelling report to assess pre-development stormwater flows for the Rotokauri North Sub-Catchment Integrated Catchment Management Plan (ICMP). This report has been prepared alongside a Private Plan Change (PPC) to rezone 133 ha (within the ICMP area) for medium density housing and a neighbourhood centre.

The full extent of modelling (including that in this report) covers the extent of land identified in Figure 1, based on existing topographical catchments. However, the ICMP covers approximately 203 hectares as shown in Figure 1 below, and is only based on land falling inside the HCC Territorial Authority Boundary.

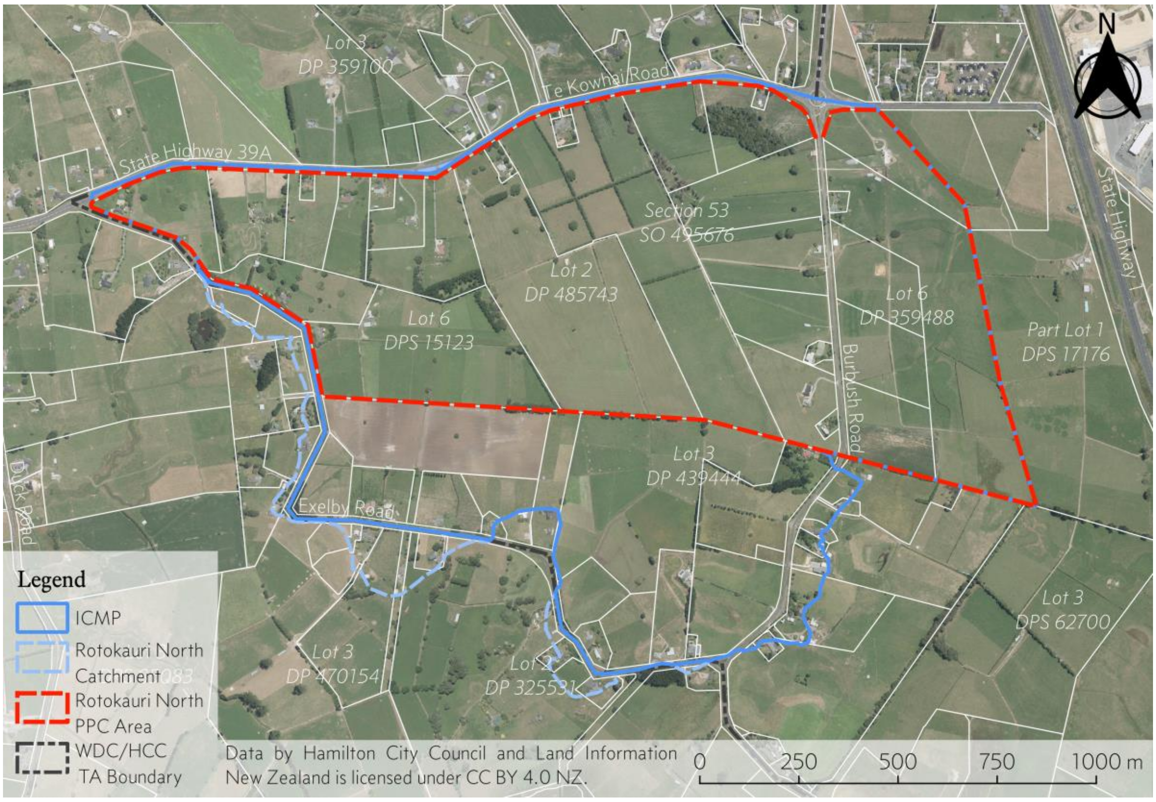

Figure 1: ICMP Area and Rotokauri North Catchment

2.0 SITE DESCRIPTION

The site is located at the edge of Hamilton City's urban limit toward the northwest corner of the city. The site is bounded to the north by State Highway 39 (Te Kowhai Road), and generally on the west and south by Exelby Road. The Waikato Expressway lies to the east and Burbush Road passes through (North – South) the middle of the site – see Figure 2.

The site is comprised of farmland pastures, with a small number of farmhouses/residential dwellings, and farm utility buildings present.

The landform is generally very flat with around 2 m fall across the site. Burbush Road is elevated some 10 m above the site to the south. The total elevation range across the ICMP catchment is from RL 27m to RL 47m.

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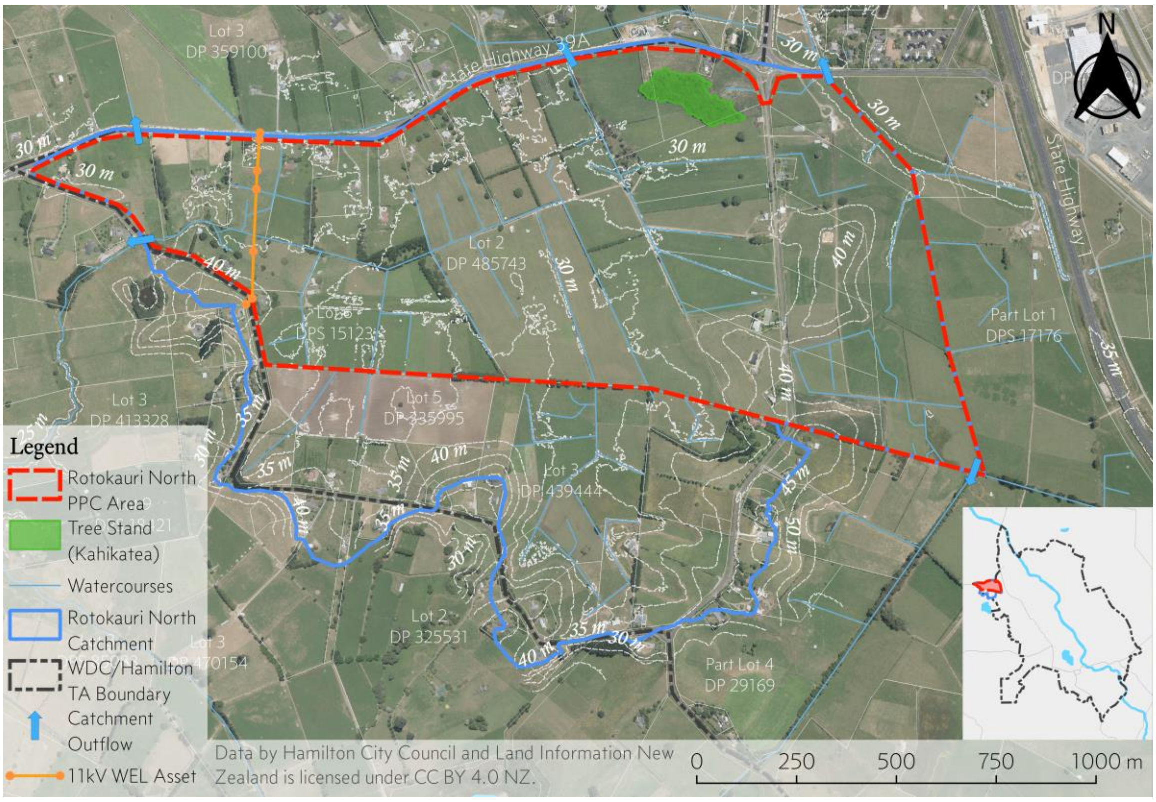

Figure 2: Site Location

3.0 CATCHMENT MODELLING BACKGROUND

The Rotokauri North development area is at the intersection of the Ohote, Te Otamanui, Mangaheka and Rotokauri South catchments. Modelling and reporting on these catchments was undertaken by external consultants for Hamilton City Council (HCC) separate to the work herein.

The majority of stormwater catchment discharge is through the Ohote catchment, which runs predominantly east-west through Rotokauri North. Previous modelling for the Ohote catchment included a restriction on the Exelby Road culvert that limited flows to 0.7m^3/s. If the Exelby Road culvert discharge rate previously used is in fact greater than 0.7m^3/s, stormwater detention devices constructed upstream to limit the catchment discharge rate to 0.7m^3/s will be oversized. For example, preliminary assessment indicates that 85,000 m^3 detention will be required for Q = 0.7m^3/s; increasing Q to 2.58m^3/s reduces detention requirements to approximately 30,000 m^3.

There is no apparent physical reason for this limit. Consequently, the actual pre-development flows for the Ohote catchment are unclear.

Three separate models have been produced to determine peak flow at the Exelby Road culvert. 1D models were based on Auckland Council TP108 (Auckland Regional Council, 1999) methodology, HEC-HMS analysis, and 2D modelling using HEC-RAS.

Two-dimensional modelling using HEC-RAS was also undertaken for the portions of Te Otamanui, Mangaheka, and Rotokauri South catchments that fall within the Rotokauri North ICMP and PPC area.

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4.0 ONE DIMENSIONAL MODELLING

To maintain consistency with the Rotokauri South ICMP and the associated stormwater modelling, a TP108 analysis for the predevelopment Ohote catchment (refer to Appendix K – TP108 Calculation) was undertaken such that model results would be comparable with previous AECOM modelling. The analysis inputs were based on values used for the AECOM modelling as noted below.

Catchment size:	136.39 ha from file “MikeModelCatchmentData.gdb.zip” supplied by AECOM on 18/10/18.
Curve Number (CN):	A single weighted average curve number of 73.5 was calculated from the sub-catchment curve numbers in file “MikeModelCatchmentData.gdb.zip” supplied by AECOM on 18/10/18. The curve numbers accounted for impervious areas.
Initial Abstraction, I*a*:	5mm, supplied by AECOM in email on 18/10/18.
Channelisation Factor, C:	1.00 (Note: this was increased from 0.8 value in TP108 to reflect the poor drainage network)
24-hour rainfall depth, P24:	139.68mm, derived from a summation of the depths in the rainfall time series contained in the file “Modelled Rainfall TS.xlsx” supplied by AECOM on 18/10/18.
Catchment slope:	Existing ground surface heights from the LiDAR surface were extracted at 1 m intervals along the alignment of the main channel. The equal area method determined the catchment slope to be 0.17%.

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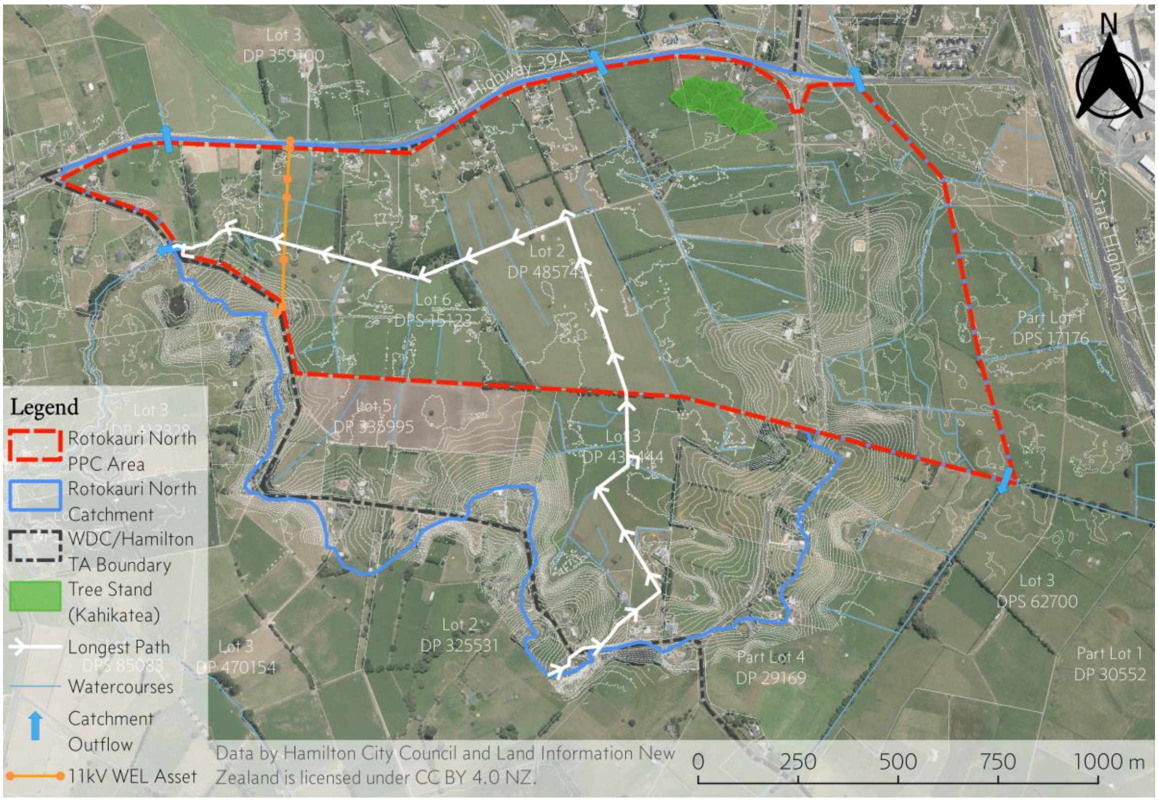

Figure 3: Plan of catchment slope alignment for TP108 calculation

Figure 2 above shows that aside from the ridge running along the west, south and east edges of the catchment, the Rotokauri North ICMP catchment has minimal grade.

An additional HEC-HMS model was built to calculate a predevelopment 1% AEP peak flow immediately upstream of the Exelby Road culvert. The TP108 inputs described above were used in the model with the following additional inputs:

Software used:	HEC-HMS v4.2.1;
Hyetograph time interval:	5 minutes;
Hyetograph data:	from file “MikeModelCatchmentData.gdb.zip” supplied by AECOM on 18/10/18. The data supplied is shown in Appendix B;
Nested storm event duration:	24 hours;
Simulation run period:	24 hours;
Simulation step interval:	1 minute;
Loss method:	SCS Curve Number;
Lag time, t_p:	$t_p = 0.666 * t_c$; and
Peak Rate Factor (PRF):	The default PRF of 484 was used to allow comparison with the PRF used by TP108;

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4.1 Model Limitations

HEC-HMS was used only for one-dimensional (1D) runoff calculations. As an output it provided a rainfall runoff hydrograph. Peak discharge and total runoff volume at given locations are also able to be estimated. No other outputs are provided.

Although HEC-HMS can model baseflow discharge and volume, no baseflow model was used. The model outputs were for surface runoff data only. The methodology assumes that all rain falling within the catchment contributes to surface runoff. HEC-HMS does not directly model any 2D effects, such as storage at ground surface or below surface, grid cell size, shape or relative elevation of adjacent cells, tailwater, etc.

4.2 Boundary Conditions

Precipitation

The precipitation boundary condition was based on a 24-hour duration with rainfall depths proportioned over the event profile as per previous modelling by AECOM.

4.3 1D model Results

The predevelopment 1% AEP peak flow for the two analyses at the upstream side of the Exelby Road culvert were:

- TP108 analysis = 6.3 m^3/s; and
- HEC-HMS analysis = 7.6 m^3/s.

4.4 1D model Discussion

AECOM estimated peak flow for Ohote Catchment to be 0.7m^3/s (revised 2.7 m^3/s in subsequent AECOM sensitivity modelling), using their coupled Mike Urban model (1D/2D). McKenzie & Co. Consultants TP108 and HEC-HMS calculated peak flows were 6.3 m^3/s and 7.6 m^3/s respectively.

McKenzie & Co. consider the TP108 and HEC-HMS analyses to be unsuitable for determining the predevelopment peak flows at Exelby Road for the Ohote catchment as the catchment characteristics (limited topography, poor land drainage network) cannot be replicated adequately. TP108 (Auckland Regional Council, 1999, p. 3) limitation notes also state that the TP108 methodology may not be appropriate for flat catchments with storage capacity, which is reflective of the Ohote Catchment.

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5.0 TWO-DIMENSIONAL MODELLING METHODOLOGY

A new two-dimensional model was developed to assess the flows within the pre-development catchment for the Ohote, Te Otamanui, Mangaheka and Rotokauri catchments, i.e., the Rotokauri North ICMP extents. Development of the new model was limited to the Rotokauri North ICMP catchment.

AECOM previously undertook 2D modelling as part of the Rotokauri South ICMP (AECOM, 2016). The methodology herein was developed to allow for comparison with the AECOM modelling.

5.1 Model Configuration

The model was developed in HEC-RAS as a grid utilising the 2D flow modelling capabilities of the software. The 2D area was selected based on the natural topography of the catchments. Culverts were modelled from field survey data. The drainage network was modelled to match field observations and observed direction of flow. General surface elevation was derived from LiDAR acquired July 2018.

A digital elevation model (DEM) was derived (12d software) from the LiDAR information, with primary drainage channels and streams defined within the topography by manually adjusting the DEM. The manual adjustment was such that the channels and streams matched information from:

- Site surveying (culvert invert levels);
- Field observations (channel widths, position in relation to topography); and
- Corrections due to LIDAR results being affected by vegetation.

Where streams and channels were defined in the DEM, they were based on an assumed base width of 2.0m, as typically observed on site.

The DEM was used as the terrain association within HEC-RAS. Two-dimensional (2D) flow areas were defined for the stream catchments within the Rotokauri North catchment.

Breaklines were added to clearly define the primary drainage channels and streams, with additional breaklines added as required to model local topographic conditions.

The 2D model was configured as follows:

- 5m grid based on DEM;
- 1-2 m variable grid along all breaklines; and
- Manning's *n* = 0.042 for all surfaces, mid-way between established values of 0.035 (pasture, farmland) and 0.05 (flood plains – light brush).

Table 1 below summaries the HEC-RAS surface used for modelling stormwater runoff.

Table 1: 2D Grid Cell Summary

Catchment Reference	Number of Cells	Largest Cell (m^2)	Smallest Cell (m^2)	Average Cell (m^2)
Ohote (Exelby Road Culvert)	75,186	60.6	0.7	18.4

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Catchment Reference	Number of Cells	Largest Cell (m^2)	Smallest Cell (m^2)	Average Cell (m^2)
Te Otamanui (Te Kowhai Road West)	3,315	46.9	1.1	22.4
Te Otamanui (Te Kowhai Road East)	20,005	53.7	0.7	19.7
Mangaheka (Te Kowhai / Burbush)	18,826	55.0	2.2	22.2
Rotokauri South	21,877	60.5	2.1	23.9

5.2 HEC-RAS limitations

As HEC-RAS is primarily suited to river systems, it does not allow for infiltration modelling, nor definition of impervious/pervious areas. The software assumes that all rainfall on the grid will contribute to catchment runoff.

The selection of Manning's *n* (0.042) was such that it would represent the equivalent roughness of the catchment.

Regarding previous catchment modelling by AECOM[1], the global roughness value used was a Manning's *M* of 24.18, equivalent to a Manning's *n* of 0.041. While AECOM have used DHI Mike to model the 2D flow scenario, the global roughness values between the DHI Mike and HEC-RAS models were considered equivalent.

5.3 Boundary Conditions

Precipitation

A boundary condition of all 2D surfaces modelled assumed precipitation across a surface was constant. Precipitation was based on a 24-hour duration, with rainfall depths proportioned over the event profile as per previous modelling by AECOM for the Ohote Catchment – refer to section 4.0 One Dimensional Modelling above. This rainfall data was used rather than the Regional ITS rainfall data so as to allow for consistent comparison of results between different modelling methodologies:

- 50% Average Exceedance Probability (AEP) (1 in 2 year) rainfall event depth = 66.2 mm
- 10% Average Exceedance Probability (AEP) (1 in 10 year) rainfall event depth = 99.1 mm
- 1% Average Exceedance Probability (AEP) (1 in 100 year) rainfall event depth = 139.7 mm

Initial modelling with the rainfall hyetograph as per Figure 3 was undertaken based on assumption that the catchment was fully saturated, high groundwater present and initial abstraction losses

[1] Email from Stepanka Vajlikova (AECOM) to Andrew Hunter (McKenzie & Co.), "RNDA - Modelling Inputs", 25 September 2018.

equivalent to 0mm. The initial modelling prediction of flow at the Exelby Road Culvert showed a flow rate considerably greater than that predicted by AECOM previously.

Following discussions between McKenzie & Co. Consultants, AECOM and HCC, a revised rainfall hyetograph was developed. The resultant initial abstraction was 5mm to match the previous AECOM modelling.

Following correction for soil types and relevant CN values net rainfall hyetographs were created (as used in the original AECOM model), thereby reflecting reduced runoff from pervious surfaces. The hyetographs were then adjusted such that the first 5mm of rainfall was removed from the time series to model initial abstraction.

The resultant hydrographs showed a moderate correlation[2] with the AECOM modelling, and were used for the results within this report.

Table 2: Design Rainfall Depths[3]

Average Exceedance Probability (AEP) (%)	Design Rainfall Depth (mm) (AECOM)	Design Rainfall Depth (mm) (McKenzie & Co.)
50	66.2	35.5
10	99.1	55.5
1	139.7	78.7

[2] Correlation between AECOM and McKenzie & Co hydrographs for the 1% AEP event was $\rho = 0.8$. The McKenzie & Co hydrograph has a higher initial peak and discharges more rapidly than the AECOM hydrograph. The McKenzie & Co model discharges 90,000 m^3 over 24 hours, approximately 87% of AECOMs model for the same time period.

[3] Design rainfall adopted by McKenzie & Co Consultants was net after initial abstraction of 5mm removed.

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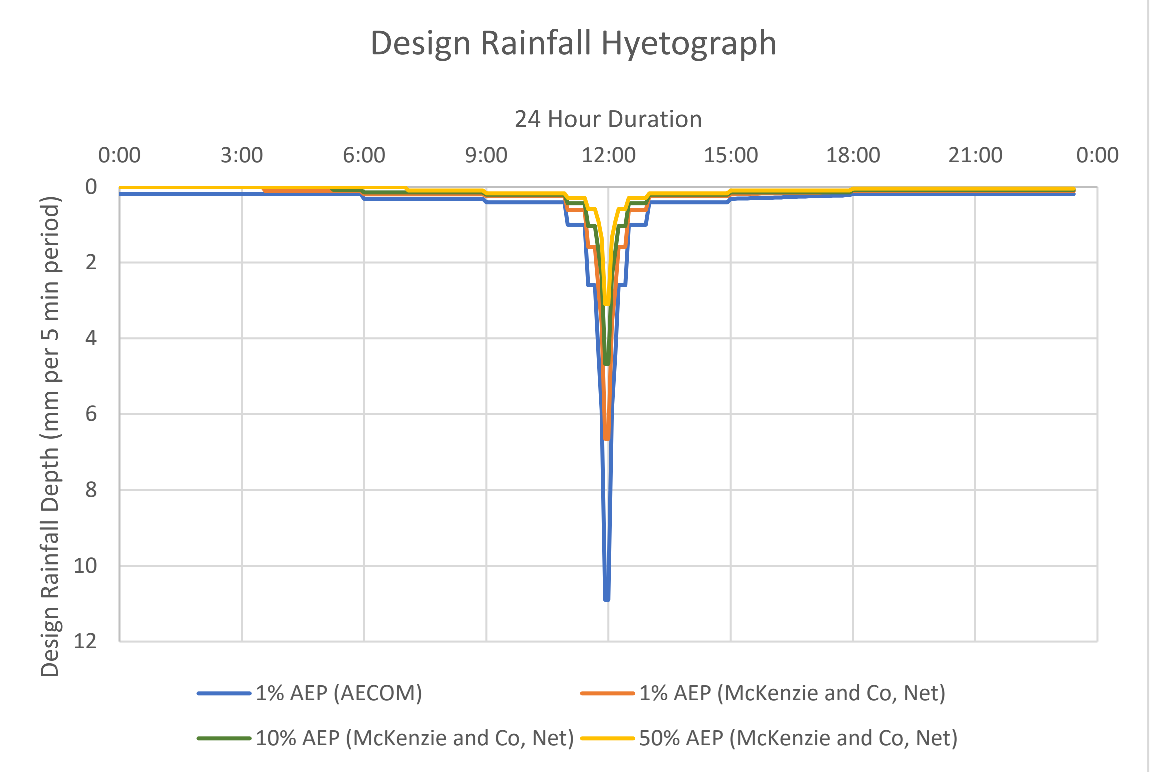

Figure 4: 24 Hour Rainfall Depth Distribution, 1%, 10%, and 50% AEP[4]

Downstream

Normal depth boundary conditions were defined for all 2D surfaces, with a friction line of 0.001 (1 in 1,000). The parameters were defined such that separate water surfaces were computed for all cells along the boundary condition line.

Storage Area / 2D Area Connections

Each catchment, except Rotokauri South, has a culvert underneath existing roads, which controls the outflow. These culvert and road configurations were modelled as Storage Area/2D Area connections within HEC-RAS. Each connection is modelled as a structure (spillway/weir) along the road centreline, with the culvert modelled through the spillway/weir. Culvert details were added as per survey information, with minor adjustments to suit connecting cell values.

For model stability purposes the spillway/weir was modelled using 2D equations rather than the weir equation. *Figure 4* below shows the arrangement of the Exelby Road culvert. The spillway profile was based on the DEM along the road, with some local adjustments to suit individual elevations of the adjacent cells.

[4] *ibid* 3

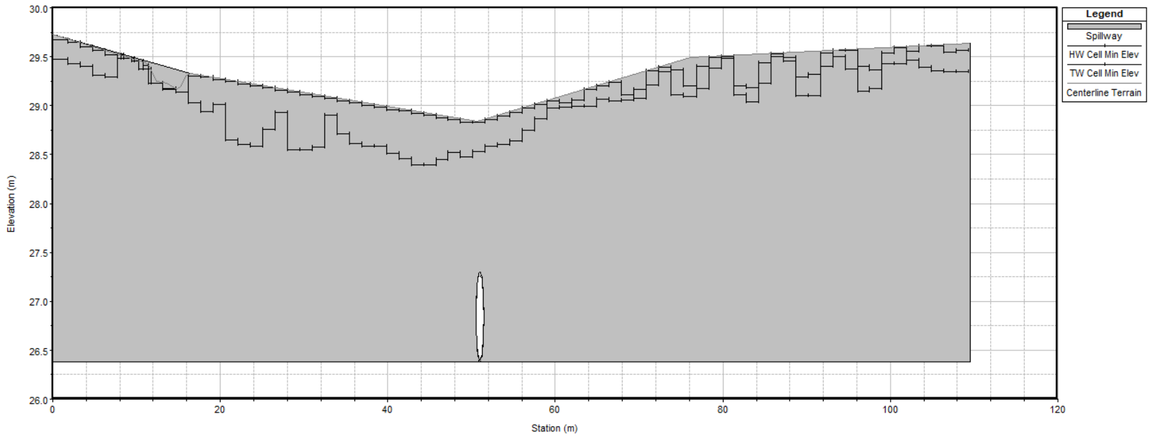

Figure 5: Typical Storage Area/2D Area Connection

Rotokauri South was not modelled with a culvert as there was no suitable hydraulic features with which to model the boundary between the ICMP/PPC area and the downstream catchment area. Results for this catchment were extracted from the boundary condition as outlined above.

Inflow

The Mangaheka catchment included inflow from upstream portion of the Mangaheka catchment to the east of State Highway 1. The DEM did not extend past SH1. As such, the peak predicted flows from Beca's Mangaheka ICMP[5] were used to develop synthetic hydrographs.

An initial model run, excluding the inflow, was used to define the hydrograph shape for the 1% 10% and 50% AEP responses. The 1% and 10% AEP hydrographs were scaled such that the peak flows matched those within Tables 4 and 6 of the Mangaheka IMCP (Adams, 2018). The 50% AEP hydrograph was scaled based on the assumption that peak flow would be 61% of 10% AEP flow, with 61% being difference between net rainfall depths for the two events.

[5] Mangaheka Integrated Catchment Management Plan – Stormwater 1D Modelling Report (Beca, 6 June 2017).

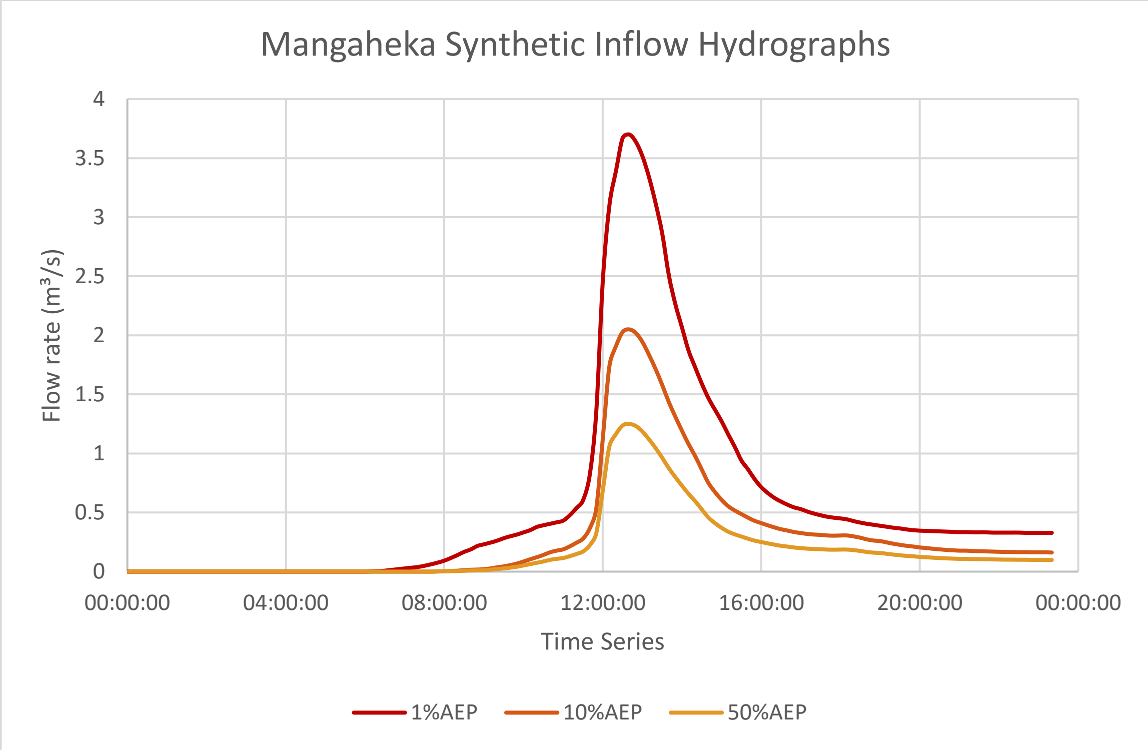

Figure 6: Mangaheka Inflow Hydrographs

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Table 3: Culvert Parameters

Culvert Parameter	Exelby Road Culvert	Te Kowhai Road (West)	Te Kowhai Road (East)	Te Kowhai / Burbush Road
Catchment	Ohote	Te Otamanui	Te Otamanui	Mangaheka
Culvert Diameter as surveyed (mm)	900	300 and 150	900	1200
Culvert Diameter as modelled (mm)	900	300	900	1200
Culvert Upstream Invert (m, RL) as surveyed	26.39	28.81	28.02	27.95
Culvert Upstream Invert (m, RL) as modelled	26.42	28.52	28.2	28.33
Culvert Downstream Invert (m, RL) as surveyed	26.38	28.34	27.96	27.95
Culvert Downstream Invert (m, RL) as modelled	26.38	28.35	27.96	27.90
Culvert Length (m) as surveyed	12.2	41.3	20.7	24.8
Culvert Length (m) as modelled	14.4	33.7	82.9	34.5

Adjustment to the culvert invert levels was necessary so as to match the estimated ground level of the connecting cells within the 2D grid. While the culvert details were surveyed, the 2D grid was based on LiDAR with the difference between the two datasets expected due to accuracy tolerances, etc. The differences within the surveyed and modelled information was not considered to critically affect the predicted results.

While additional topographical survey around the culverts would improve the grid resolution, the requirement for this survey should be considered in context of criticality of the information.

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5.4 Simulation Parameters

The simulation was configured with the following parameters to achieve accuracy and model stability:

- Initial conditions time = 1 hour
- Equation = Diffusion wave
- Maximum iterations for 2D cells = 60
- Volume tolerance for 2D cells = 0.003

Time step divisions were used to shorten the simulation time, while also providing sufficient accuracy to reduce instabilities. Table 4 shows the time steps adopted for the simulation time periods.

Table 4: Simulation Period Time Steps

Simulation Period Start Time	Simulation Period End Time	Time Step Interval (sec)
0:00	11:45	30
11:45	19:00	6
19:00	23:25	30

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6.0 TWO DIMENSIONAL RESULTS

Three rainfall events were modelled:

- 50% AEP
- 10% AEP
- 1% AEP

Results were extracted from the culvert and downstream boundary condition locations to define the pre-development flows within the Rotokauri North ICMP. All rainfall events were based on a 24-hour duration, with total depths as per Section 5.3.

6.1 50% AEP Results

The peak flows through the culverts and boundary condition were as outlined in Table 5 below. These were considered to be representative of the pre-development flows.

Table 5: 50% AEP 2D Results

Location Reference	Catchment	Peak Flow (m^3/s)
Exelby Road	Ohote	1.95
Te Kowhai Road (West)	Te Otamanui	0.11
Te Kowhai Road (East)	Te Otamanui	0.82
Te Kowhai/Burbush Roads	Mangaheka	1.49
Rotokauri South (Boundary Condition)	Rotokauri South	0.46

6.2 10% AEP Results

The peak flows through the culverts and boundary condition were as outlined in Table 6 below. These were considered to be representative of the pre-development flows.

Table 6: 10% AEP 2D Results

Location Reference	Catchment	Peak Flow (m^3/s)
Exelby Road	Ohote	2.41
Te Kowhai Road (West)	Te Otamanui	0.11
Te Kowhai Road (East)	Te Otamanui	1.53
Te Kowhai/Burbush Roads	Mangaheka	2.38
Rotokauri South (Boundary Condition)	Rotokauri South	1.30

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6.3 1% AEP Results

The predicted hydrographs at the culverts and boundary condition were extracted from the model results. For Te Kowhai Road (West)/(East), and Te Kowhai/Burbush Road there was no predicted overtopping of the road (all flow conveyed by the respective culverts). At Exelby Road, the 1% AEP flows were predicted to overtop the culvert, flowing across the road to the downstream system.

Table 7: 1% AEP 2D Results

Location Reference	Catchment	Peak Flow (m^3/s)
Exelby Road	Ohote	3.25
Te Kowhai Road (West)	Te Otamanui	0.12
Te Kowhai Road (East)	Te Otamanui	1.82
Te Kowhai/Burbush Roads	Mangaheka	3.21
Rotokauri South (Boundary Condition)	Rotokauri South	1.77

The hydrographs over the 24-hour simulation period are presented below, with Exelby Road results discussed further in the subsequent section – see Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10.

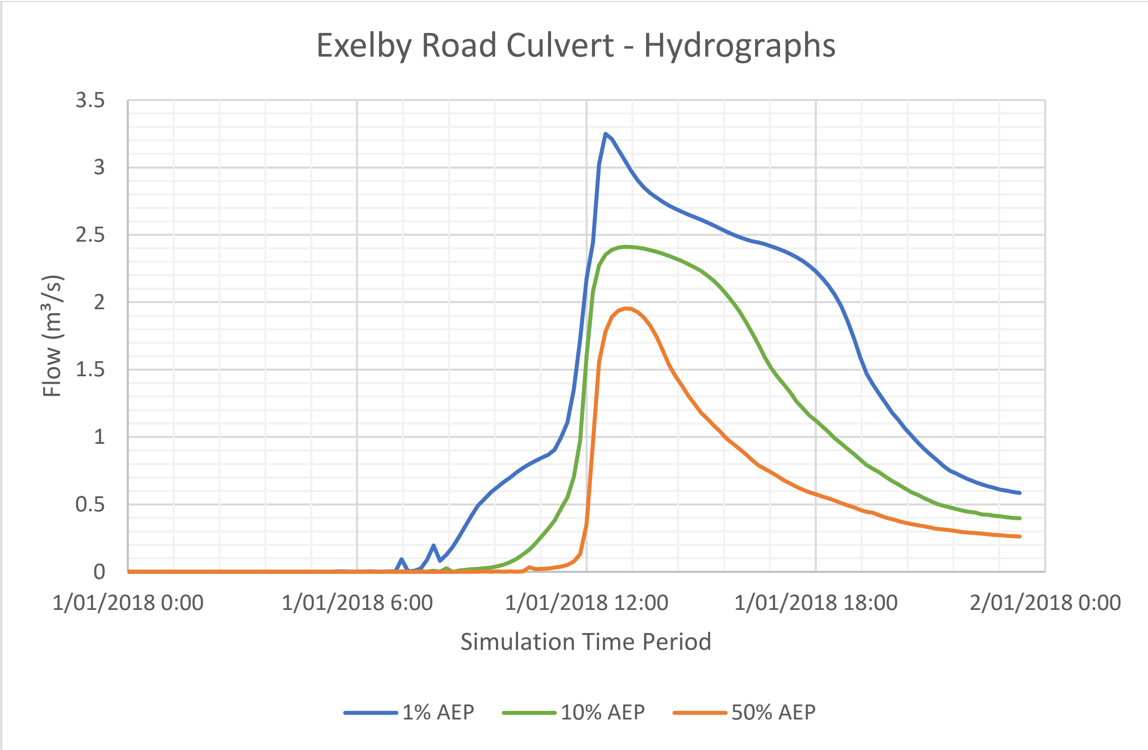

Figure 7: Exelby Road Culvert Flow

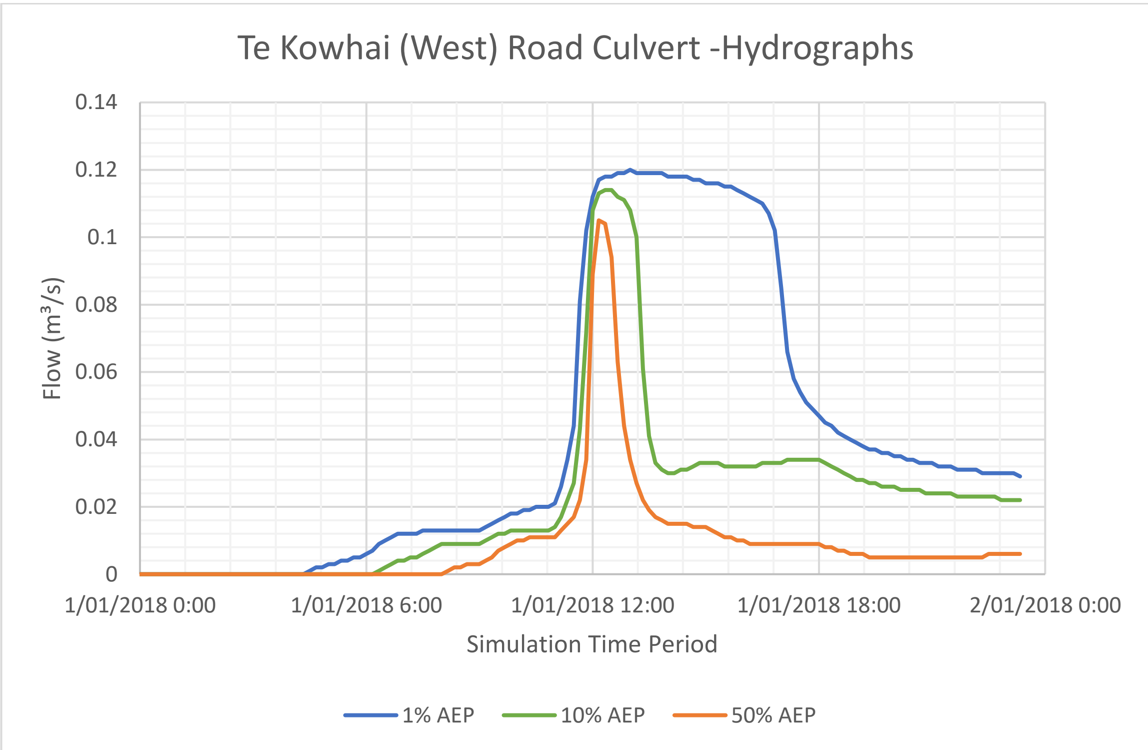

Figure 8: Te Kowhai Road (West) Culvert Flow

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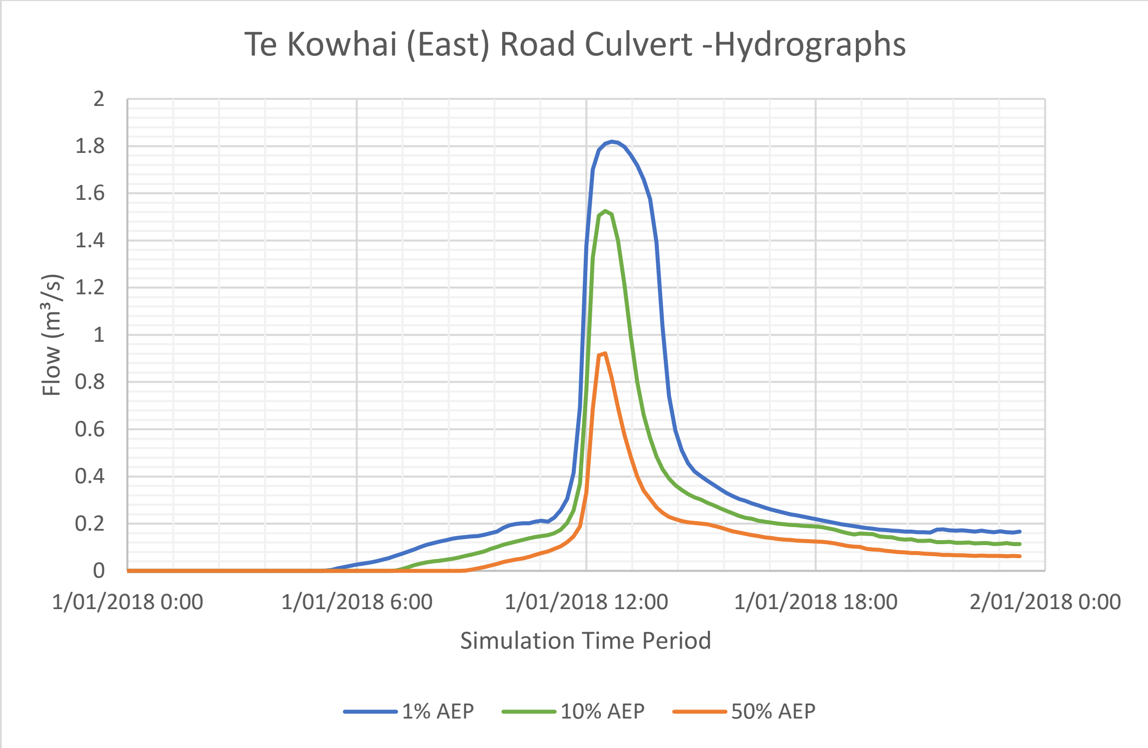

Figure 9: Te Kowhai Road (East) Culvert Flow

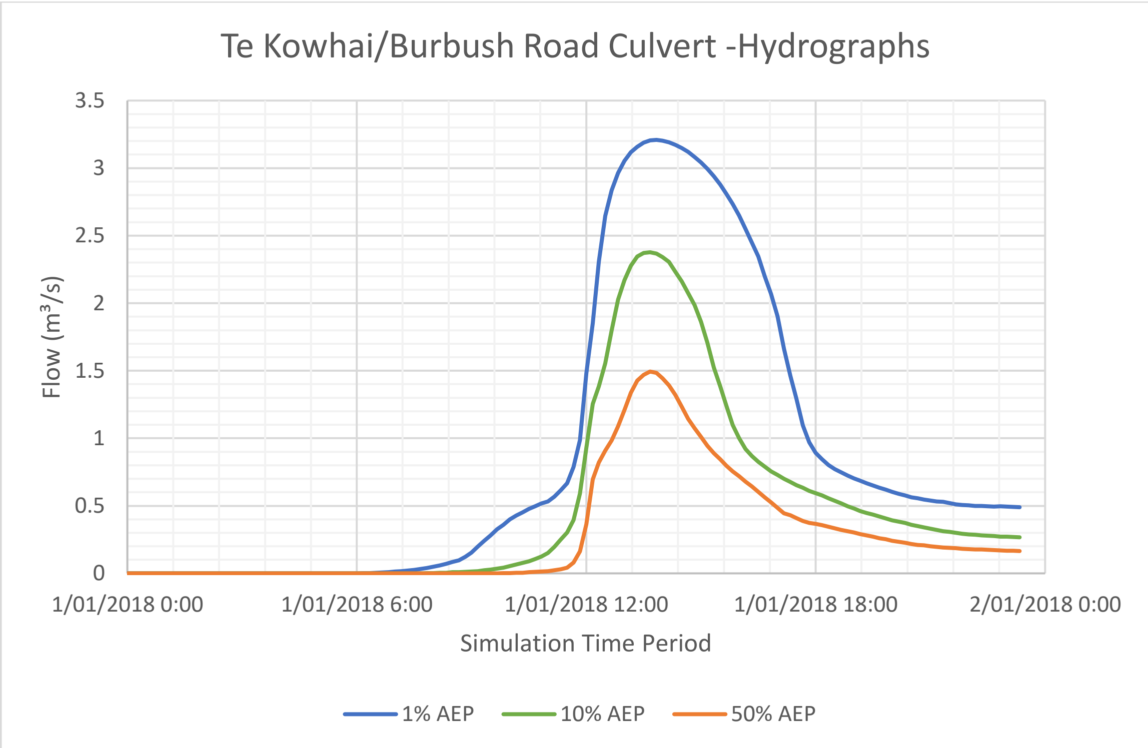

Figure 10: Te Kowhai/Burbush Road Culvert Flow

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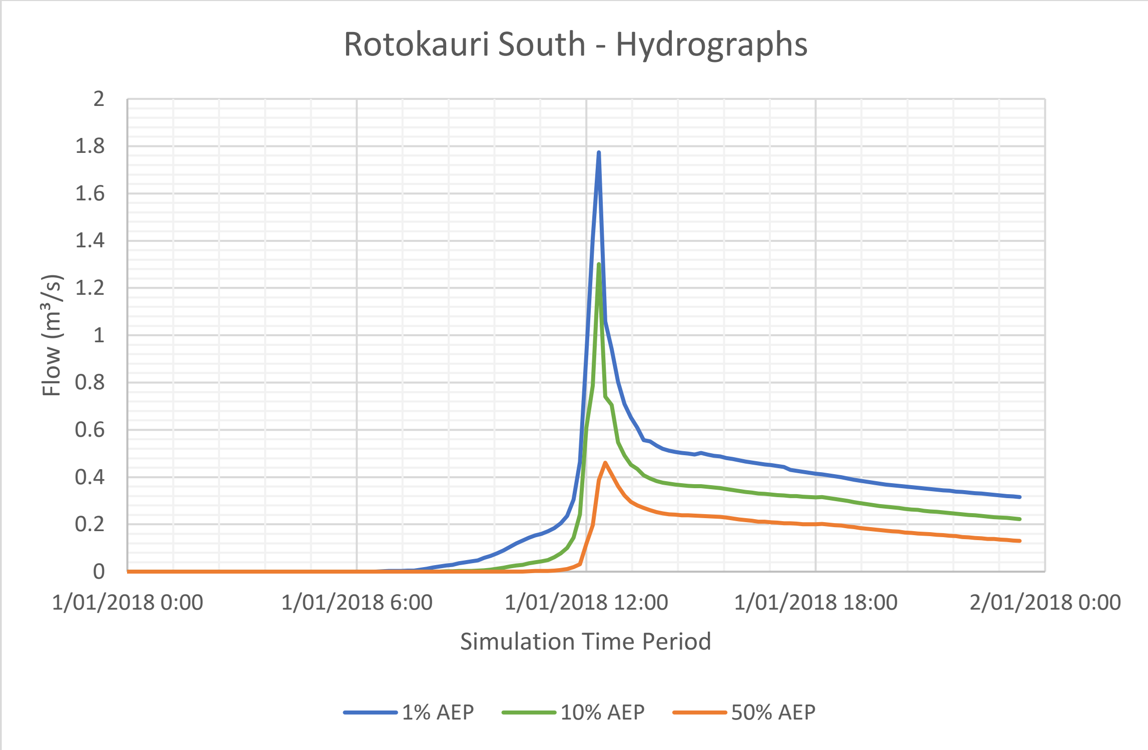

Figure 11: Rotokauri South Boundary Condition Flow

6.4 Exelby Road Discussion

The model predicted that the culvert at Exelby Road would overtop, with excess flow passing over the road and then into the downstream channel area. The flow through the Exelby Road culvert was 2.55 m^3/s, and the overflow across the road was 0.70 m^3/s. The predicted peak flow presented in Table 7 and Figure 6 above is the summation of these two flows.

The peak culvert flow rate of 2.55 m^3/s was comparable with the peak flow from previous AECOM modelling.

6.5 Te Kowhai (West) Discussion

The predicted peak culvert flows for the three design rainfall events were comparable due to the contributing catchment topography. Inspection of the hydrographs show the 1%AEP event has longer duration that the smaller 10% and 50% AEP events.

6.6 Mangaheka Discussion

The predicted peak flows were compared with the results documented by Beca (Adams, 2018) for the Te Kowhai / Burbush Roads culvert, and summarised in the following table.

Table 8: Te Kowhai/Burbush Peak Flow Comparison

Design Rainfall Event (AEP)	Peak Flow (m^3/s) - Beca Model	Peak Flow (m^3/s) - McKenzie & Co. Model	Difference (m^3/s)	Difference (%)
50%	See below[6]	1.49	-	-
10%	2.53	2.38	0.15	6%
1%	3.48	3.21	0.27	8%

Table 9: Te Kowhai/Burbush Water Level at Culvert (Upstream) Comparison

Design Rainfall Event (AEP)	Peak Flow (mRL - Beca Model	Peak Flow (mRL) - McKenzie & Co. Model	Difference (m)	Difference (%)
50%	See below[7]	29.47	-	-
10%	30.04	29.79	0.25	0.8
1%	30.46	30.19	0.27	0.9

Based on the peak flow results and water level predictions, the two models were considered comparable noting the difference in modelling approaches:

- Beca model based on 1-dimensional analysis; whereas
- McKenzie & Co model is based on 2-dimensional analysis.

Inspection of the 1-dimensional maps within the Beca report (Adams, 2018) and the 2-dimensional results showed a strong correlated in regards to flooding extent.

6.7 Rotokauri South Discussion

Visual inspection of the flooding extent results for the AECOM[8] and McKenzie & Co. model predictions showed a reasonable correlation. The flooding extents as modelled within McKenzie & Co HEC-RAS were considered to be representative of the ED scenario.

The AECOM modelling extent also covered part of the Mangaheka catchment within the Rotokauri North ICMP area. Inspection of the result maps showed a strong correlation between the AECOM and McKenzie & Co. predicted model extents.

[6] Note Beca report did not contain results for 50% AEP design rainfall analysis.

[7] *ibid* 6

[8] Rotokauri Stormwater Modelling – Model Build Report, AECOM Final Revision (23/9/16).

7.0 TWO-DIMENSIONAL SENSITIVITY MODELLING

Two sensitivity models were developed to check the boundary conditions assumptions and catchment roughness. The sensitivity analysis was based on 1% AEP design rainfall.

7.1 Boundary Conditions Sensitivity

The normal depth boundary condition for all 2D areas were amended from a friction line of 0.001 (1:1000) to a friction line of 0.005 (1:200). This sensitivity model assessed the performance of the downstream conditions having reduced tail water due to a steeper normal depth boundary condition.

The model predicted that there was minimal difference between peak flows, with the exception of the Rotokauri South result, refer to Figure 11 to Figure 15. Therefore, the model predictions were considered to be representative of the catchment flows regardless of downstream boundary conditions.

The Rotokauri South result indicated that increasing the downstream friction line allowed for flow to exit the modelled area at double the rate of the base case. However, the extent of flooding predicted was comparable with the base case due to the relatively short duration of the peak flow.

7.2 Catchment Roughness

Manning's *n* for the catchments was increased from 0.042 to 0.060 (floodplain, light brush and trees) to assess the impact of the peak flows arriving at the culverts. This change was undertaken as a global amendment to all surfaces.

Except for the Ohute catchment, the models predicted minimal change in peak flow. Peak flow from the Ohute catchment reduced by approximately $0.8m^3/s$, which is to be expected given increased roughness will tend to hold back stormwater runoff. Refer to Figure 11 to Figure 15 below. Therefore, given the variability in peak flows observed for the Ohute catchment when validating the catchment model (see section 8.0 below) the model predictions were considered to be representative of the catchment flows regardless of roughness values across the catchment surface.

7.3 Sensitivity Results

Model predictions for the two sensitivity scenarios were compared with the base case results, and are documented in Table 10 and Figure 11 to Figure 15 below.

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Table 10: 2D Culvert Sensitivity Scenario Results

Location Reference	Catchment	Base Case Peak Flow (m^3/s)	Downstream Boundary Condition Scenario Peak Flow (m^3/s)	Catchment Roughness Scenario Peak Flow (m^3/s)
Exelby Road	Ohote	3.25	2.99	2.40
Te Kowhai Road (West)	Te Otamanui	0.12	0.12	0.12
Te Kowhai Road (East)	Te Otamanui	1.82	1.81	1.66
Te Kowhai/Burbush Roads	Mangaheka	3.21	3.23	3.09
Rotokauri South (Boundary Condition)	Rotokauri South	1.77	3.34	1.39

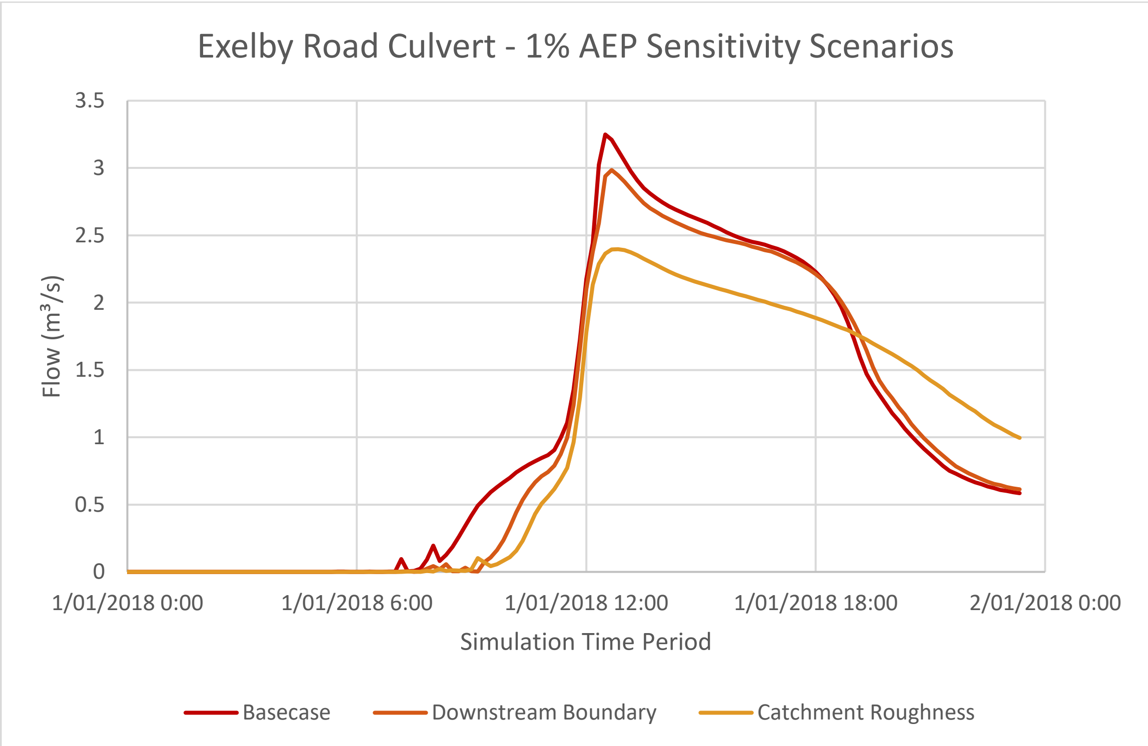

Figure 12: Exelby Road Culvert Flows – Sensitivity Scenarios

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Figure 13: Te Kowhai Road (West) Culvert Flows – Sensitivity Scenarios

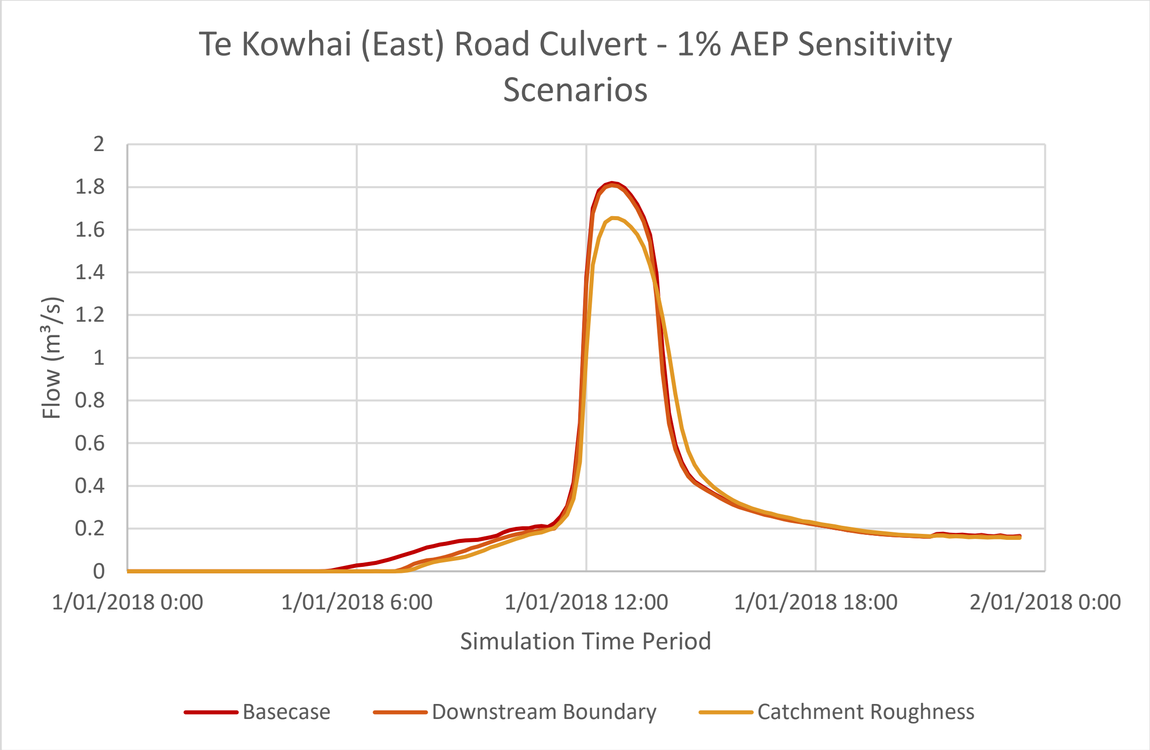

Figure 14: Te Kowhai Road (East) Culvert Flows – Sensitivity Scenarios

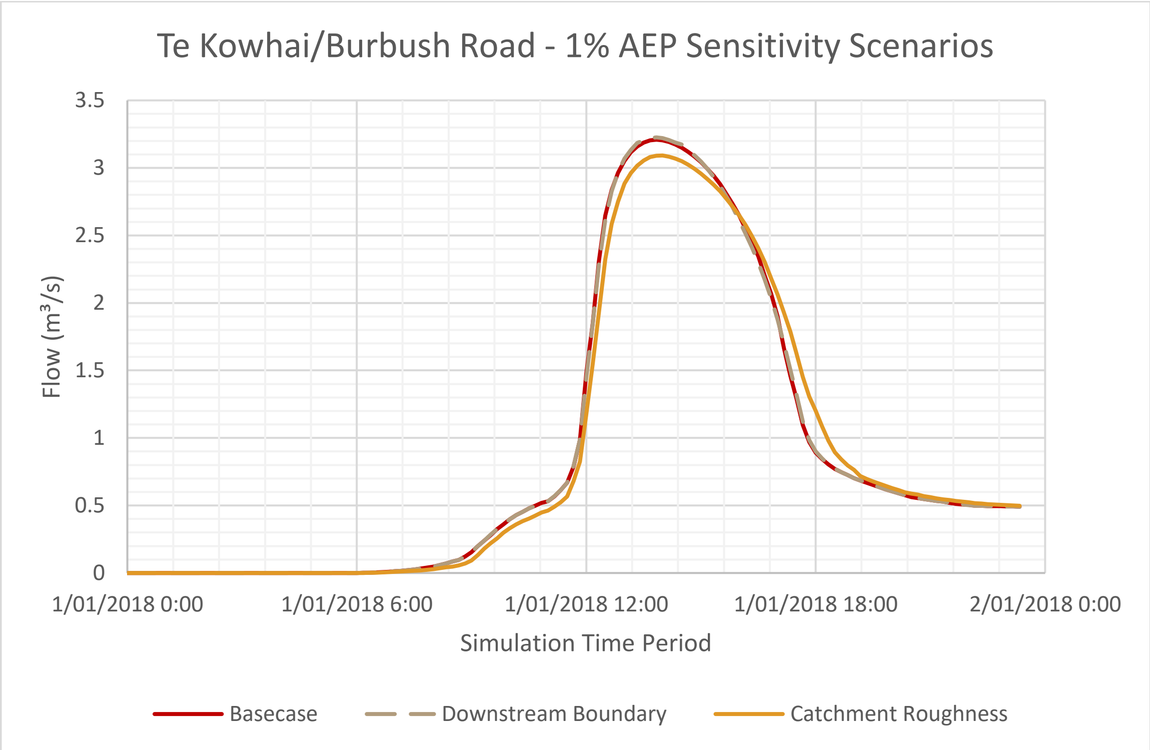

Figure 15: Te Kowhai/Burbush Roads Culvert Flows – Sensitivity Scenarios

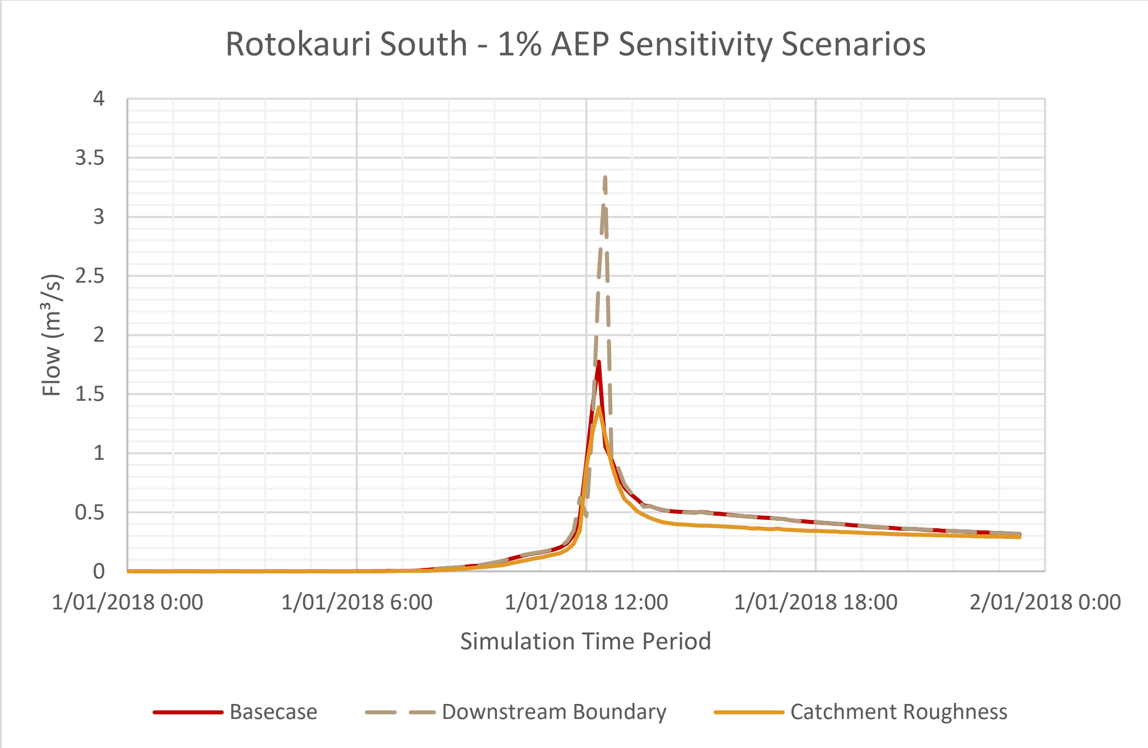

Figure 16: Rotokauri South Boundary Condition Flow – Sensitivity Scenario

8.0 TWO-DIMENSIONAL RESULTS COMPARISON FOR OHOTE

The following modelling scenarios were undertaken to test the validity of HEC-RAS results for the 1% AEP design rainfall event to compare with the previous wider Ohote catchment modelling undertaken by AECOM:

A. Net rainfall and initial abstraction adjusted to match CN = 73.5
Inspection of the AECOM supplied catchments showed that the average Curve Number (CN) for the MPD catchment was 73.5, with resultant initial abstraction being ~5mm. The net rainfall time series was adjusted such that it was 73.5% of previous time series value (as used in original AECOM model). The time series values that summed to 5mm were removed (set to zero) to model the initial abstraction.

B. Net rainfall and initial abstraction adjusted to match CN = 50.0
A sensitivity scenario was modelled based on average Curve Number (CN) of 50, with the resultant initial abstraction being 12.7mm calculated as per WRC SRM TR2018/02. The net rainfall time series was adjusted such that it was 50% of previous time series value (as used in original AECOM model). The time series values that summed to 12.7mm were removed (set to zero) to model the initial abstraction.

C. Net rainfall and initial abstraction adjusted to match CN = 61.0
The rainfall scenario used for base case assessment.

D. As per C. above with Eddy Viscosity Transverse Mixing Coefficient = 3.5. HEC-RAS defaults to a Coefficient of 0. Adopting a value of 3.5 was based on the assumption that values between 2.0-5.0 tend to produce strong transversal mixing over rough surfaces.

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These scenarios were compared with:

- McKenzie & Co. model using AECOM design rainfall without losses or adjustments for Curve Numbers (Pre-Net Rainfall);
- AECOM Maximum Probable Development (MPD) results;
- AECOM Net Rainfall rain on grid results without losses or adjustments for Curve Numbers.

Table 11: Flow Scenario Summary

Scenario	Peak Flow (m^3/s)	Average Flow (m^3/s)
McKenzie & Co. – Pre-Net Rainfall	4.68	1.81
AECOM – MPD	2.28	1.00
AECOM – Net Rainfall, rain on grid	2.70	-
A (CN = 73.5)	3.77	1.32
B (CN = 50)	2.59	0.70
C (CN = 61) (Base case)	3.25	1.01
D (CN = 61 + Eddy Viscosity Coefficient = 3.5)	3.22	1.01

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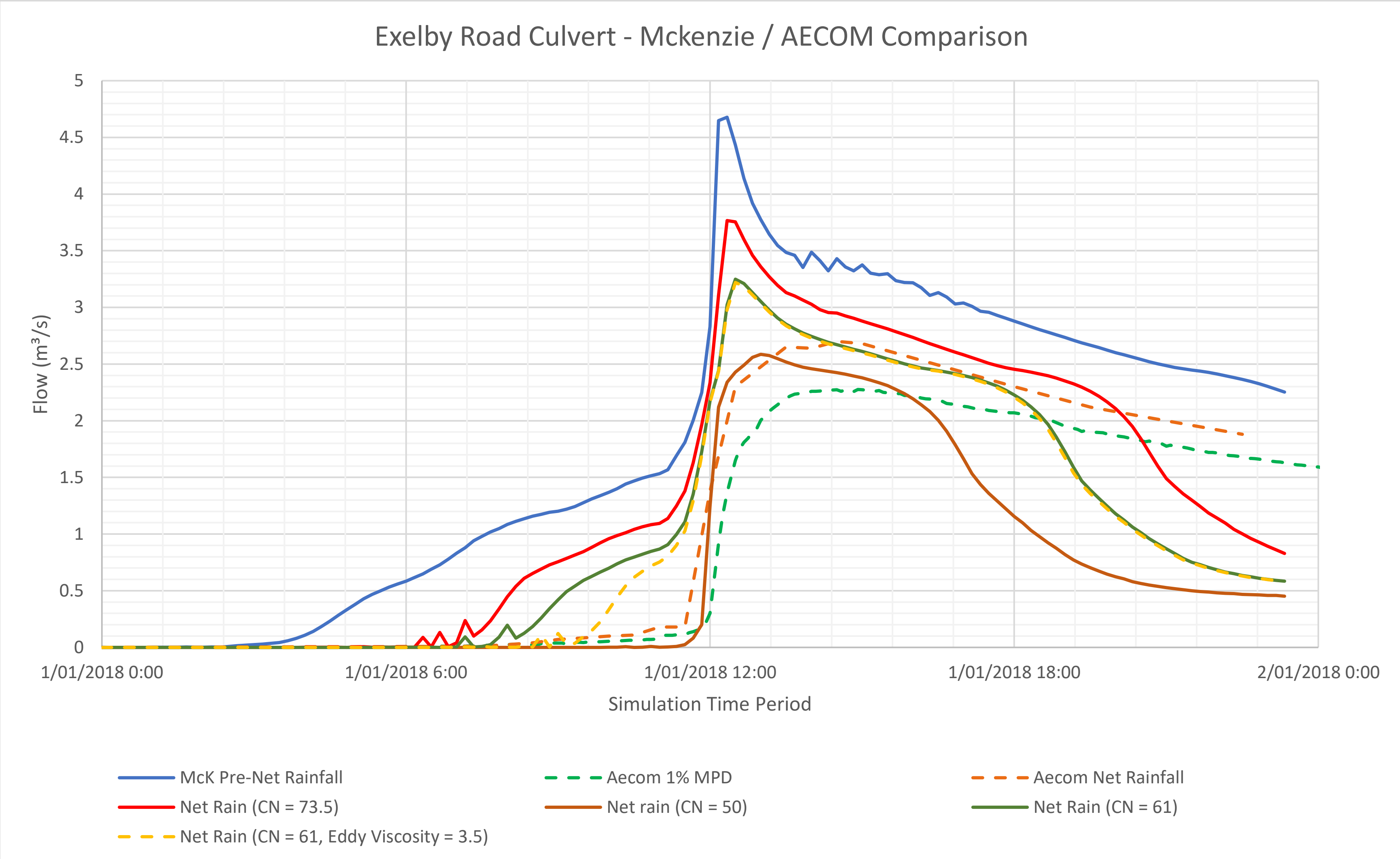

Figure 17: 2D Validation Results for the Ohute Catchment

8.1 Results Commentary

The McKenzie & Co HEC-RAS model with adjusted terrain and net rainfall scenarios were unable to replicate the hydrographs predicted by AECOM's Mike Urban models. Two scenarios had moderate correlations:

- AECOM 1% AEP and Scenario B Net Rainfall (CN =50). The hydrograph shapes show a slight correlation (r^2 = 0.7) with small relative difference in predicted peak flows. However, the Curve Number of 50 and resultant initial abstraction of 12.7mm were not considered representative of the catchment.
- AECOM Net Rainfall and Scenario C Net Rainfall (CN = 61). The hydrograph shapes correlate moderately well (r^2 = 0.8) with small relative difference in predicted peak flows. The Curve Number of 61 and resultant initial abstraction of 8.1mm were considered representative of the existing development catchment, particularly for Winter seasonal flow conditions where groundwater has been observed to be very high.

The results of Scenario D showed that the addition of the Eddy Viscosity Transverse Mixing Coefficient did not affect the predicted results at the Exelby Road culvert.

The McKenzie & Co. Pre-Net Rainfall model, Scenarios A and B were not considered representative of the 1% AEP flows. Scenario C was considered representative of a "wet" existing development catchment as has been observed during Winter and Spring conditions.

8.2 Summary and Recommendation

With reference to AECOM[9] correspondence and previous meetings, McKenzie & Co. Consultants agree that differences in predicted peak flows are to be expected when modelling using different software due to implementation differences for the respective numerical engines and adoption and implementation of different loss models. However, visual comparison of the flood extents predicted for each approach shows reasonable correlation between predictions. The key differences between the models are the peak flows, and the duration over which runoff is held within the terrain.

McKenzie & Co. modelling has focused on a lower loss model than that adopted by AECOM to reflect more conservativism in the runoff volume generated. The McKenzie & Co. model has a higher level of terrain information (and modification) to replicate field observations and culvert survey data.

Based on comparison of the sensitivity scenarios, related soil type assumptions and initial abstraction, Scenario C was considered to be representative of the catchment response for 1% AEP design rainfall event.

[9] Chris Hardy (Aecom) to Jackie Colliar (HCC) and Nathanael Savage (HCC), 'Rotokauri north hydrology', 19 November 2018

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9.0 CONCLUSION AND RECOMMENDATION

A one dimensional hydrological/hydraulic model was built using both TP108 and HEC-HMS for the Ohote catchment to assess the Existing Development flows for the 1% AEP rainfall event. The application of TP108 was not considered to accurately represent the flat topography and storage capacity of the catchment, which is a well-known and documented limitation of TP108 (Auckland Regional Council, 1999). Given there is very limited grade/fall within the Ohute catchment, McKenzie & Co. consider TP108 modelling to be unsuited for determination of accurate peak flow estimation of the Ohote catchment.

A two-dimensional hydraulic model was built using HEC-RAS for the Ohote and Te Otamanui catchments for the Rotokauri North physical catchment. The model was built to allow for assessment of the pre-development 1% AEP flows from the catchments.

Four culverts, one at Exelby Road, and three along Te Kowhai Road, were included within the model as they approximate the discharge locations from the ICMP/PPC to the downstream receiving environment. A boundary condition for the ICMP/PPC area within the Rotokauri South catchment was used to model the interface with the larger downstream catchment. The predicted peak flows at the culverts and boundary condition locations for the 1% AEP were:

- Exelby Road = 3.25 m^3/s (refer further below)
- Te Kowhai Road (West) = 0.12 m^3/s
- Te Kowhai Road (East) = 1.82 m^3/s
- Te Kowhai/Burbush Roads = 3.21 m^3/s
- Rotokauri South = 1.77 m^3/s

At Exelby Road the model predicted ponding on the upstream side of the culvert that would ultimately overflow across Exelby Road. The flow through the Exelby Road culvert was estimated to be 2.55 m^3/s, resulting in an overflow across the road was 0.70 m^3/s. The predicted peak flow presented above was the summation of these two flows.

While the peak flow rates do not provide a complete correlation with the AECOM results, the 2D modelling results were considered comparable when with the 1D modelling predictions.

The predicted peak flows from the culverts for the 1% AEP were also assessed for two sensitivity scenarios, changes in downstream boundary conditions (grade change), and catchment roughness. Both sensitivity scenarios suggest reasonable peak flow consistency at the culverts for the model changes assessed.

Due to the differences in modelling software, and input datasets, it is recommended that peak flow out of the Ohute catchment of 0.7m^3/s be adopted in accordance with the Rotokauri ICMP (Hart, 2017). However, given the peak flow variability estimated as part of this preliminary stormwater modelling investigation we recommend that peak flow discharge not be limited to this and that the Rotokauri North ICMP should not preclude the opportunity to refine this figure based on additional topography information and further stormwater runoff model agreement. Ultimately, this work can be undertaken as part of the stormwater discharge consenting process with WRC.

The Exelby Road culvert forms the primary discharge point for the Ohote catchment within the Rotokauri North Sub-Catchment ICMP. As outlined the Rotokauri North Stormwater an Music

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Modelling Report (Rudsits, 2019), significant detention volume will be required to buffer peak flows to 80% ED. There are a number of options for discharge of stormwater at the Exelby Road culvert, which could include the following:

- Retain culvert as is;
- Upgrade culvert to allow for 80% of 1% AEP_{cc} ED flow to pass unattenuated;
- Upgrade culvert to allow for >100% of 1% AEP_{cc} ED flow.
- Potential to lower invert of Exelby Culvert to minimise earthwork volumes.

Preliminary analysis indicates that retention of the existing culvert will require in the order of 85,000 m^3 detention (900mm Culvert, Q = 0.7m^3/s). Increasing the culvert to allow 80% of the 1% AEP_{cc} ED flow to pass unattenuated (1,200mm Culvert, Q = 2.58m^3/s), reduces detention requirements to approximately 30,000 m^3. Increasing the culvert further to allow >100% of 1% AEP_{cc} ED flow to pass unattenuated (1,500mm Culvert, Q = 5.00m^3/s), reduces detention requirements to approximately 23,000 m^3.

As such, we reiterate the previous recommendation that peak flow discharge should not limited through the Rotokauri North ICMP so as to not preclude the opportunity to refine the ultimate boundary conditions at the Exelby Road culvert (maximum discharge rate) as additional topographical information is obtained, further stormwater runoff model agreement is reached, and as detailed design of stormwater detention devices for the Ohute catchment progresses.

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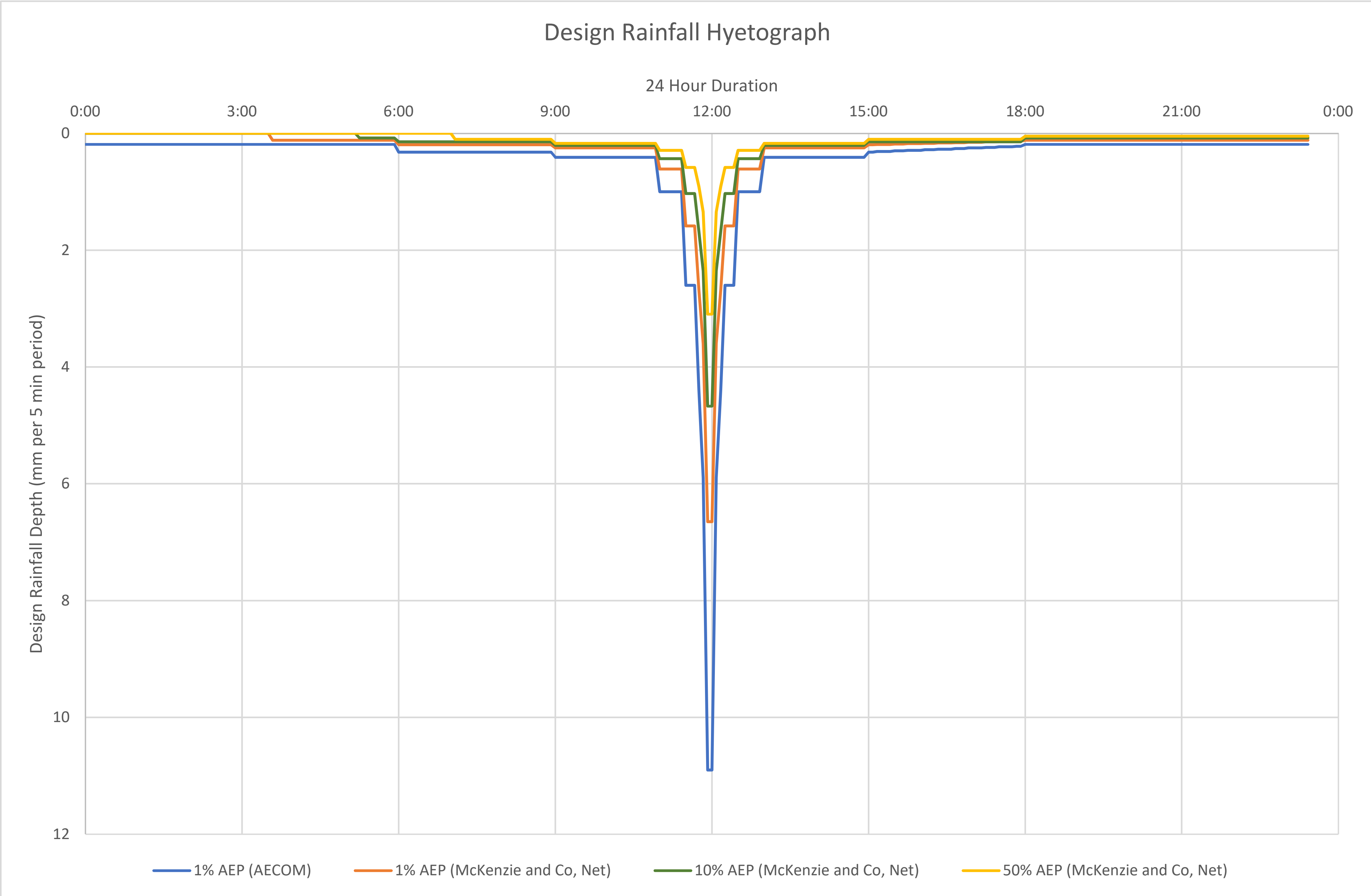
APPENDIX A – HEC-HMS INFORMATION

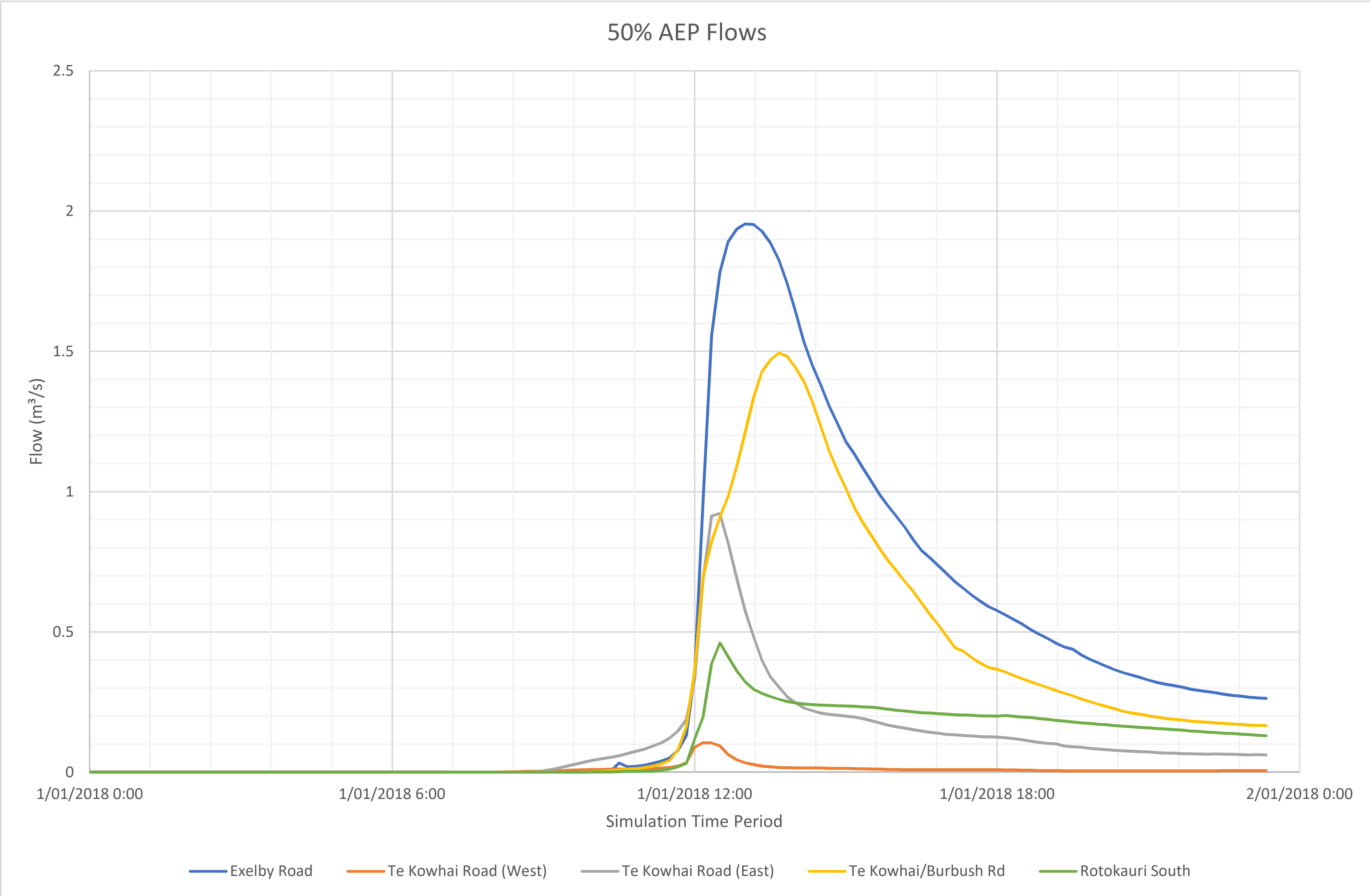
1D HEC-HMS SW model inputs: Ohote catchment predevelopment

Catchment ID	Area (km2)	Area weighted CN	soil storage S (mm)	Ia (mm)	catchment slope Sc (m/m)	catchment length L (km)	channelisation factor C	time of concentration tc (mins)	Catchment lag time (mins)	Peak Rate Factor (PRF)
Ohote	1.3639	73.5	91.60	5.00	0.0017	2.466	1.0	139.26	92.75	484

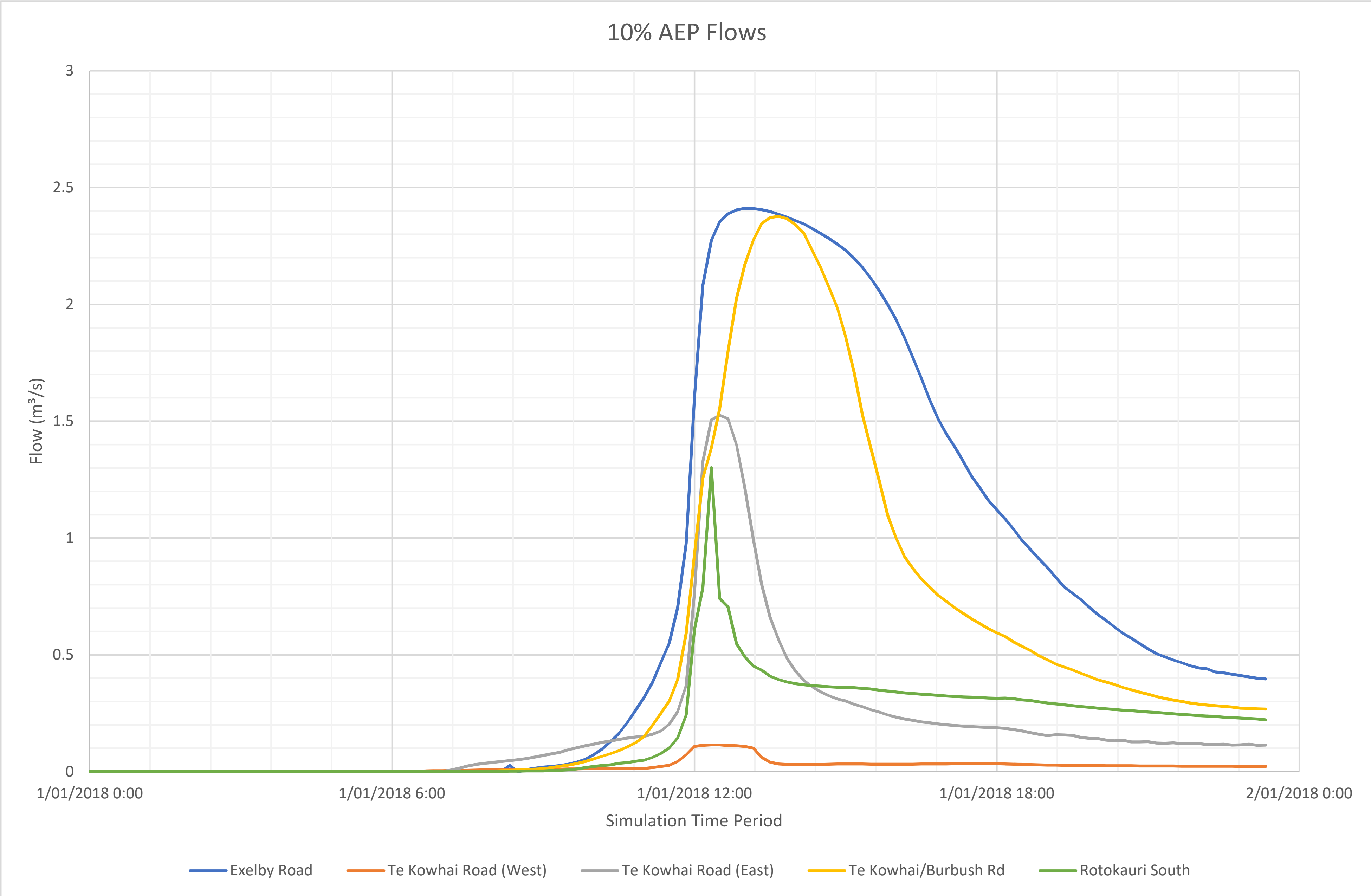
APPENDIX B – DESIGN RAINFALL HYETOGRAPHS


Design Rainfall Hyetograph
24 Hour Duration
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
0
2
4
6
8
10
12
Design Rainfall Depth (mm per 5 min period)
1% AEP (AECOM)
1% AEP (McKenzie and Co, Net)
10% AEP (McKenzie and Co, Net)
50% AEP (McKenzie and Co, Net)

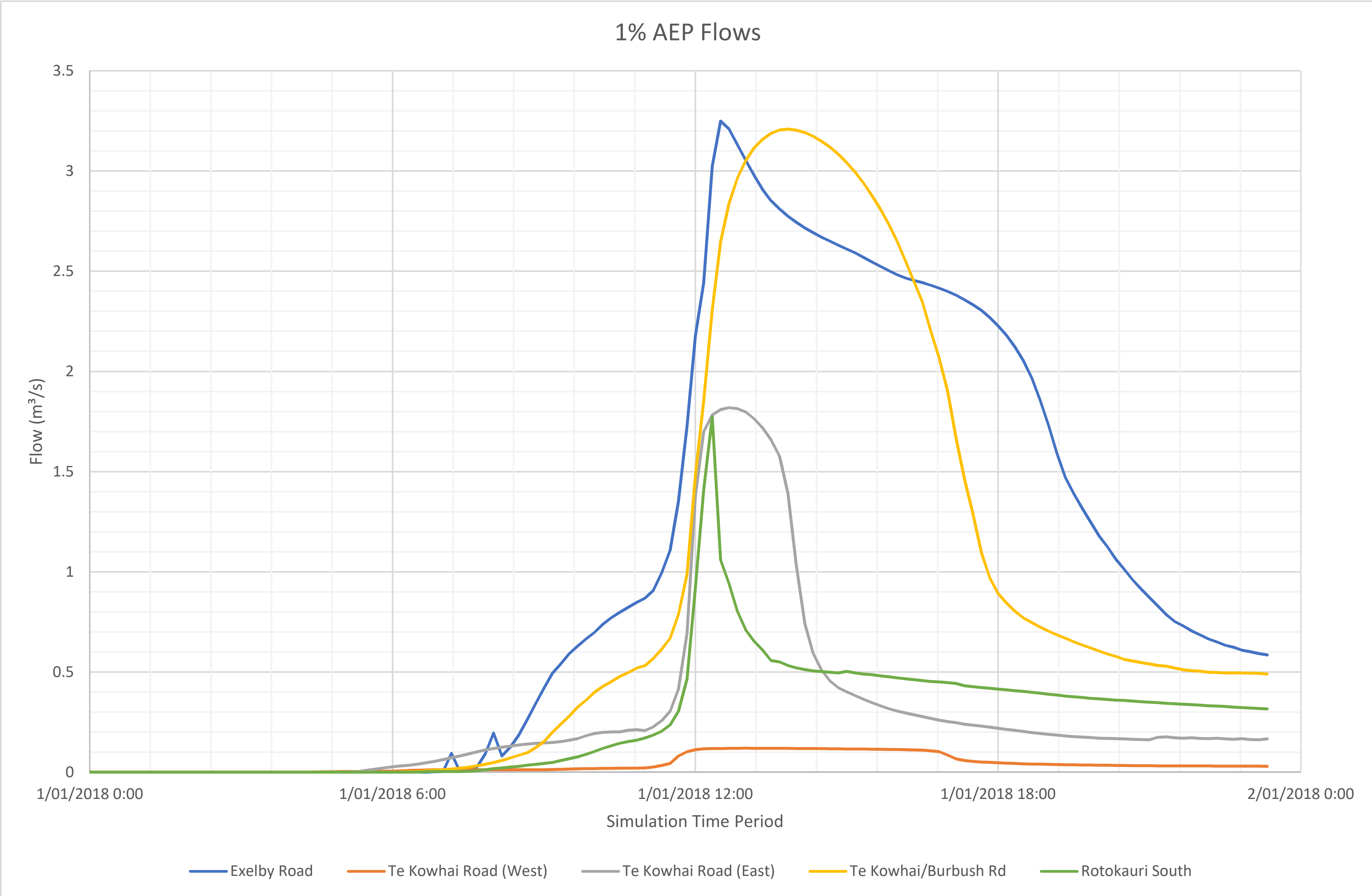
APPENDIX C – 50% AEP HYDROGRAPHS


50% AEP Flows
Flow (m³/s)
2.5
2
1.5
1
0.5
0
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
Exelby Road
Te Kowhai Road (West)
Te Kowhai Road (East)
Te Kowhai/Burbush Rd
Rotokauri South

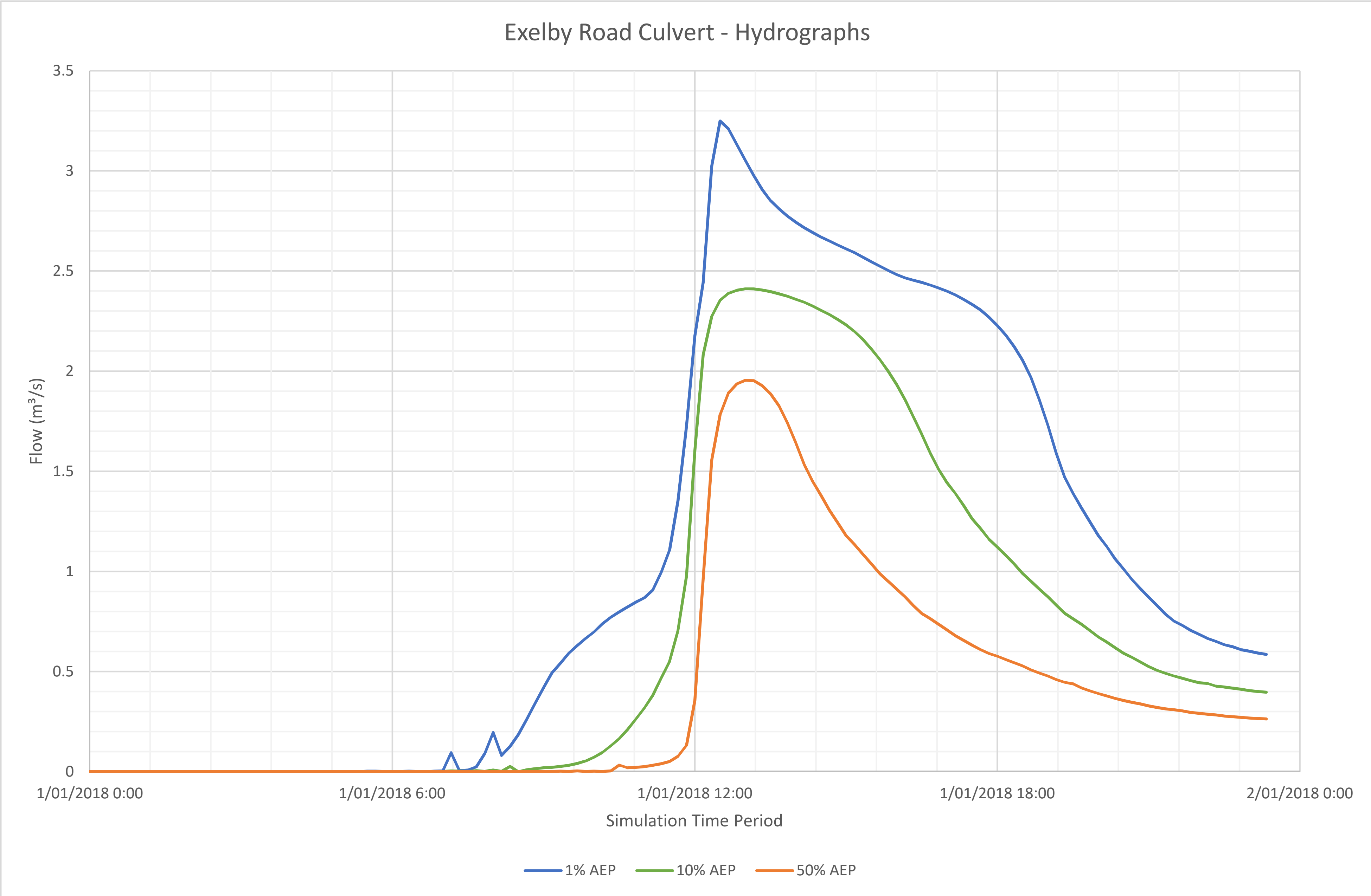
APPENDIX D – 10% AEP HYDROGRAPHS


10% AEP Flows
Flow (m³/s)
3
2.5
2
1.5
1
0.5
0
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
Exelby Road
Te Kowhai Road (West)
Te Kowhai Road (East)
Te Kowhai/Burbush Rd
Rotokauri South

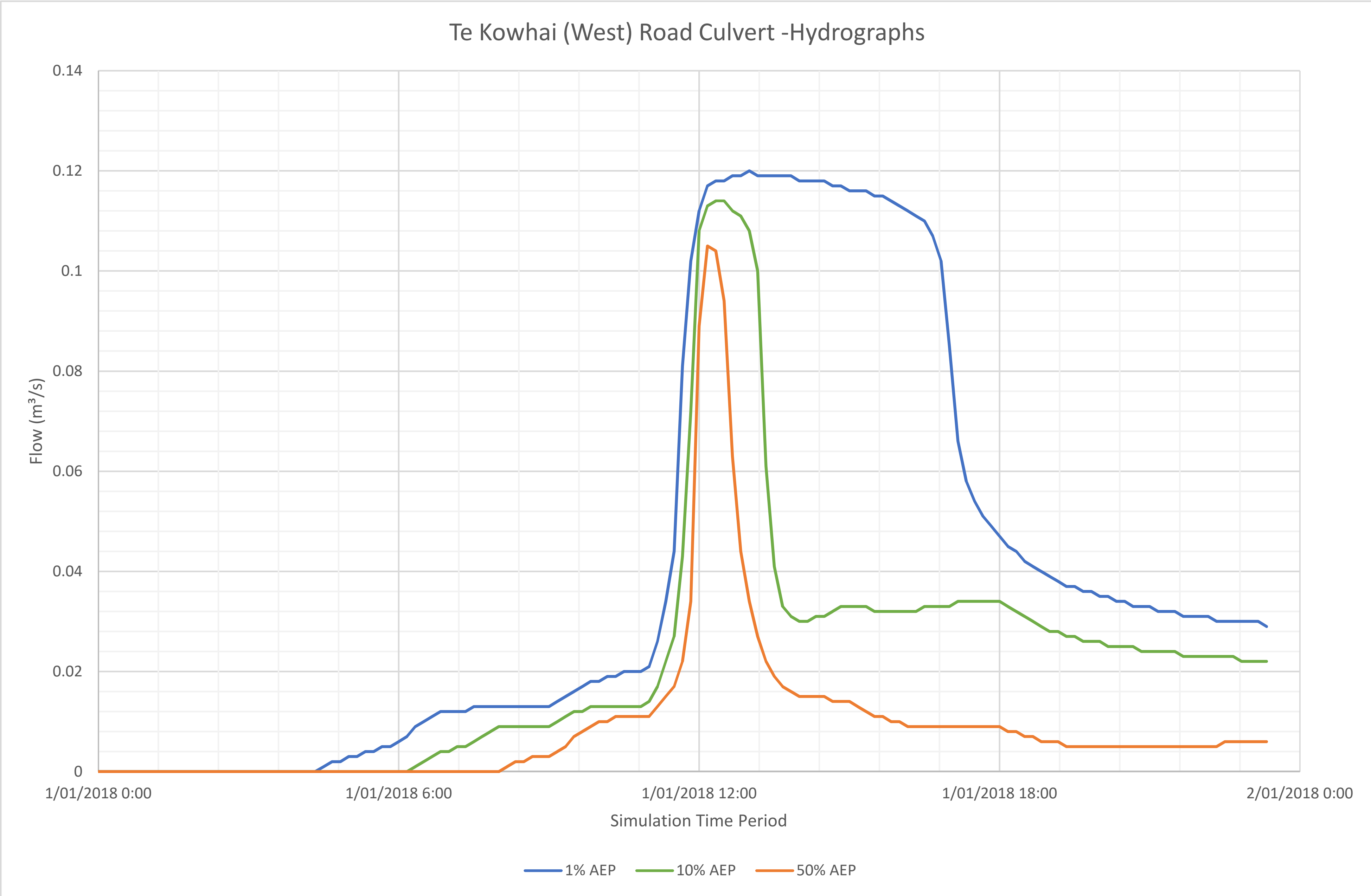
APPENDIX E – 1% AEP HYDROGRAPHS


1% AEP Flows
Flow (m³/s)
3.5
3
2.5
2
1.5
1
0.5
0
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
Exelby Road
Te Kowhai Road (West)
Te Kowhai Road (East)
Te Kowhai/Burbush Rd
Rotokauri South

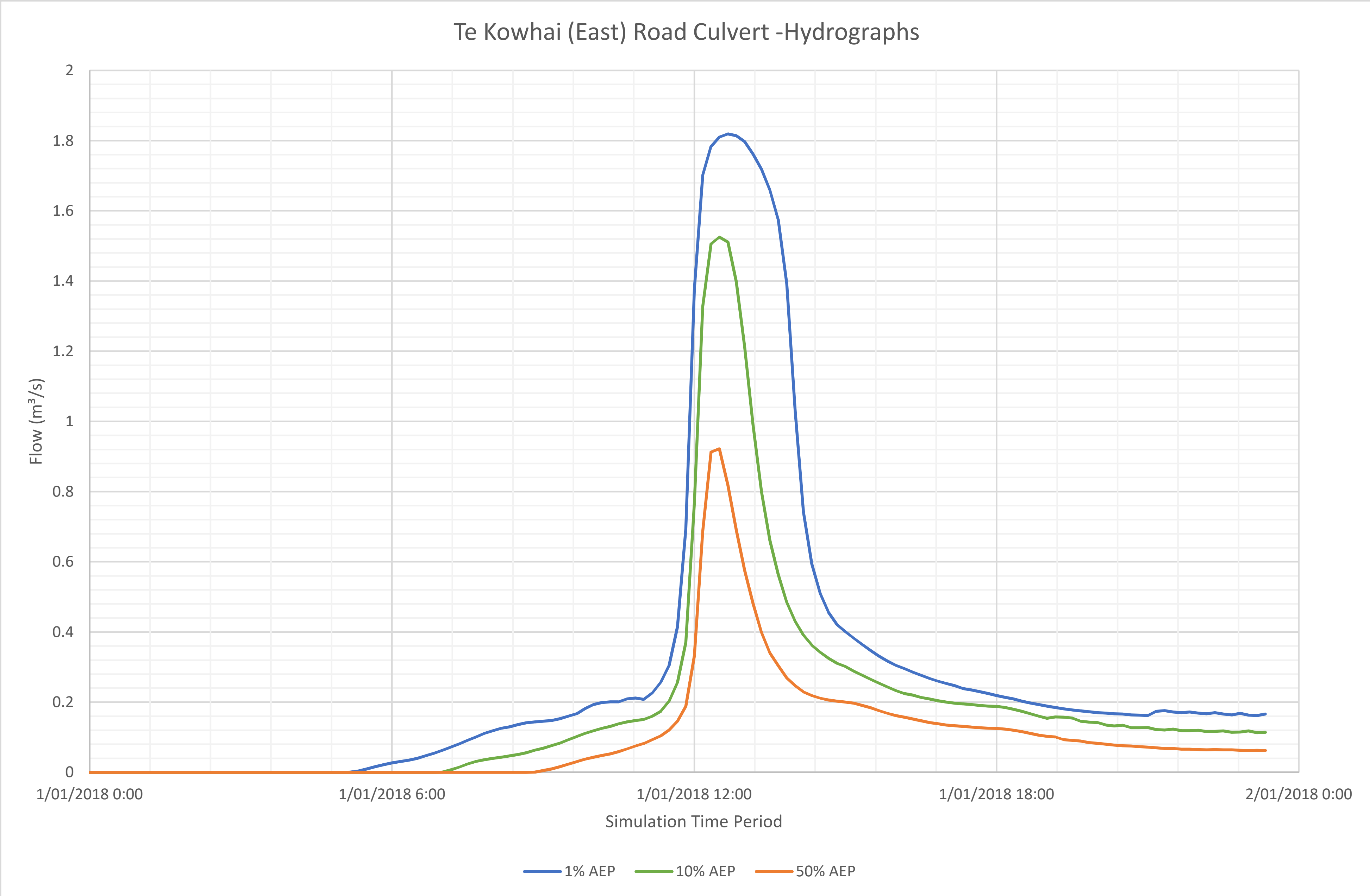
APPENDIX F – EXELBY ROAD HYDROGRAPHS


Exelby Road Culvert - Hydrographs
3.5
3
2.5
2
1.5
1
0.5
0
Flow (m³/s)
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
1% AEP
10% AEP
50% AEP

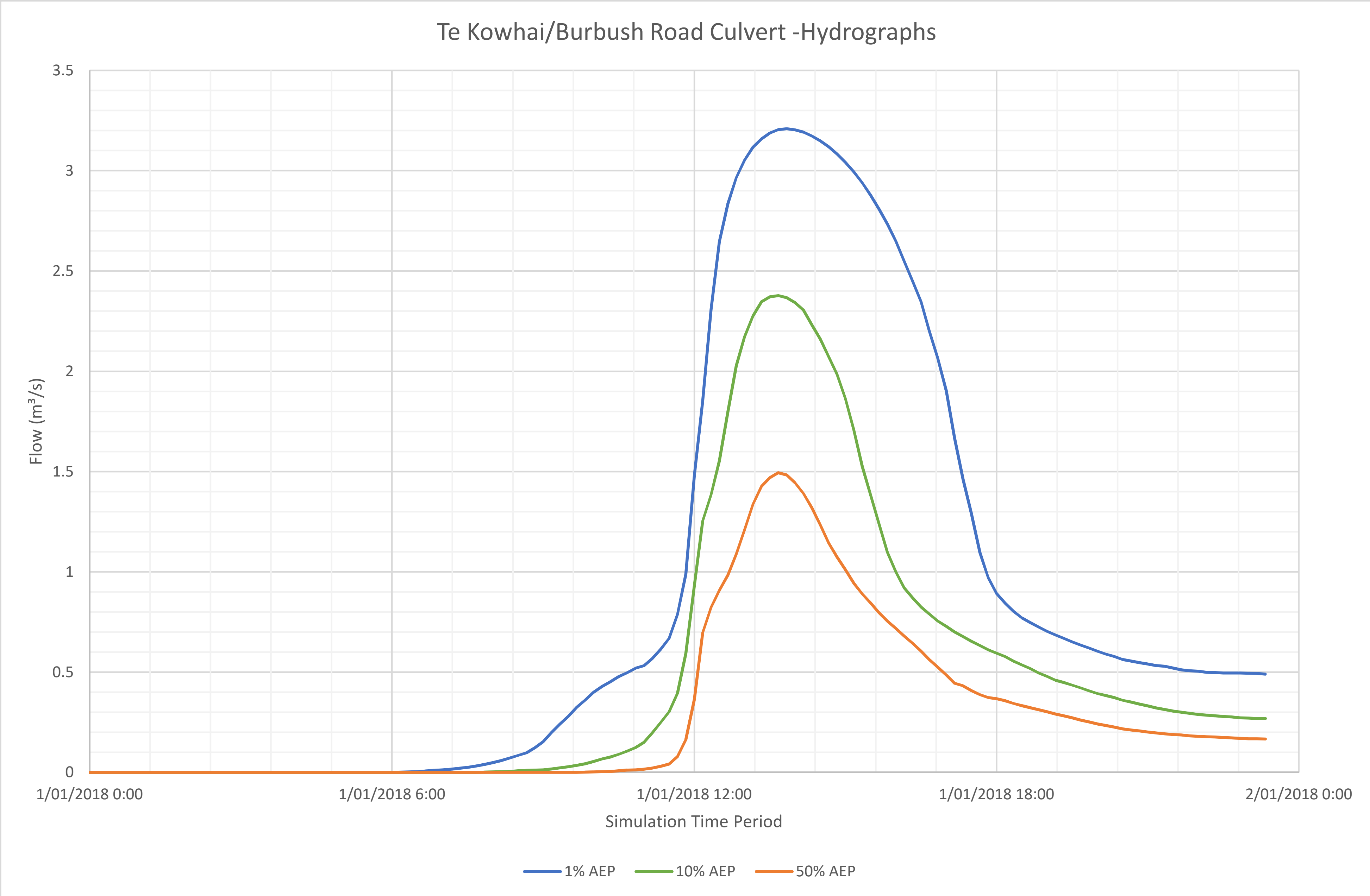
APPENDIX G – TE KOWHAI ROAD (WEST) HYDROGRAPHS


Te Kowhai (West) Road Culvert -Hydrographs
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Flow (m³/s)
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
1% AEP
10% AEP
50% AEP

APPENDIX H – TE KOWHAI ROAD (EAST) HYDROGRAPHS

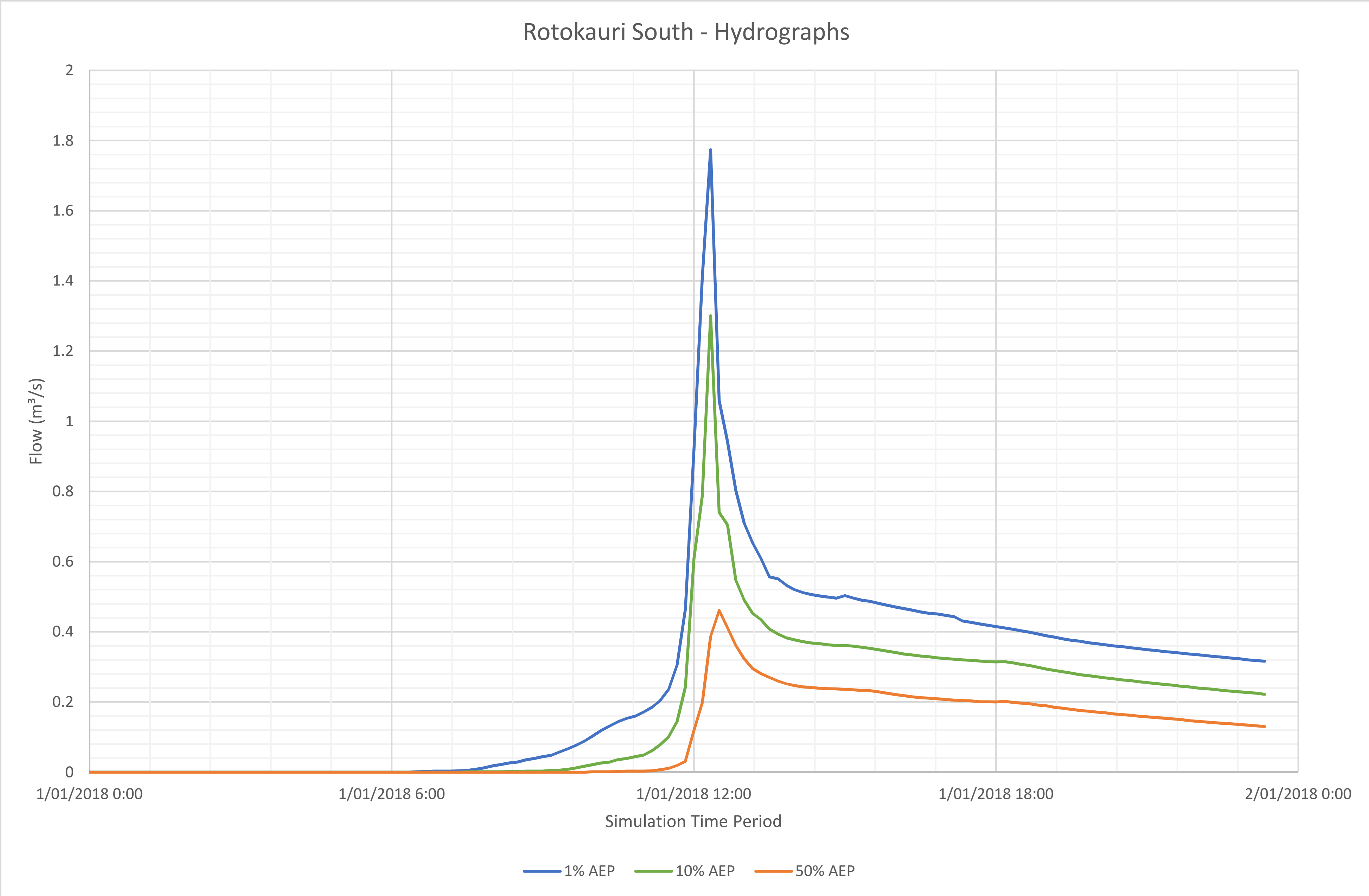

Te Kowhai (East) Road Culvert -Hydrographs
Flow (m³/s)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
1% AEP
10% AEP
50% AEP

APPENDIX I – TE KOWHAI/BURBUSH ROAD HYDROGRAPHS

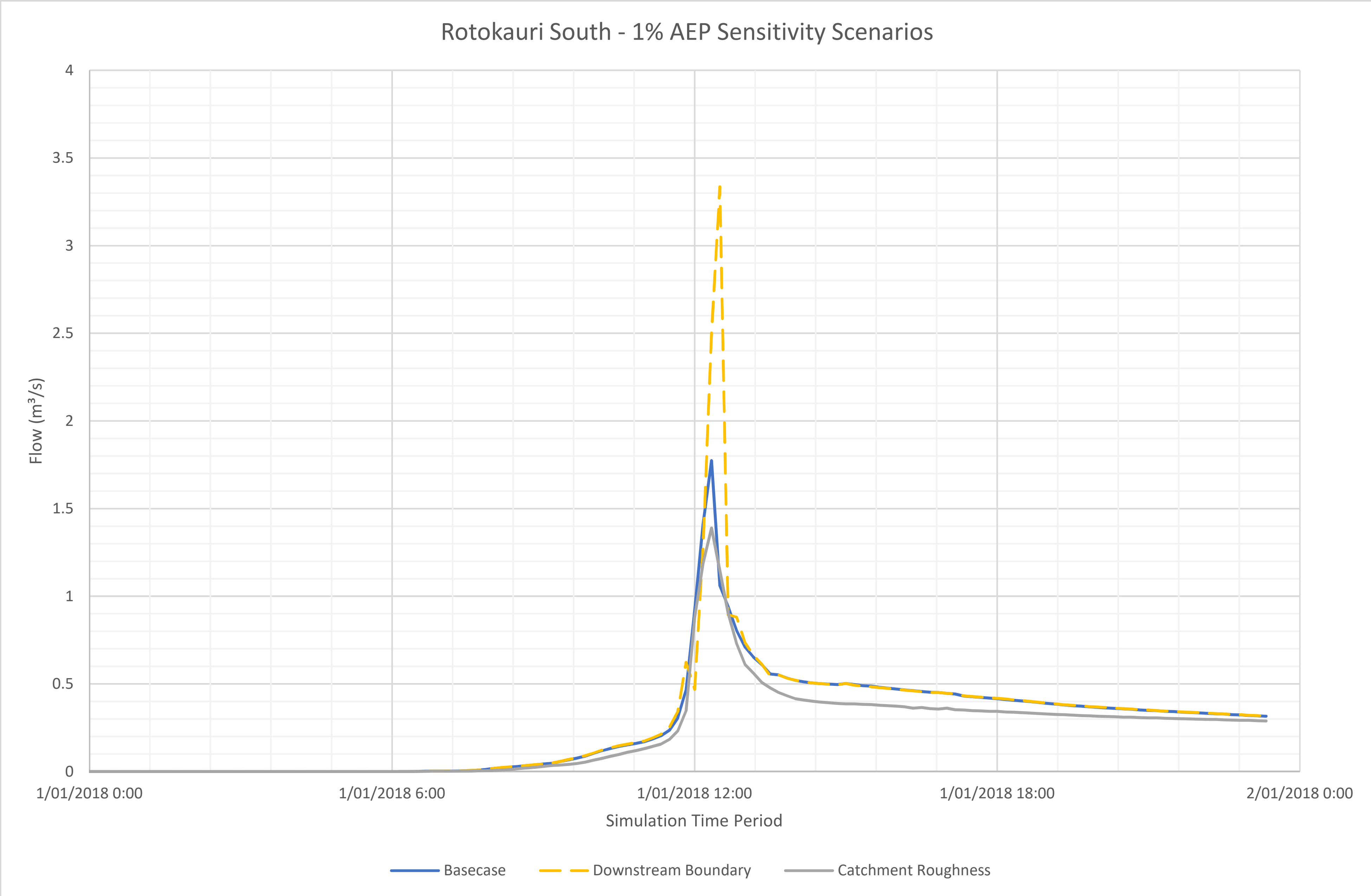


Te Kowhai/Burbush Road Culvert -Hydrographs
3.5
3
2.5
2
1.5
1
0.5
0
Flow (m³/s)
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
1% AEP
10% AEP
50% AEP

APPENDIX J – ROTOKAURI SOUTH HYDROGRAPHS



Rotokauri South - Hydrographs
Flow (m³/s)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
1% AEP
10% AEP
50% AEP


Rotokauri South - 1% AEP Sensitivity Scenarios
Flow (m³/s)
4
3.5
3
2.5
2
1.5
1
0.5
0
1/01/2018 0:00
1/01/2018 6:00
1/01/2018 12:00
1/01/2018 18:00
2/01/2018 0:00
Simulation Time Period
Basecase
Downstream Boundary
Catchment Roughness

APPENDIX K – TP108 CALCULATION

McKENZIE&CO CONSULTANTS LTD

TP108 calculation
Catchment: Ohote
Project: 1693
Location: Rotokauri North

TP 108 calculation—100 year ARI

Catchment area (A) (km²):	**1.3639**	From MikeModelCatchmentData.gdb.zip supplied by AECOM on 18/10/18
Impervious Area	0.0000	
Percentage of catchment (impervious)	0.0%	
Percentage of catchment (pervious)	100%	
Effective curve number:	**73.5**	supplied by AECOM email dated 18/10/18
Effective Initial abstraction (Ia, mm):	**5.00**	supplied by AECOM email dated 18/10/18
Effective storage (S, mm):	**91.6**	From TP108: S=((1000/CN)-10)×25.4
ARI (yr):	100	
24 hour rainfall depth (P_{24}) (mm):	139.680	From MikeModelCatchmentData.gdb.zip supplied by AECOM on 18/10/18

Time of concentration

Channelisation factor, C	1.00
Catchment length (km)	2.466

Catchment slope (Equal area method)

Point location	Elevation (m)	h (m)	Distance (x) m	Δx (m)	h̄ (m)	Δ Area (A) = h̄ × Δx (m²)
Pt A	28.314	0.000	0.0	0	0.000	—
	28.28	-0.034	1	1	-0.017	-0.017
	28.26	-0.054	2	1	-0.044	-0.044
	28.244	-0.070	3	1	-0.062	-0.062
	28.228	-0.086	4	1	-0.078	-0.078
	28.218	-0.096	5	1	-0.091	-0.091
	28.233	-0.081	6	1	-0.088	-0.088
	28.283	-0.031	7	1	-0.056	-0.056
	28.344	0.030	8	1	0.000	0.000
	28.397	0.083	9	1	0.056	0.056
	28.441	0.127	10	1	0.105	0.105
	28.445	0.131	11	1	0.129	0.129
	28.364	0.050	12	1	0.091	0.091
	28.216	-0.098	13	1	-0.024	-0.024
	28.039	-0.275	14	1	-0.186	-0.186
	27.852	-0.462	15	1	-0.368	-0.368
	27.665	-0.649	16	1	-0.556	-0.556
	27.486	-0.828	17	1	-0.739	-0.739
	27.362	-0.952	18	1	-0.890	-0.890
	27.351	-0.963	19	1	-0.958	-0.958
	27.402	-0.912	20	1	-0.938	-0.938
	27.455	-0.859	21	1	-0.886	-0.886
	27.475	-0.839	22	1	-0.849	-0.849
intermediate rows not shown for brevity						
	52.431	24.117	2454	1	24.095	24.095
	52.474	24.160	2455	1	24.139	24.139
	52.516	24.202	2456	1	24.181	24.181
	52.575	24.261	2457	1	24.232	24.232
	52.681	24.367	2458	1	24.314	24.314
	52.765	24.451	2459	1	24.409	24.409
	52.809	24.495	2460	1	24.473	24.473
	52.815	24.501	2461	1	24.498	24.498
	52.811	24.497	2462	1	24.499	24.499
	52.796	24.482	2463	1	24.490	24.490
	52.779	24.465	2464	1	24.474	24.474
	52.765	24.451	2465	1	24.458	24.458
	52.752	24.438	2466	1	24.445	24.445
Sum				2466.0		5158.859

Catchment slope (m/m)	**0.00170**	Equal-area slope of the above time of concentration line. Calculated by:	$S_C = \frac{2A}{L^2}$
Time of concentration (hrs)	**2.321**	From Section 4.2 of TP108, time of concentration calculated as:	$t_C = 0.14CL^{0.66}\left(\frac{CN}{200-CN}\right)^{-0.55} S_c^{-0.30}$

TP108 coefficient—C*:	0.41	From TP108: c*=(P_{24}-2×Ia)/(P_{24}-2×Ia+2×S)
Specific flow rate—q*:	0.033	From Figure 5.1 of TP108 (BLUE ARROW).
Peak flow rate (q_p) (m³/s):	**6.29**	From TP108: q_p=q*×A×P24
Runoff depth (Q_{24}) (mm):	80	From TP108: Q_{24}=((P_{24}-Ia)²)/((P_{24}-Ia)+S)
Runoff volume (V_{24}) (m³):	109341	From TP108: V_{24}=1000×Q_{24}×A