Flood Studies

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M34000_046 SPRING CREEK FLOOD STUDY					
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REV	DESCRIPTION	AUTHOR	REVIEWER	APPROVED BY	DATE
Rev 0	DRAFT	Gordon Huang	Amir Joorabchi	Mark Page	6 April 2017
Rev 1	Client Issue	Gordon Huang	Amir Joorabchi	Mark Page	26 May 2017
Rev 2	Client Issue	Gordon Huang	Amir Joorabchi	Mark Page	27 June 2017
Signatures		[signature]	[signature]	[signature]	

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1. INTRODUCTION

1.1 Background and Objectives

Engeny Water Management (Engeny) was engaged by Toowoomba Regional Council (Council) to undertake a flood study update for the Spring Creek catchment. The purpose of the study was to develop updated hydrologic and hydraulic models and associated flood mapping based on the 2016 revision of Australian Rainfall and Runoff (ARR 2016) (EA, 2016) and incorporate the latest Council datasets. As such, this study builds upon the previous hydrologic and hydraulic modelling undertaken for the Spring Creek Urban Stormwater Management Plan (Spring Creek USMP) (Engeny, 2015).

1.2 Study Area

Spring Creek originates in the suburb of Glenvale, and flows into Westbrook Creek. The location of the study area is illustrated in Figure 1.1.

The Spring Creek catchment area is approximately 66 square kilometres which is located to the west of Toowoomba. Spring Creek originates to the west of the Gore Highway near Darling Heights and flows for approximately 16.5 km until it joins Westbrook Creek. Spring Creek and Westbrook Creek drain to the Condamine River via Oaky Creek.

Glenvale Creek is a tributary of Spring Creek and has a reach of approximately 7 km before joining Spring Creek. The confluence with Spring Creek is approximately 3.5 km downstream of the Holcim quarry entrance near Junction of Drayton Wellcamp and Boundary St).

Spring Creek has a major tributary to the south which rises to the west of the Gore Highway near Harristown and flows for approximately 4.6 km until it joins the main channel approximately 0.3 km downstream of the Boral quarry entrance near Junction of Toowoomba-Cecil Plains Rd and Hanrahanas Rd.

1.3 Study Scope

The following scope of works was undertaken as part of the Spring Creek flood model and mapping update:

- Collation and review of Council GIS datasets required for input into the flood modelling process. This would include:
  - Topographic data (i.e. LiDAR)
  - Land use planning data
  - Hydraulic structure data (bridges, culverts).
- Identification of data gaps within the supplied GIS datasets.

- Review of the catchment characteristics (i.e. land use and hydraulic structures) adopted in the XPRAFTS model, and confirm suitability of use for the updated study.
- Combine input layers from existing TUFLOW models developed for the Spring Creek USMP and augment with additional data identified during the data collation and review process.
- Review and update the XPRAFTS hydrology model from the Spring Creek USMP based on the new rainfall depths, losses and ensemble temporal patterns from AR&R (2016).
- Undertake the hydrologic analysis for Spring Creek for the 10% AEP, 1% AEP and PMF flood events for ultimate catchment conditions. Incorporation of existing flood mitigation measures (i.e. detention basins) into the hydrologic/hydraulic models where suitable information can be obtained.
- Review and update of Engeny's previously developed Spring Creek TUFLOW model (2015). Simulation of the 10% AEP, 1% AEP and PMF flood events based on hydrologic inputs (ultimate land use) from the XPRAFTS model.
- Sensitivity analysis of one scenario for the 1% AEP (understood to be the Defined Flood Event).
- Climate change analysis for year 2090 which will provide an assessment of rainfall intensity and the resultant flow increase and sensitivity analysis for an increase in culvert blockage.
- Review and update of the TUFLOW rain on grid (RoG) model representing the overland flow path analysis for ultimate catchment development 1% AEP.

Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
P: 07 3221 7174
F: 07 3236 2399
E: admin@engeny.com.au

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Spring Creek Flood Study Update

Figure 1.1

Study Area

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2. PROJECT DATA

2.1 Topographic Data

The following data was provided by Council for use in the study:

- 2010 LiDAR land survey data.
- 2015 LiDAR land survey data.

The 2010 LiDAR data were mainly used in the upper area of the catchment where it was not covered by the 2015 LiDAR data.

2.2 Aerial Imagery

Aerial imagery of the Spring Creek catchment (2016) was used within the catchment extent.

2.3 Council Assets Data

The following MapInfo GIS layers provided by Council were used in this study:

- DCDB.
- Land use planning zones.
- Stormwater pipes and pits.

2.4 Site Inspections

A number of site inspections were undertaken by Engeny in 2015 as part of the Spring Creek USMP (Engeny, 2015). The purpose of these inspections was to develop an understanding of the catchment in terms of waterway characteristics, catchment roughness (Manning's n), hydraulic controls (i.e. bridges, culverts, earth embankments, etc.) and to obtain measurements (where possible) of hydraulic structures. Findings from the previous site inspection were used in this study.

2.5 Previous Studies

2.5.1 Spring Creek and Glenvale Creek Flood Studies

The flood study for Spring Creek (TRC, 2014b) and Glenvale Creek (TRC, 2014a) were previously undertaken and adopted by TRC. The hydraulic (MIKE11) and hydrologic XPRAFTS models were provided for use in the Spring Creek Urban Stormwater Management Plan.

2.5.2 Spring Creek Urban Stormwater Management Plan (Engeny, 2015)

The scope of the Spring Creek USMP (Engeny, 2015) included undertaking a flood assessment of the Spring Creek catchment for the purpose of defining the flood conveyance corridor largely for development control purposes. The study was undertaken using the previously developed XPRAFTS hydrology models (TRC, 2014a & b) which were revised for the Spring Creek USMP (Engeny, 2015). Council's previously developed MIKE-11 models (TRC, 2014a & b) were converted to 1D/2D TUFLOW hydraulic model and extended to the confluence with Westbrook Creek.

3. HYDROLOGIC MODEL DEVELOPMENT

3.1 Overview

Hydrologic modelling for this study was undertaken using XPRAFTS software to estimate catchment runoff. XPRAFTS is an industry-standard, non-linear, hydrologic routing package and has been used extensively in similar studies across Australia.

Key input requirements for the XPRAFTS model include:

- Catchment area.
- Catchment routing properties (slope, impervious, PERN).
- Rainfall loss rates.
- Design rainfall input.

No further validation has been undertaken as the XPRAFTS model was validated to Rational Method calculation (Engeny, 2015). A split-catchment approach was adopted in XPRAFTS to model the urbanised and non-urbanised areas with different PERN values.

3.2 XPRAFTS Model

3.2.1 Catchment Delineation

Sub-catchment delineation for Spring Creek was adopted from the model provided by Toowoomba Regional Council and the topographic information summarised in Section 2.1. The overall Spring Creek catchment study area is approximately 66.4 km^2. The adopted sub-catchment delineation is shown in Figure 3.2.

3.2.2 Sub-catchment Data

Sub-catchment data such as percentage impervious values and catchment slopes have been adopted based on review of aerial photography, Council land use mapping and topographic data. Details of sub-catchment data adopted in XPRAFTS model is provided in Appendix A.

The XPRAFTS two sub-catchment approach was utilised, whereby each sub-catchment is divided into pervious and impervious contributions. Catchments were delineated into pervious and impervious catchments by using the supplied land use planning data by Council. Constant PERN values were adopted for the pervious and impervious contributing catchments which are outlined as follows:

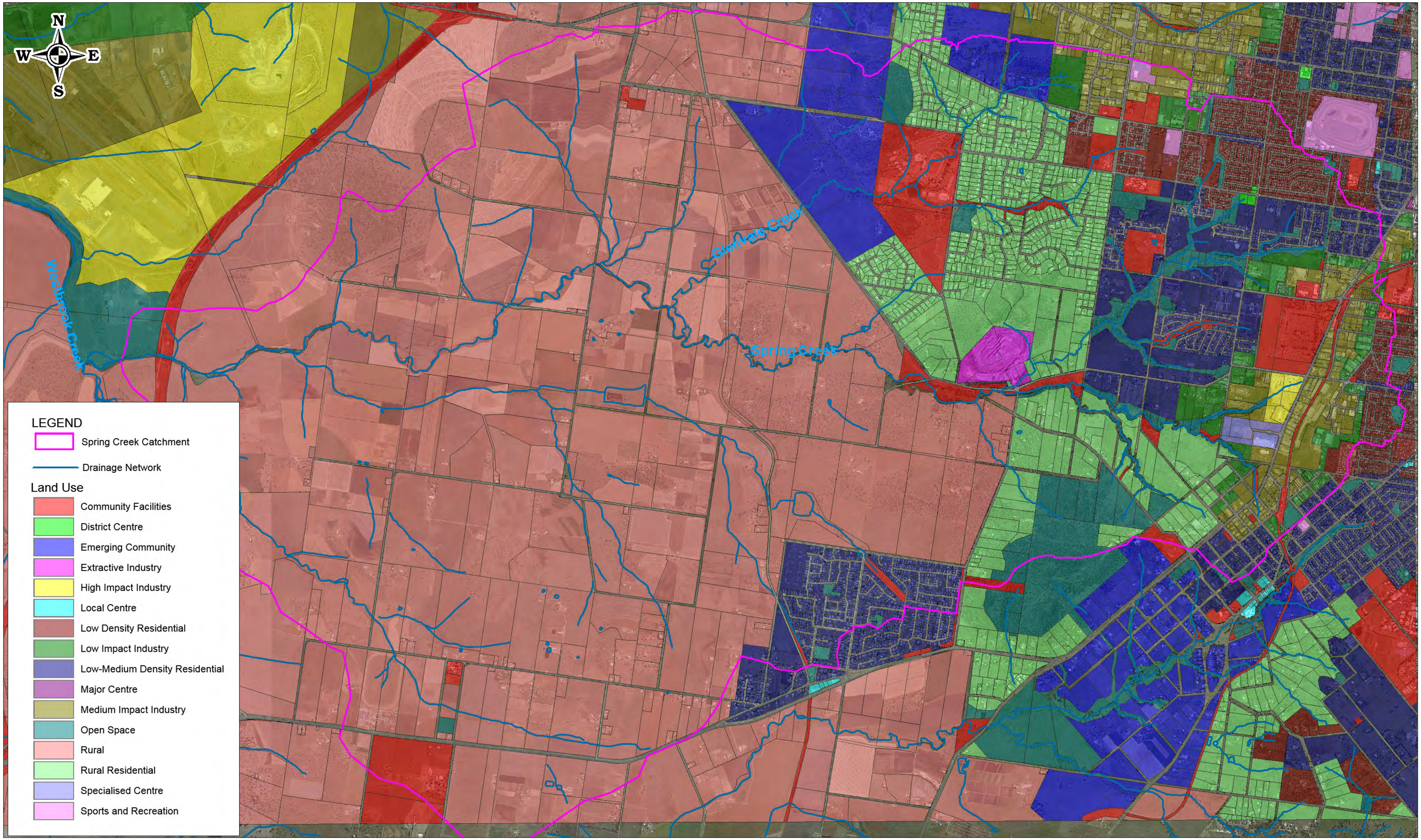
- Impervious area PERN value = 0.025.

- Pervious area PERN value = 0.05.

3.2.3 Land Use

Future (ultimate) land use planning for the catchment was supplied as a GIS layer for use in this study. The latest land use plan was reviewed and compared with the previously adopted plan in XPRAFTS and TUFLOW models (Engeny, 2015). The models have not been revised as no changes were identified. The ultimate land use plan adopted for the Spring Creek USMP is illustrated in Figure 3.1.

The majority of the existing land use for the catchment consists of rural residential and open space with discrete areas of residential and industrial (typically poultry farms) land use in the upper catchment areas. The proposed future (ultimate) land uses comprises a mixture of low and medium density residential, rural residential and industrial land use in the mid to upper reaches of the catchment with predominantly rural land use in the lower reaches of the catchment.



Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
P: 07 3221 7174
F: 07 3236 2399
E: admin@engeny.com.au

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Spring Creek Flood Study Update

Figure 3.1

Ultimate Land Use Plan

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The adopted fraction impervious was confirmed by Council and align with industry standard guidelines such as Queensland Urban Drainage Manual (QUDM) (DEWS, 2013). The fraction impervious values adopted for the study are presented in Table 3.1.

Table 3.1 Fraction Impervious Values Adopted for the Land Use Planning Zones

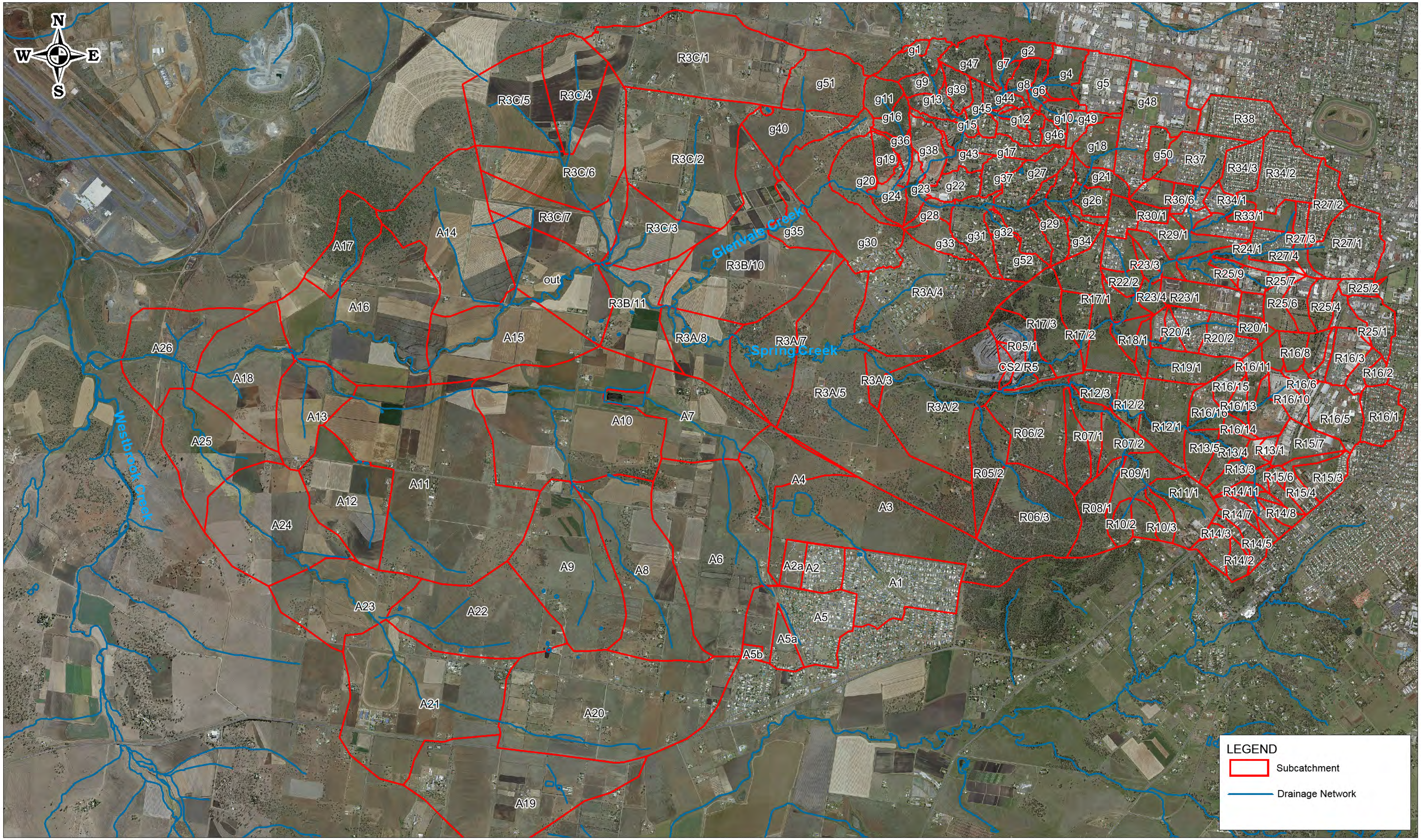
Zone	Fraction Impervious
Low Density Residential	60%
Low-Medium Density Residential	70%
Rural Residential	15%
Emerging Community	60%
Rural	0%
District Centre	100%
Specialised Centre	80%
Local Centre	90%
Open Space	0%
Sport & Recreation	10%
Road	90%
Community Facilities	75%
Low Impact Industry	90%
Medium Impact Industry	90%
High Impact Industry	90%

3.2.4 Model Parameters

The XPRAFTS model parameters that were specified included:

- Rainfall losses.
- Storage Delay Time Coefficient (B_x).
- Non-linearity exponent (m).

The XPRAFTS default values of m = -0.285 and B_x = 1 were adopted for this study.



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P: 07 3221 7174
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Figure 3.2

Subcatchment Layout

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3.2.5 Channel Routing

The lag routing approach was adopted for channel routing within the XPRAFTS model. Nominal routing had been applied in the previous model as channel routing was modelled hydraulically and only local inflows were extracted from the hydrologic model.

In order to perform a critical duration and temporal pattern analysis using the XPRAFTS model, lag times were adjusted to align with peak flow timing from the hydraulic model.

3.3 Design Rainfall

3.3.1 IFD data

Design rainfall depths have been developed for Spring Creek using the Australian Rainfall and Runoff 2016 IFD generation tool available on the Bureau of Meteorology (BoM) website (www.bom.gov.au). IFD data was generated for a number of locations within the study area and it was found there was negligible variance in rainfall estimates across the catchment area (maximum ~1% difference for 2 hour storm duration). The IFD data at the catchment centroid was therefore adopted, and is displayed in Table 3.2.

Table 3.2 Spring Creek IFD Data (mm/hr)

Duration	10% AEP	1% AEP
15 mins	116	176
30 mins	80.5	123
45 mins	62.3	95.9
1 hr	51.1	79.1
1.5 hr	38	59.1
2 hr	30.5	47.6
3 hr	22.2	34.6
4.5 hr	16.1	25
6 hr	12.8	19.9
9 hr	9.39	14.5
12 hr	7.58	11.6

3.3.2 Aerial Reduction Factors

Aerial Reduction Factors (ARFs) have been calculated for the Spring Creek catchment area using the Short Duration ARF equation (EA, 2016). ARFs have been calculated using the methodology for catchments between 10 km^2 and 1,000 km^2 for the Semi-arid inland QLD zone (EA, 2016).

The short duration ARFs depend on the storm duration and catchment area. The total catchment area of Spring Creek is 66.4 km^2. Given this flood study update has been undertaken for the whole catchment, applying ARFs calculated for the catchment outlet may underestimate flow at the upper reaches of the catchment. Therefore, in order to determine reasonable flow estimation, ARFs corresponding to half the catchment area (i.e. 33.2 km^2) was applied. In addition, the majority of the areas of interest (i.e. rural residential area) are located in the upper and mid reaches of the Spring Creek catchment. Table 3.3 shows the ARFs for various catchment sizes in the Semi-arid Inland QLD zone. Adopted ARFs for the Spring Creek catchment are shown below in Table 3.4.

Table 3.3 Areal Reduction Factors

Duration	Catchment Area					
	66.4 km^2		33.2 km^2		10 km^2	
	10% AEP	1% AEP	10% AEP	1% AEP	10% AEP	1% AEP
30 min	0.78	0.75	0.83	0.80	0.89	0.87
60 min	0.83	0.80	0.87	0.84	0.92	0.89
120 min	0.86	0.82	0.89	0.85	0.93	0.90
360 min	0.92	0.89	0.94	0.91	0.96	0.95

Table 3.4 Adopted Spring Creek ARFs

Storm Duration (hours)	10% AEP	1% AEP
15	0.77	0.75
30	0.83	0.80
45	0.85	0.83
60	0.87	0.84

Storm Duration (hours)	10% AEP	1% AEP
90	0.88	0.85
120	0.89	0.85
180	0.90	0.86
270	0.91	0.88
360	0.94	0.91
540	0.95	0.94
720	0.96	0.94

3.3.3 Design Temporal Pattern and Critical Duration Analysis

The critical duration analysis was undertaken using the updated XPRAFTS model outputs. Ten locations were assessed throughout the catchment representing upstream, midstream and downstream locations within the Spring Creek catchment as shown in Figure 3.3.

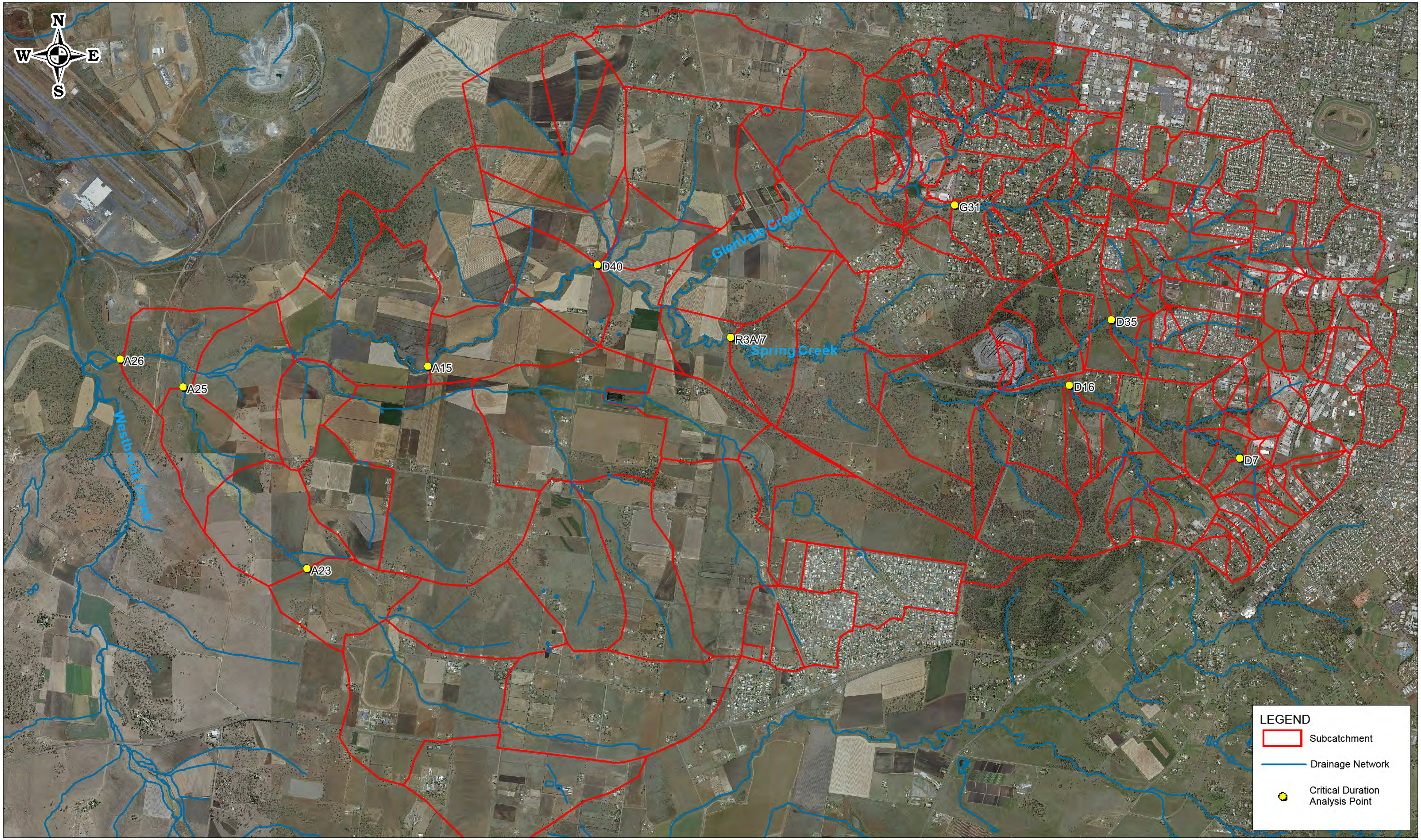
The temporal pattern ensemble approach was used to develop flood hydrographs and peak flow estimates for the Spring Creek catchment. Ensemble temporal patterns for the 'Central Slopes' zone were applied to the 10% and 1% AEP events. The ensemble of 10 temporal patterns was simulated for each AEP and duration (30, 60, 90, 120, 180, 270 and 360 minutes) to produce an ensemble of flood hydrographs. The average peak flow for each simulated duration was used to determine the critical duration at each location assessed. The temporal pattern closest to the average peak flow of the 10 ensemble storms was adopted as the representative design storm for each of the determined critical durations.

A summary of results from this analysis is presented in Table 3.5, and all results are presented in Appendix B.

Table 3.5 Results from Critical Duration and Temporal Pattern Analysis

Location	10% AEP Event		1% AEP Event	
	Critical Duration/s (mins)	Selected Temporal Pattern/s	Critical Duration/s (mins)	Selected Temporal Pattern/s
A15	360	3	90	1

Location	10% AEP Event		1% AEP Event	
A25	720	7	180	6
A26	360	3	180	6
D16	30	3	90	7
D35	30	3	30	6
D40	360	3	90	1
D7	30	3	30	6
G31	90	2	90	7
R3A/7	90	5	90	1
A23	720	7	180	9



Level 11, 344 Queen St, Brisbane QLD 4000
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Figure 3.3

Location of Critical Duration Analysis Points

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Reasonable agreement was achieved for the peak timing of flow hydrographs between XPRAFTS and TUFLOW models for the selected locations. This confirmed that both model results are consistent and the methodology adopted to reduce the number of temporal patterns required to be run in the hydraulic model is acceptable.

3.3.4 Design Event Burst Rainfall Losses

The following storm losses were sourced from ARR 2016 for the Spring Creek catchment:

- Initial Storm Loss – 40 mm
- Continuing Loss – 1 mm/hr

Storm losses include the pre-burst rainfall however typical hydrologic assessments only model the storm burst hyetograph. The burst rainfall loss can be calculated as:

Burst Loss (mm) = Storm Loss (mm) – Pre-Burst Rainfall (mm)

Median pre-burst rainfall depths for the Spring Creek catchment were subtracted from the storm losses for each ARI and duration (obtained from AR&R Data Hub). The median preburst data and adopted initial storm burst losses for the Spring Creek hydrology model are shown in Table 3.6 below. The burst losses adopted for the 10 % AEP models remained as the storm loss of 40 mm as median preburst depths were less than 1.5 mm. No losses were adopted for the PMP.

Table 3.6 Initial Storm Burst Losses (1% AEP)

Event		Storm Loss (mm)	Median Preburst (mm)	Burst Loss (mm)
1% AEP	30	40	3.2*	36.8
	60	40	3.2	36.8
	90	40	7.2	32.8
	120	40	7.0	33.0
	180	40	7.1	32.9
	270	40	5.9	34.1
	360	40	4.7	35.3

**The median pre-burst depth for the 30 minute storm is assumed to be similar to the 60 minute storm.*

3.3.5 Probable Maximum Precipitation (PMP)

Based on the critical duration of the design storms in this study, the Generalised Short-Duration Method (GSDM) (BoM, 2003) was applied to Probable Maximum Precipitation (PMP) generation. The parameters in generating the PMP estimate are given in Table 3.7.

Table 3.7 Probable Maximum Precipitation Parameters

PMP Parameter	Value for Adopted
Catchment Area (km2)	66.4
Elevation Adjustment Factor	1
Moisture Adjustment Factor	0.84

The derived PMP depths used in the study are summarised in Table 3.8.

Table 3.8 Derived Probable Maximum Precipitation Depths

Duration (hrs)	PMP Depth (mm)
1	340
2	500
3	610
4	690
5	760
6	810

The design temporal distribution for short duration PMP was applied to the rainfall depths as recommended for use with the GSDM (BoM, 2003).

3.4 XPRAFTS MODEL VALIDATION

Historical stream flow records were not available within or in close proximity to the study area and as a result, a complete hydrologic or hydraulic model calibration could not be undertaken as part of this study.

As such, the Rational Method was employed to validate the 1% and 10% AEP storm peak flow results calculated from the XPRAFTS model. It was considered the Rational Method was an appropriate alternative methodology for hydrological validation, given the relatively small catchment areas contributing to the existing and future urban areas within the Spring Creek catchment.

The time of concentration (t_c) was calculated by adopting a combination of standard inlet time, kerb flow and channel/waterway flow, average velocity, or Bransby Williams method where appropriate.

The Rational Method calculation was performed for three catchments throughout the study area for existing and ultimate development scenarios. The catchments were chosen to provide a good distribution of land use characteristics and catchment size.

Table 3.9 shows that there is good agreement between the peak flow results calculated using the Rational Method and those estimated from the XPRAFTS model. Some discrepancies can be expected due to the different methodologies that each approach uses, however the differences in peak flow predictions (generally less than +/-20 %) suggests that the XPRAFTS model results are suitable for predicting design flood event runoff hydrographs within the study area.

Table 3.9 1% AEP Storm Event Peak Flow Validation Summary

XPRAFTS Node Outlet	Total Catchment Area (ha)	Time of Concentration (min)	Rational Method (m^3/s)	XPRAFTS (m^3/s)	Difference (m^3/s)
G31	245	71.9	40.7	33.9	20%
R3A/7	1931	162.4	173.5	213.2	-19%
A25	933	198.9	58.8	52.3	12%

4. HYDRAULIC MODEL DEVELOPMENT

4.1 Overview

A 1D/2D TUFLOW hydraulic model for Spring Creek and Glenvale Creek was previously developed as part of USMP study (Engeny, 2015) based on MIKE11 hydraulic models (TRC, 2014a & b). The Spring Creek hydraulic model extent includes the upper reaches of Spring Creek and Glenvale Creek down to the confluence of Spring Creek and Westbrook Creek.

4.2 Topography

The Spring Creek model includes a combination of LiDAR data captured in 2010 and 2015. The 2015 topographic extent did not cover the upper reaches of Spring Creek and therefore the 2010 data was used to supplement the 2015 data. The transition zones between the 2010 and 2015 topography datasets were typically smooth and were deemed appropriate for use in the study.

4.3 Grid Size and Timestep

Review of the TUFLOW model (Engeny, 2015) model shows that a 4 m grid cell size was considered appropriate for providing sufficient definition of the waterway in the model. A model time step of 2 seconds was found to provide a stable model configuration.

4.4 Model Boundaries

4.4.1 Hydrologic Inputs

Sub-catchment flows within the model domain have been applied as ‘flow over area’ boundaries. This type of boundary applies inflows initially in the lowest elevation cell within the catchment and then to all wet cells after that. The inflow boundaries are based on the sub-catchment delineation and are shown in Figure 3.2.

4.4.2 Downstream Boundary Conditions

The downstream boundary of the models was defined as normal depth boundary represented as a function of the channel cross section and an assumed hydraulic grade.

4.5 Hydraulic Roughness

The hydraulic roughness (Manning’s ‘n’) applied in the TUFLOW model was based on the planning scheme GIS dataset supplied by Council, i.e. ultimate land use conditions have been adopted in the hydraulic modelling. Manning’s ‘n’ values adopted for the defined land use types were based on industry standard values consistent with the latest AR&R update (EA, 2016) and QUDM (DEWS, 2013).

The adopted Manning's 'n' values are summarised in Table 4.1.

Table 4.1 Land Use, Manning's 'n' Values and Direct Rainfall Design Losses

Land Use Type	Manning's 'n'
Road/Channel	0.025
Open Water	0.03
Open Space, Sport & Recreation, Grass Channel	0.05
Waterway	0.07
Rural, Bush	0.09
Rural Residential, Emerging Community	0.12
Low Density Residential, Low-Medium Density Residential	0.15
Medium Impact Industry, Low Impact Industry, High Impact Industry, Extractive Industry	0.2
Community Facilities, Local Centre, District Centre, Specialised Centre, Major Centre	0.2

4.6 Hydraulic Structures

The cross-drainage hydraulic structures located within the main waterway previously adopted in the TUFLOW model (Engeny, 2015) were reviewed. A number of missing structures within the hydraulic model extent were identified and included where survey data was provided by Council. Dimensions and details of the structures were adopted from a number of sources including;

- The previously developed Spring Creek and Glenvale Creek hydraulic models.
- TRC's stormwater pipe network data (GIS).
- TRC survey of the hydraulic structures.

4.7 Overland Flow Path Modelling

An overland flow path assessment was undertaken for the Spring Creek catchment to determine existing overland flow paths through future development areas.

A rain on grid approach was adopted for the 1 % AEP for the 30, 60 and 90 minutes storm duration. In order to reduce the simulation time, the adopted temporal patterns were selected based on the rainfall analysis for reporting points in the rural residential area in XPRAFTS. No 1D hydraulic structure (i.e. pits and pipes) were included in the assessment of overland flow paths. The overland flow path mapping extent for the Spring Creek catchment is provided in Figure 4.1.

Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
P: 07 3221 7174
F: 07 3236 2399
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Figure 4.1

Extent of Overland Flow Path Mapping

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4.8 Flood Risk Mapping

Flood risks zones FR1 to FR4 were determined using the methodology presented the FRAPESA report (MWH & Hawksley Consulting, 2016). The flood risk matrix for category definitions is presented in Table 4.2.

Table 4.2 Flood Risk Matrix (Source: FRAPESA)

Flood Likelihood	Flood Hazard			
	Low	Significant	High	Extreme
Extreme flood event (PMF)	FR-1	FR-1	FR-1	FR-1
Defined flood event (1% AEP)	FR-2	FR-2	FR-3	FR-4
Frequent flood event (10% AEP)	FR-2	FR-3	FR-4	FR-4

Council has adopted the flood hazard categories defined by the Queensland Reconstruction Authority (2012) in the document *Planning for more resilient floodplains Part 2* (QRA, 2012). The categories are determined from depth, velocity and the depth-velocity product.

The PMF, 1% AEP and 10% AEP were the selected extreme, defined and frequent flood events respectively.

The 1% AEP flood results from the Overland Flow Path models were processed in order to map the TRC Overland Flow Path Classification 1 and 2 (OFP1 and OFP2) extents. The process applied to classifying the results into OFP1 and OFP2 was as follows:

- All areas where the flood depth was less than 0.07 m were removed.
- All areas where the depth x velocity (Z0) product was less than 0.01 m^2/s were removed.
- From the remaining extent, areas which had a low ZQRA hazard classification and depth less than 0.1 m were classified as OFP1, with the remaining areas classified as OFP2.
- Finally, the creek Flood Risk Mapping extent was used to trim the OFP results, and the OFP and creek Flood Risk Mapping results were combined to produce the final Flood Risk Map presented in Appendix C.

4.9 Sensitivity Scenario for Blockage of Hydraulic Structures

A sensitivity scenario for 50% blockage of all pipe and culvert structures was analysed to assess the variability of model results to key input parameters. The sensitivity scenario was modelled for the ultimate 1% AEP design event and resulting differences assessed throughout the catchment.

4.10 Climate Change Scenarios

A climate change scenario for the 2090 planning horizon was simulated to assess the effects of predicted rainfall intensity increase due to climate change. The latest AR&R update (EA, 2016) prescribes the methodology for estimating this rainfall increase. A projected rainfall intensity (I_P) is obtained using the equation:

$$I_P = I_{ARR} \times 1.05^{T_m}$$

where I_{ARR} is the current design rainfall intensity and T_m is the projected temperature increase. This increase is found using data from the Climate Futures web tool (CSIRO, 2015). The Spring Creek catchment falls within the ‘East Coast North’ Natural Resource Management (NRM) cluster. Temperature increase data from an ensemble of Global Climate Models (GCMs) is presented. The consensus is a 1.5 – 3.0°C increase (median of 2.25°C) for the RCP4.5 scenario and a 4.1°C median increase for the RCP8.5.

The RCP4.5 scenario median was selected. The projected rainfall increase factor is therefore 1.12. For modelling purposes, rainfall was increased by 12% in the hydrologic model for the climate change scenario. The adopted 12% increase in rainfall intensity was consistent with the recommended value for RCP6 in Appendix A.

5. DESIGN FLOOD MODELLING RESULTS

5.1 Design Event Simulation

The flood model was simulated for the 10%, 1% AEP storm events described in Section 4 and 5. Mapping of peak flood extent for the simulated design flood events are presented in Appendix C.

Table 5.1 summarises peak flood level results upstream of crossings at the selected reporting locations. Reporting locations are shown in Figure 5.1.

Table 5.1 Design Event Peak Flood Results

ID	Location	Peak Flood Level (m AHD)		
		10% AEP	1% AEP	PMF
RP1	Glenvale Rd	604.59	604.70	605.34
RP2	Greenwattle St	604.12	604.22	604.84
RP3	McDougall St	575.29	575.59	577.02
RP4	Boundary St	551.16	551.55	553.32
RP5	Boundary St South	533.38	533.90	538.19
RP6	Quarry	535.59	536.77	539.22
RP7	McDougall St	574.15	575.00	577.02
RP8	Golf Course	573.64	574.26	577.98
RP9	Golf Course	570.04	570.28	571.68
RP10	Greenwattle St	593.50	593.95	595.80
RP11	Stenner St	605.70	605.80	606.82
RP12	Hursley Rd	558.49	558.64	559.53
RP13	Harvey Rd	543.14	543.38	544.82
RP14	Harvey Rd	538.76	539.61	540.94
RP15	Drayton Wellcamp Rd	512.52	513.47	514.78

ID	Location	Peak Flood Level (m AHD)		
		10% AEP	1% AEP	PMF
RP16	Wellcamp Westbrook Rd	485.14	485.43	487.46
RP17	Wellcamp Westbrook Rd	484.74	485.18	486.76
RP18	Schultz Rd	479.20	479.60	481.60
RP19	Wellcamp Westbrook Rd	482.16	482.26	483.01
RP20	Shilliday Rd	511.72	511.83	512.63
RP21	Bunkers Hill School Rd	504.41	504.54	505.84
RP22	Blackwell Rd	500.16	500.35	501.50
RP23	Glenvale Rd	587.54	587.67	588.47

Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
P: 07 3221 7174
F: 07 3236 2399
E: admin@engeny.com.au
ENGENY WATER MANAGEMENT

TOOWOOMBA REGIONAL COUNCIL

0 700 1400
Scale in Metres (1:35,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Spring Creek Flood Study Update

Figure 5.1

Location of Reporting Points

Job Number: M34000_046
Revision: 0
Drawn: AJ
Date: 5 Apr 2017

5.2 Climate Change Impact Results

A simulation for climate change (2090) was undertaken for 1% AEP flood event. The increased rainfall due to predicted climate change for the year 2090 resulted in an increase in peak flood levels by average 100 mm upstream of the crossings provided in Table 5.2.

Table 5.2 Design Event Peak Flood Results – Climate Change Scenario

ID	Location	1% AEP Peak Flood Level (m)		
		Base Case	Climate Change	Difference
RP1	Glenvale Rd	604.70	604.74	0.04
RP2	Greenwattle St	604.22	604.30	0.07
RP3	McDougall St	575.59	575.64	0.05
RP4	Boundary St	551.55	551.69	0.14
RP5	Boundary St South	533.90	534.43	0.53
RP6	Quarry	536.77	536.95	0.18
RP7	McDougall St	575.00	575.25	0.25
RP8	Golf Course	574.26	574.57	0.31
RP9	Golf Course	570.28	570.34	0.05
RP10	Greenwattle St	593.95	594.17	0.22
RP11	Stenner St	605.80	605.84	0.04
RP12	Hursley Rd	558.64	558.70	0.05
RP13	Harvey Rd	543.38	543.46	0.08
RP14	Harvey Rd	539.61	539.71	0.10
RP15	Drayton Wellcamp Rd	513.47	513.54	0.07
RP16	Wellcamp Westbrook Rd	485.43	485.49	0.07
RP17	Wellcamp Westbrook Rd	485.18	485.27	0.08
RP18	Schultz Rd	479.60	479.69	0.09

ID	Location	1% AEP Peak Flood Level (m)		
		Base Case	Climate Change	Difference
RP19	Wellcamp Westbrook Rd	482.26	482.27	0.01
RP20	Shilliday Rd	511.83	511.86	0.02
RP21	Bunkers Hill School Rd	504.54	504.57	0.03
RP22	Blackwell Rd	500.35	500.37	0.02
RP23	Glenvale Rd	587.67	587.69	0.03

5.3 Culvert Blockage Sensitivity

A sensitivity analysis was undertaken for 50% culvert blockage for the 1% AEP flood event peak flood level in accordance with ARR 2016 guideline. Culvert blockage resulted in a change in peak flood levels by up to 1 m upstream of the crossings provided in Table 5.3.

Table 5.3 Design Event Peak Flood Results – Culvert Blockage Scenario

ID	Location	1% AEP Peak Flood Level (m)		
		Base Case	50% Blockage	Difference
RP1	Glenvale Rd	604.70	604.72	0.02
RP2	Greenwattle St	604.22	604.43	0.21
RP3	McDougall St	575.59	575.59	0.00
RP4	Boundary St	551.55	551.55	0.00
RP5	Boundary St South	533.90	534.81	0.91
RP6	Quarry	536.77	537.16	0.39
RP7	McDougall St	575.00	576.01	1.01
RP8	Golf Course	574.26	574.27	0.01
RP9	Golf Course	570.28	570.30	0.02
RP10	Greenwattle St	593.95	593.97	0.02

ID	Location	1% AEP Peak Flood Level (m)		
		Base Case	50% Blockage	Difference
RP11	Stenner St	605.80	605.77	-0.03
RP12	Hursley Rd	558.64	558.71	0.07
RP13	Harvey Rd	543.38	543.42	0.04
RP14	Harvey Rd	539.61	539.73	0.12
RP15	Drayton Wellcamp Rd	513.47	513.62	0.15
RP16	Wellcamp Westbrook Rd	485.43	485.42	-0.01
RP17	Wellcamp Westbrook Rd	485.18	485.19	0.00
RP18	Schultz Rd	479.60	479.60	0.00
RP19	Wellcamp Westbrook Rd	482.26	482.26	0.00
RP20	Shilliday Rd	511.83	511.84	0.01
RP21	Bunkers Hill School Rd	504.54	504.55	0.01
RP22	Blackwell Rd	500.35	500.34	-0.01
RP23	Glenvale Rd	587.67	587.78	0.11

6. SUMMARY AND CONCLUSIONS

Engeny was engaged by Council to undertake an updated Spring Creek flood study. The study builds upon the previous hydrologic and hydraulic modelling undertaken for the Spring Creek Urban Stormwater Management Plan) (Engeny, 2015) and includes the latest council datasets and ARR 2016 rainfall data.

The XPRAFTS hydrologic model developed as part of the previous study (Engeny, 2015) was adopted for use in the current study. The design hydrology was updated to be consistent with ARR 2016 which involved:

- Updating IFD data.
- Updating ARFs.
- Simulation of design rainfall using the ensemble temporal pattern approach.

The previously developed TUFLOW hydraulic model (Engeny, 2015) was reviewed and updated with the inflows from the revised XPRAFTS model.

The following design events were simulated using the updated TUFLOW model:

- 10% AEP (ultimate catchment conditions).
- 1% AEP (ultimate catchment conditions).
- PMF event (ultimate catchment conditions).

In addition to the above design events, the following scenarios were simulated based on the 1% AEP ultimate catchment event:

- 1% AEP, 2090 climate change scenario (ultimate catchment conditions).
- 50% blockage of all pipe and culvert structures (ultimate catchment conditions).

Key results from these scenarios are as follows:

- Increased rainfall due to climate change in year 2090 resulted in an increase in peak flood levels by an average 100 mm.
- Culvert blockage resulted in a change in peak flood levels by up to 1 m.

7. REFERENCES

1. Australian Government Bureau of Meteorology (www.bom.gov.au).

2. Australia Government Bureau of Meteorology (2003) The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-duration Method (GSDM).

3. CSIRO (2015), Climate Change in Australia, Projections for Australia's NRM Regions, Technical Report, retrieved from www.climatechangeinaustralia.gov.au/en.

4. Engeny Water Management (2015), Spring Creek Urban Stormwater Management Plan (Spring Creek USMP).

5. Engineers Australia (EA) (2016), *Australian Rainfall & Runoff.*

6. MWH & Hawksley Consulting (2016), Flood Risk Assessment, Planning Evaluation and Planning Scheme Amendment (FRAPESA) Project, Consolidated Flood Risk Assessment and Planning Evaluation Report - Phases 2 & 3.

7. Toowoomba Regional Council (2014a), Glenvale Flood Study.

8. Toowoomba Regional Council (2014b), Spring Creek Flood Study.

9. Queensland Department of Energy and Water Supply (2013), Queensland Urban Drainage Manual.

10. Queensland Reconstruction Authority (2012), Planning for stronger, more resilient floodplains Part 2 – Measures to support floodplain management in future planning schemes.

8. QUALIFICATIONS

a. In preparing this document, including all relevant calculation and modelling, Engeny Water Management (Engeny) has exercised the degree of skill, care and diligence normally exercised by members of the engineering profession and has acted in accordance with accepted practices of engineering principles.

b. Engeny has used reasonable endeavours to inform itself of the parameters and requirements of the project and has taken reasonable steps to ensure that the works and document is as accurate and comprehensive as possible given the information upon which it has been based including information that may have been provided or obtained by any third party or external sources which has not been independently verified.

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APPENDIX A

Rainfall and Sub-Catchment Data

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	151.865
Latitude	-27.586
Selected Regions (clear)	
River Region	show
ARF Parameters	show
Storm Losses	show
Temporal Patterns	show
Areal Temporal Patterns	show
Interim Climate Change Factors	show
Baseflow Factors	show

Region Information

Data Category	Region
River Region	Condamine-Culgoa Rivers
ARF Parameters	Semi-arid Inland QLD

Data

River Region

Division	Murray-Darling Basin
RivRegNum	23.0
River Region	Condamine-Culgoa Rivers

Layer Info

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ARF Parameters

Long Duration ARF

$$Areal\ reduction\ factor = Min\left\{1, \left[1 - a\left(Area^{b} - c\log_{10}Duration\right)Duration^{-d} + eArea^{f}Duration^{g}\left(0.3 + \log_{10}AEP\right) + h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\right]\right\}$$

Zone	Semi-arid Inland QLD
a	1.59E-01
b	2.83E-01
c	2.50E-01
d	3.08E-01
e	7.30E-07
f	1.00E+00
g	3.90E-02
h	0.00E+00
i	0.00E+00

Short Duration ARF

$$ARF = Min\left[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36} + 2.26\ \text{x}\ 10^{-3}\ \text{x}\ Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right) + 0.0141\ \text{x}\ Area^{0.213}\ \text{x}\ 10^{-0.021\frac{(Duration-180)^2}{1440}}\left(0.3 + \log_{10}(AEP)\right)\right]$$

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Storm Losses

Storm Initial Losses (mm)	40.0
Storm Continuing Losses (mm/h)	1.0

Layer Info

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Version	2016_v1

Temporal Patterns | Download (.zip)

CODE	CS
LABEL	Central Slopes

Layer Info

Time Accessed	28 March 2017 05:19PM
Version	2016_v1

Areal Temporal Patterns | Download (.zip)

CODE	CS
LABEL	Central Slopes

Layer Info

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BOM IFD Depths

Click here (http://www.bom.gov.au/water/designRainfalls/revised-ifd/?year=2016&coordinate_type=dd&latitude=-27.586&longitude=151.865&sdmin=true&sdhr=true&sdday=tru to obtain the IFD depths for catchment centroid from the BoM website

Median Preburst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

min (h) \AEP(%)	50	20	10	5	2	1
60 (1.0)	0.4 (0.014)	0.8 (0.019)	1.1 (0.021)	1.3 (0.022)	2.4 (0.034)	3.2 (0.04)
90 (1.5)	0.1 (0.004)	0.3 (0.006)	0.4 (0.006)	0.5 (0.007)	4.3 (0.055)	7.2 (0.081)
120 (2.0)	0.1 (0.002)	0.2 (0.004)	0.3 (0.005)	0.4 (0.005)	4.2 (0.049)	7.0 (0.074)
180 (3.0)	0.0 (0.0)	0.0 (0.001)	0.1 (0.001)	0.1 (0.001)	4.1 (0.045)	7.1 (0.069)
360 (6.0)	0.1 (0.001)	0.1 (0.002)	0.2 (0.002)	0.2 (0.002)	2.8 (0.026)	4.7 (0.039)
720 (12.0)	0.0 (0.0)	0.8 (0.011)	1.4 (0.015)	1.9 (0.018)	7.4 (0.06)	11.6 (0.083)
1080 (18.0)	0.0 (0.0)	1.8 (0.021)	3.1 (0.03)	4.2 (0.036)	9.1 (0.065)	12.7 (0.081)
1440 (24.0)	0.0 (0.0)	1.4 (0.015)	2.3 (0.021)	3.2 (0.025)	8.3 (0.054)	12.1 (0.071)
2160 (36.0)	0.0 (0.0)	0.1 (0.001)	0.1 (0.001)	0.2 (0.001)	1.8 (0.01)	3.0 (0.015)
2880 (48.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.0)	0.7 (0.004)	1.2 (0.006)
4320 (72.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

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10% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
90 (1.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
120 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
180 (3.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
360 (6.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
720 (12.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1080 (18.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1440 (24.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2160 (36.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2880 (48.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4320 (72.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

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25% Preburst Depths

min (h)\AEP (%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.0)	0.0 (0.001)	0.0 (0.001)	0.1 (0.001)	0.0 (0.0)	0.0 (0.0)
90 (1.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.001)	0.1 (0.001)
120 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
180 (3.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.001)	0.1 (0.001)
360 (6.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
720 (12.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1080 (18.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1440 (24.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2160 (36.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
2880 (48.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
4320 (72.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

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75% Preburst Depths

min (h) \AEP(%)	50	20	10	5	2	1
60 (1.0)	10.5 (0.338)	11.3 (0.264)	11.9 (0.233)	12.4 (0.209)	20.4 (0.289)	26.4 (0.333)
90 (1.5)	3.4 (0.097)	6.4 (0.134)	8.4 (0.147)	10.3 (0.155)	30.7 (0.39)	46.1 (0.519)
120 (2.0)	6.1 (0.163)	9.4 (0.184)	11.6 (0.19)	13.7 (0.194)	36.1 (0.428)	52.8 (0.555)
180 (3.0)	9.1 (0.222)	12.6 (0.226)	14.9 (0.225)	17.2 (0.222)	40.0 (0.435)	57.1 (0.55)
360 (6.0)	7.5 (0.155)	15.5 (0.238)	20.8 (0.27)	25.8 (0.29)	37.2 (0.352)	45.8 (0.384)
720 (12.0)	6.0 (0.103)	16.6 (0.215)	23.6 (0.259)	30.3 (0.289)	39.3 (0.317)	46.1 (0.33)
1080 (18.0)	1.3 (0.019)	13.7 (0.158)	21.9 (0.215)	29.8 (0.254)	38.9 (0.28)	45.7 (0.293)
1440 (24.0)	1.0 (0.014)	8.7 (0.093)	13.8 (0.124)	18.7 (0.146)	31.9 (0.209)	41.7 (0.244)
2160 (36.0)	0.1 (0.001)	3.9 (0.036)	6.4 (0.05)	8.8 (0.06)	20.3 (0.116)	29.0 (0.147)
2880 (48.0)	0.0 (0.0)	2.8 (0.024)	4.7 (0.033)	6.4 (0.04)	12.0 (0.062)	16.1 (0.074)
4320 (72.0)	0.0 (0.0)	0.2 (0.001)	0.3 (0.002)	0.4 (0.002)	6.3 (0.028)	10.7 (0.042)

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90% Preburst Depths

min (h) \AEP(%)	50	20	10	5	2	1
60 (1.0)	24.7 (0.797)	32.8 (0.767)	38.2 (0.749)	43.4 (0.732)	66.7 (0.948)	84.2 (1.065)
90 (1.5)	17.0 (0.49)	31.8 (0.666)	41.6 (0.73)	50.9 (0.77)	111.3 (1.414)	156.6 (1.765)
120 (2.0)	37.2 (0.998)	41.4 (0.809)	44.1 (0.724)	46.8 (0.661)	91.2 (1.082)	124.5 (1.31)
180 (3.0)	24.0 (0.584)	40.9 (0.731)	52.1 (0.784)	62.8 (0.814)	88.8 (0.965)	108.2 (1.042)
360 (6.0)	30.9 (0.636)	53.8 (0.825)	68.9 (0.895)	83.4 (0.937)	99.9 (0.944)	112.2 (0.941)
720 (12.0)	25.6 (0.441)	43.4 (0.561)	55.2 (0.606)	66.4 (0.634)	91.3 (0.735)	109.9 (0.786)
1080 (18.0)	15.8 (0.243)	37.7 (0.436)	52.2 (0.513)	66.2 (0.563)	88.0 (0.633)	104.4 (0.668)
1440 (24.0)	18.9 (0.268)	29.6 (0.314)	36.7 (0.33)	43.5 (0.338)	69.7 (0.458)	89.4 (0.522)
2160 (36.0)	12.4 (0.157)	21.2 (0.198)	27.0 (0.213)	32.6 (0.221)	47.7 (0.273)	59.0 (0.3)
2880 (48.0)	9.8 (0.115)	18.5 (0.158)	24.2 (0.173)	29.6 (0.182)	44.9 (0.231)	56.3 (0.258)
4320 (72.0)	1.7 (0.018)	6.0 (0.046)	8.9 (0.056)	11.7 (0.063)	33.7 (0.151)	50.1 (0.199)

Layer Info

Time Accessed	28 March 2017 05:19PM
Version	2016_v1

Interim Climate Change Factors

Values are of the format temperature increase in degrees Celcius (% increase in rainfall)

	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.977 (4.9%)**	0.892 (4.5%)	**1.057 (5.3%)**
2040	**1.225 (6.1%)**	1.129 (5.6%)	**1.485 (7.4%)**
2050	**1.477 (7.4%)**	1.422 (7.1%)	**1.953 (9.8%)**
2060	**1.687 (8.4%)**	1.705 (8.5%)	**2.469 (12.3%)**
2070	**1.832 (9.2%)**	1.948 (9.7%)	**3.047 (15.2%)**
2080	**1.978 (9.9%)**	2.216 (11.1%)	**3.621 (18.1%)**
2090	**2.039 (10.2%)**	2.515 (12.6%)	**4.163 (20.8%)**

Layer Info

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Version	2016_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values

Baseflow Factors

DOWNSTREAM	7025.0
AREA_SQKM	473.4
CATCH_NO	7140.0
R3RUNOFF	0.27
R1RUNOFF	0.049

Layer Info

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Catchment Name	Pervious Area [ha]	Impervious Area [ha]	Catchment Slope [%]
A1	50.78	18.42	6.36
A10	4.82	196.36	1.68
A11	3.59	261.12	3.88
A12	2.04	75.26	2.32
A13	1.59	54.71	3.52
A14	4.14	119.76	7.3
A15	1.76	97.30	1.82
A16	3.36	162.84	4.5
A17	0.30	37.48	17.76
A18	3.87	84.78	6.42
A19	41.45	120.45	2.18
A2	12.77	5.74	6.28
A20	11.03	200.16	6.36
A21	27.73	150.50	2.6
A22	0.00	110.13	4.88
A23	1.43	78.89	2.82
A24	0.47	113.30	4.3
A25	1.23	76.61	4.3
A26	12.34	60.38	6.36
A2a	7.15	2.90	3.334
A3	5.62	131.33	6.84
A4	2.63	41.82	5.42
A5	34.21	29.69	4.92
A5a	8.54	3.54	7.4
A5b	1.83	0.80	4.4
A6	5.06	159.32	4.9
A7	3.58	77.29	2.38
A8	3.51	121.41	5.18
A9	3.45	119.07	5.7
CS2/R5	6.82	1.92	35.384
D1	0.00	0.00	0.002
D10	0.00	0.00	0.002
D11	0.00	0.00	0.002
D12	0.00	0.00	0.002
D13	0.00	0.00	0.002
D14	0.00	0.00	0.002
D15	0.00	0.00	0.002
D16	0.00	0.00	0.002
D17	0.00	0.00	0.002
D18	0.00	0.00	0.002
D19	0.00	0.00	0.002
D2	0.00	0.00	0.002
D20	0.00	0.00	0.002
D21	0.00	0.00	0.002
D22	0.00	0.00	0.002
D23	0.00	0.00	0.002
D24	0.00	0.00	0.002
D25	0.00	0.00	0.002
D26	0.00	0.00	0.002
D27	0.00	0.00	0.002
D28	0.00	0.00	0.002
D29	0.00	0.00	0.002
D3	0.00	0.00	0.002
D30	0.00	0.00	0.011
D31	0.00	0.00	0.02
D32	0.00	0.00	0.02
D33	0.00	0.00	0.02
D34	0.00	0.00	0.02
D35	0.00	0.00	0.02
D36	0.00	0.00	0.02
D37	0.00	0.00	0.02
D38	0.00	0.00	0.02
D4	0.00	0.00	0.002
D40	0.00	0.00	0.02
D41	0.00	0.00	0.02
D5	0.00	0.00	0.001
D6	0.00	0.00	0.002
D7	0.00	0.00	0.002
D8	0.00	0.00	0.002
D9	0.00	0.00	0.002
G1	0.73	1.75	11.5
G10	4.02	4.26	12.88
G11	4.48	8.00	30.32
G12	0.70	3.97	12.18
G13	2.34	7.67	10.4
G14	1.00	3.11	12.42
G15	0.62	2.57	5.98
G16	3.50	5.69	26.74
G17	6.86	14.60	9.36
G18	10.89	7.04	9.92
G19	6.69	2.68	21.5
G2	5.65	3.96	16.86
G20	17.07	11.14	7.4
G21	3.12	7.98	13.96
G22	6.18	7.03	4.96
G23	7.56	2.52	6.16
G24	10.03	3.44	6.5
G25	3.12	11.12	10.9
G26	2.26	8.23	12.7
G27	9.50	29.22	10.96
G28	5.67	1.86	8.86
G29	3.29	12.62	13.8
G3	3.29	12.74	17.04
G30	43.61	35.61	5.32
G31	4.52	19.53	8.04
G32	0.98	3.88	9.64
G33	8.72	5.36	11.72
G34	1.87	7.40	14.78
G35	3.22	18.85	2.7
G36	5.43	1.88	14.66
G37	2.65	7.66	4.74
G38	11.59	5.32	6.18
G39	2.02	7.65	11.38
G4	14.87	2.08	17.96
G40	22.49	13.96	4.72
G41	1.27	1.32	13.7
G42	2.10	5.21	11
G43	4.68	4.52	4.68
G44	1.79	5.62	7.22
G45	2.17	7.84	7.94
G46	1.61	3.43	10.82
G47	7.87	8.94	10.24
G48	43.90	17.06	5.62
G49	5.20	3.34	9.32
G5	24.86	3.04	4.72
G50	5.34	4.86	9.62
G51	23.29	20.70	13.92
G52	3.98	12.67	17.44
G6	2.57	1.54	15.02
G7	4.10	4.53	13.82
G8	5.18	3.68	10.86

Catchment Name	Pervious Area [ha]	Impervious Area [ha]	Catchment Slope [%]
G9	1.35	7.56	15.88
R05/1	8.64	11.47	1.32
R05/2	0.81	30.42	9.26
R05/3	3.42	0.67	44.316
R06/2	11.37	45.69	12.5
R06/3	7.96	65.53	18.056
R07/1	3.95	10.15	15.312
R07/2	5.25	12.10	13.96
R07/3	4.33	13.69	19.366
R08/1	1.60	26.92	14.487
R09/1	4.07	19.27	8.14
R1	2.00	77.39	8.008
R10/1	2.79	6.37	17.928
R10/2	0.93	7.76	19.646
R10/3	2.39	5.76	19.138
R11/1	7.03	21.75	12.17
R12/1	19.25	16.38	3.82
R12/2	6.15	7.23	3.82
R12/3	5.52	8.30	2.836
R13/1	2.77	0.49	7.968
R13/3	9.51	3.27	3.54
R13/4	6.47	6.69	3.72
R13/5	3.36	9.89	8.04
R14/1	6.54	2.12	9.238
R14/10	1.42	0.17	7.08
R14/11	3.71	0.53	10.624
R14/13	3.35	0.48	10.38
R14/2	5.05	1.97	7.49
R14/3	1.92	0.83	10.9
R14/4	3.34	0.68	3.26
R14/5	8.24	1.81	3.368
R14/6	2.11	0.48	6.998
R14/7	5.71	0.79	7.28
R14/8	3.09	2.72	8.014
R14/9	5.95	0.90	4.828
R15/2	3.81	1.25	7.626
R15/3	12.24	3.39	14.286
R15/4	9.96	1.92	4.048
R15/6	2.18	0.25	7.774
R15/7	16.62	2.28	14.34
R16/1	14.22	7.80	2.186
R16/10	11.14	1.32	14.9
R16/11	7.51	1.23	10.86
R16/12	12.23	2.81	12.346
R16/13	5.28	1.57	7.9
R16/14	3.29	0.84	11.686
R16/15	7.59	1.29	12.59
R16/16	9.12	4.01	13.816
R16/17	4.00	0.52	7.612
R16/2	3.56	1.61	3.362
R16/3	14.66	1.76	7.408
R16/4	5.11	1.65	5.592
R16/5	25.28	3.46	11.038
R16/6	4.46	0.65	8.164
R16/7	6.34	1.38	8
R16/8	6.98	2.33	7.816
R16/9	4.62	1.54	5.48
R17/1	18.50	23.39	2.94
R17/2	2.73	12.20	2.34
R17/3	8.37	32.80	4.56
R18/1	3.72	5.01	5.594
R19/1	14.11	9.47	10.912
R19/2	3.80	3.40	9.962
R20/1	5.26	1.93	11.74
R20/2	11.93	5.47	12.122
R20/3	7.46	4.62	8.966
R20/4	2.37	3.74	15.422
R20/5	2.60	2.11	17.114
R22/1	8.02	3.15	10.16
R22/1a	4.94	5.44	14
R22/2	5.25	3.01	10.836
R23/1	14.65	6.78	8.8
R23/2	6.29	4.59	15.75
R23/3	3.09	1.69	3.8
R23/4	2.06	4.89	3.8
R23/5	3.68	6.31	3.8
R24/1	5.42	3.86	9.418
R25/1	13.53	3.61	5.446
R25/10	5.57	6.56	10.31
R25/2	5.52	0.74	2.748
R25/3	8.07	1.32	7.812
R25/4	9.74	2.34	8.43
R25/5	8.90	2.52	10.57
R25/6	10.28	2.59	11.294
R25/7	2.30	0.26	9.04
R25/8	5.84	1.16	9.376
R25/8a	4.18	1.59	5.7
R25/9	1.39	3.06	6.27
R27/1	32.52	9.28	9.446
R27/2	13.22	6.60	10.638
R27/3	6.70	3.09	8.74
R27/4	9.38	6.12	10.526
R28/2	6.58	2.79	14.2
R29/1	12.12	8.44	9.99
R30/1	3.07	2.61	16.13
R32/1	5.73	4.94	11.428
R33/1	1.44	1.23	12.106
R34/1	4.82	4.36	4.238
R34/2	27.49	12.01	11.316
R34/3	11.81	5.89	9.748
R35/1	1.94	1.58	12.346
R35/2	3.12	2.11	4.256
R36/4	4.92	4.42	16.204
R36/6	3.43	1.93	15.958
R37	17.33	13.83	8.824
R38	19.91	10.87	8.824
R3A/2	24.67	87.28	4.006
R3A/3	0.42	13.09	15.702
R3A/4	31.35	93.60	20.204
R3A/5	8.47	183.79	7.24
R3A/7	2.55	64.43	5.18
R3A/8	1.47	47.34	4.376
R3B/10	2.97	137.69	3.82
R3B/11	2.71	57.25	3.068
R3C/1	10.98	129.93	10.044
R3C/2	9.20	129.28	3.226
R3C/3	0.77	46.32	3.398
R3C/4	0.00	51.05	10.334
R3C/5	0.01	72.75	11.102
R3C/6	2.95	87.75	7.124
R3C/7	3.29	55.84	8.398

APPENDIX B

Critical Duration and Temporal Pattern Analysis

1:10 AEP Storm Event - Critical Duration and Temporal Pattern Analysis

Row Labels	Sum of 1	Sum of 2	Sum of 3	Sum of 4	Sum of 5	Sum of 6	Sum of 7	Sum of 8	Sum of 9	Sum of 10
A15	**1471.4**	**1399.3**	**1258.6**	**1290.8**	**1229.4**	**1428.2**	**1268.6**	**1311.8**	**1363.4**	**1785.4**
30.0	133.3	126.0	133.0	132.6	120.2	139.7	134.4	131.9	92.5	151.2
60.0	136.0	144.3	145.0	144.4	140.2	128.5	124.7	126.9	133.6	122.1
90.0	169.9	162.1	165.2	130.7	147.9	132.1	140.0	147.0	133.7	162.0
120.0	154.9	154.0	143.2	161.0	122.1	157.2	121.4	152.9	148.8	162.8
180.0	165.9	122.7	102.2	127.7	120.5	149.2	110.5	150.0	119.5	180.1
270.0	103.3	104.5	124.3	134.7	137.0	135.8	111.7	138.5	179.6	236.0
360.0	106.9	129.1	151.2	161.5	166.4	183.7	130.8	124.9	147.8	226.1
540.0	131.0	79.6	146.6	124.5	89.1	113.1	126.9	162.0	143.4	194.2
720.0	259.5	251.7	68.3	77.1	115.1	79.3	124.9	92.9	123.0	179.0
1080.0	110.8	125.4	79.6	96.6	70.9	209.7	143.5	84.9	141.5	171.7
A25	**201.7**	**195.5**	**167.0**	**172.2**	**169.0**	**187.5**	**179.4**	**186.4**	**201.1**	**235.6**
30.0	18.1	14.8	16.5	16.4	15.3	17.2	14.1	13.6	10.7	13.4
60.0	15.8	14.1	16.0	13.9	16.3	13.9	13.1	14.9	14.3	14.9
90.0	18.4	17.2	16.8	13.8	15.4	13.4	13.1	13.2	15.3	17.8
120.0	13.5	14.5	12.1	14.2	10.5	14.0	16.4	15.4	17.3	18.4
180.0	17.5	14.6	15.2	17.6	14.7	15.0	16.6	21.2	17.6	20.7
270.0	18.0	17.5	18.6	17.9	18.1	16.7	19.6	19.1	25.7	25.6
360.0	18.4	17.8	18.6	23.6	24.2	20.3	18.8	17.7	24.6	27.8
540.0	23.4	16.3	25.8	26.5	18.0	20.0	17.9	32.5	27.2	36.2
720.0	43.1	40.1	12.8	12.0	24.7	17.3	24.7	19.3	21.9	34.7
1080.0	15.5	28.5	14.5	16.2	11.7	39.8	24.9	19.3	26.5	26.0
A26	**1776.3**	**1747.5**	**1548.0**	**1601.5**	**1540.8**	**1805.3**	**1578.4**	**1650.3**	**1757.2**	**2158.3**
30.0	133.3	126.0	133.0	132.6	120.2	139.7	134.4	131.9	92.5	151.2
60.0	140.4	148.8	149.4	148.8	145.0	133.2	129.3	131.6	138.1	126.4
90.0	187.8	179.6	180.3	163.0	162.9	146.5	154.8	162.3	149.0	177.3
120.0	179.0	179.9	174.4	189.2	151.8	180.6	140.4	177.1	169.9	182.9
180.0	197.5	156.8	138.0	157.4	153.1	184.7	149.8	176.5	160.4	210.6
270.0	131.8	136.8	164.8	178.9	190.1	185.3	140.9	178.4	222.4	278.7
360.0	143.8	163.0	202.0	208.8	211.6	243.1	187.6	174.6	218.5	275.7
540.0	197.9	121.7	201.9	195.4	139.1	159.2	175.7	242.1	217.5	257.0
720.0	309.6	339.5	91.8	101.5	168.1	128.9	159.9	144.1	187.3	259.7
1080.0	155.4	195.3	112.3	125.9	99.0	304.1	205.6	131.6	201.7	238.7
D16	**379.8**	**336.0**	**310.0**	**313.0**	**288.5**	**334.2**	**305.7**	**308.2**	**338.2**	**427.5**
30.0	49.8	41.8	45.2	44.7	38.2	49.5	46.2	43.8	39.6	54.5
60.0	47.4	43.3	42.0	44.4	41.2	38.8	38.1	35.9	44.0	39.1
90.0	49.2	45.3	46.5	35.5	41.7	37.5	37.7	38.7	41.0	49.1
120.0	38.1	37.8	35.4	43.5	27.9	38.3	33.7	38.0	37.1	44.6
180.0	37.6	28.3	25.7	27.4	27.3	33.1	27.7	38.1	25.9	44.2
270.0	30.5	24.3	24.5	25.1	30.1	29.4	24.0	27.6	51.9	49.8
360.0	26.2	32.7	31.2	30.9	33.1	40.0	24.8	24.0	28.1	47.6
540.0	21.2	17.4	28.6	23.4	14.4	20.8	23.7	30.4	26.4	36.5
720.0	59.0	43.7	16.4	19.2	21.1	13.6	25.5	16.1	20.5	31.4
1080.0	20.9	21.5	14.5	19.0	13.6	33.3	24.1	15.5	23.6	30.7
D35	**475.2**	**434.2**	**400.7**	**400.4**	**371.8**	**419.1**	**379.7**	**378.5**	**439.3**	**528.5**
30.0	62.9	58.0	62.0	62.1	56.9	65.8	63.2	62.9	56.0	78.4
60.0	56.9	58.0	62.9	60.8	57.8	52.1	51.2	48.6	59.0	52.0
90.0	65.7	60.3	60.6	45.2	50.4	43.5	48.4	48.5	50.8	50.6
120.0	47.2	52.7	45.1	59.6	36.0	50.8	39.1	44.6	50.8	57.4
180.0	46.6	36.3	32.9	33.1	36.6	40.4	36.1	45.3	30.9	54.9
270.0	39.9	30.3	29.3	29.0	37.2	37.1	28.3	31.0	67.2	64.2
360.0	33.2	42.8	38.4	36.9	40.0	51.6	28.9	26.9	36.0	59.1
540.0	22.8	22.2	32.3	26.6	15.9	23.8	26.4	34.3	37.1	40.6
720.0	74.8	50.2	21.7	24.8	24.0	17.1	30.5	19.3	24.3	35.2
1080.0	25.2	23.5	15.5	22.4	17.0	36.9	27.8	17.1	27.2	36.2
D40	**1438.1**	**1360.5**	**1226.3**	**1256.0**	**1192.8**	**1383.9**	**1233.6**	**1274.4**	**1318.1**	**1743.3**
30.0	133.3	126.0	133.0	132.6	120.2	139.7	134.4	131.9	92.5	151.2
60.0	135.3	143.6	144.3	143.8	139.5	127.7	124.0	126.2	132.9	121.4
90.0	167.6	159.6	162.9	128.0	145.8	130.1	137.9	144.7	131.5	159.9
120.0	151.5	150.3	139.4	157.2	118.4	154.0	119.2	149.5	146.2	160.4
180.0	162.1	118.6	98.6	124.3	116.5	144.8	106.2	147.2	115.1	176.6
270.0	101.4	101.0	120.0	129.2	129.9	129.6	108.6	134.3	175.2	230.7
360.0	103.6	125.2	145.3	156.0	161.4	176.5	124.1	119.2	139.7	220.4
540.0	123.2	75.0	140.4	116.4	83.3	107.8	121.5	154.3	134.2	187.7
720.0	254.3	242.1	66.3	75.0	110.1	73.8	121.1	86.6	116.0	170.7
1080.0	105.7	119.1	76.2	93.5	67.8	199.9	136.7	80.6	135.0	164.4
D7	**139.8**	**122.4**	**114.4**	**113.5**	**103.4**	**111.8**	**105.8**	**104.4**	**120.4**	**138.7**
30.0	24.6	20.8	20.3	19.8	16.6	22.9	19.3	17.7	16.6	18.1
60.0	21.7	15.8	15.2	16.4	17.2	14.8	14.3	14.8	17.0	19.4
90.0	21.1	20.6	18.5	15.7	15.9	12.5	12.8	13.3	15.7	21.5
120.0	13.0	14.1	11.8	17.4	8.7	12.5	13.8	15.5	13.6	16.9
180.0	11.7	9.9	9.0	9.5	9.9	9.8	10.7	13.3	9.2	12.9
270.0	11.8	8.3	10.0	7.2	12.3	8.9	8.0	7.5	18.0	14.0
360.0	9.2	11.8	13.0	10.0	8.6	12.4	8.7	6.2	9.5	13.3
540.0	5.3	5.7	7.6	6.3	4.4	6.1	5.7	7.6	9.7	7.9
720.0	16.0	10.4	5.5	6.2	5.4	4.5	6.8	4.7	5.6	7.2
1080.0	5.4	5.1	3.5	4.9	4.4	7.3	5.8	3.8	5.7	7.4
G31	**138.5**	**120.3**	**115.1**	**118.8**	**108.1**	**122.3**	**118.0**	**120.0**	**129.8**	**171.3**
30.0	13.7	12.7	13.2	13.3	12.3	13.8	13.2	13.4	13.5	19.2
60.0	14.7	14.4	15.0	14.7	14.2	13.2	13.2	13.3	13.4	12.4
90.0	14.7	14.0	14.8	12.3	14.5	13.3	13.3	13.2	13.3	15.8
120.0	13.0	13.1	12.4	14.5	9.7	13.4	13.9	12.4	15.1	16.6
180.0	16.1	9.7	9.0	12.5	10.0	11.9	10.5	17.0	10.9	18.2
270.0	10.3	8.3	10.8	11.2	10.7	10.3	10.9	12.2	22.3	20.8
360.0	10.1	11.9	14.3	14.4	15.1	16.2	9.6	10.5	10.8	22.4
540.0	9.4	6.0	12.9	10.3	6.2	9.5	10.6	13.8	10.6	16.9
720.0	26.7	20.7	6.4	6.7	9.3	5.4	11.5	7.3	9.0	14.3
1080.0	9.7	9.6	6.4	8.9	6.0	15.3	11.3	6.9	11.0	14.5
R3A/7	**985.5**	**902.7**	**827.6**	**841.2**	**784.5**	**908.1**	**819.1**	**846.8**	**860.9**	**1172.7**
30.0	106.6	98.3	105.1	104.8	92.9	109.5	105.7	103.3	75.8	127.1
60.0	104.2	107.0	108.6	108.5	105.2	94.2	93.5	91.2	102.5	91.9
90.0	120.8	111.2	117.9	86.4	104.6	92.8	97.9	101.2	95.4	118.6
120.0	102.3	100.7	91.8	109.0	75.6	105.4	80.5	100.7	101.2	111.3
180.0	107.5	78.0	66.3	79.6	71.5	93.1	70.1	99.7	70.6	118.7
270.0	73.4	65.2	72.6	78.0	80.7	81.4	70.2	83.1	116.2	151.2
360.0	69.4	85.2	91.2	94.4	99.8	112.6	72.7	72.6	81.3	141.9
540.0	69.7	45.1	85.9	71.3	46.7	65.5	73.1	95.5	75.4	113.3
720.0	167.5	142.7	43.4	50.6	66.0	41.0	76.2	51.2	64.9	101.3
1080.0	64.1	69.4	44.9	58.6	41.4	112.6	79.2	48.3	77.5	97.5
A23	**172.9**	**168.5**	**143.3**	**148.0**	**142.5**	**159.0**	**151.2**	**159.1**	**168.8**	**198.0**
30.0	18.1	14.8	16.5	16.4	15.3	17.2	14.1	13.6	10.7	13.4
60.0	15.4	13.8	15.7	13.6	15.9	13.5	12.8	14.5	13.9	14.5
90.0	17.8	16.5	15.6	12.6	14.0	12.0	11.7	11.8	13.9	16.3
120.0	11.6	13.5	10.6	13.5	8.4	11.9	14.2	13.3	15.0	16.1
180.0	14.0	12.2	12.3	14.3	11.5	11.9	13.5	17.7	14.3	17.1
270.0	14.4	14.3	15.0	13.8	14.7	13.3	15.9	15.3	20.7	20.4
360.0	14.8	14.6	14.9	19.2	18.8	16.3	14.7	14.8	20.0	22.3
540.0	18.4	13.5	20.5	21.7	14.3	16.1	13.9	26.3	22.2	29.6
720.0	35.8	32.4	10.6	9.9	20.0	13.8	20.4	16.1	17.2	27.6
1080.0	12.6	23.0	11.8	13.2	9.5	32.8	19.9	15.8	20.9	20.5
Grand Total	**7179.2**	**6787.0**	**6110.9**	**6255.4**	**5930.8**	**6859.4**	**6139.5**	**6339.8**	**6697.3**	**8559.2**

A15	**AVERAGE**
30.0	129.5
60.0	134.6
90.0	149.0
120.0	147.8
180.0	134.8
270.0	140.6
360.0	152.8
540.0	131.0
720.0	137.1
1080.0	123.5
A25	
30.0	15.0
60.0	14.7
90.0	15.4
120.0	14.6
180.0	17.1
270.0	19.7
360.0	21.2
540.0	24.4
720.0	25.1
1080.0	22.3
A26	
30.0	129.5
60.0	139.1
90.0	166.3
120.0	172.5
180.0	168.5
270.0	180.8
360.0	202.9
540.0	190.8
720.0	189.0
1080.0	177.0
D16	
30.0	45.3
60.0	41.4
90.0	42.2
120.0	37.5
180.0	31.5
270.0	31.7
360.0	31.9
540.0	24.3
720.0	26.6
1080.0	21.7
D35	
30.0	62.8
60.0	55.9
90.0	52.4
120.0	48.3
180.0	39.3
270.0	39.3
360.0	39.4
540.0	28.2
720.0	32.2
1080.0	24.9
D40	
30.0	129.5
60.0	133.9
90.0	146.8
120.0	144.6
180.0	131.0
270.0	136.0
360.0	147.1
540.0	124.4
720.0	131.6
1080.0	117.9
D7	
30.0	19.7
60.0	16.7
90.0	16.8
120.0	13.7
180.0	10.6
270.0	10.6
360.0	10.3
540.0	6.6
720.0	7.2
1080.0	5.3
G31	
30.0	13.8
60.0	13.8
90.0	13.9
120.0	13.4
180.0	12.6
270.0	12.8
360.0	13.6
540.0	10.6
720.0	11.7
1080.0	9.9
R3A/7	
30.0	102.9
60.0	100.7
90.0	104.7
120.0	97.9
180.0	85.5
270.0	87.2
360.0	92.1
540.0	74.2
720.0	80.5
1080.0	69.3
A23	
30.0	15.0
60.0	14.4
90.0	14.2
120.0	12.8
180.0	13.9
270.0	15.8
360.0	17.0
540.0	19.7
720.0	20.4
1080.0	18.0

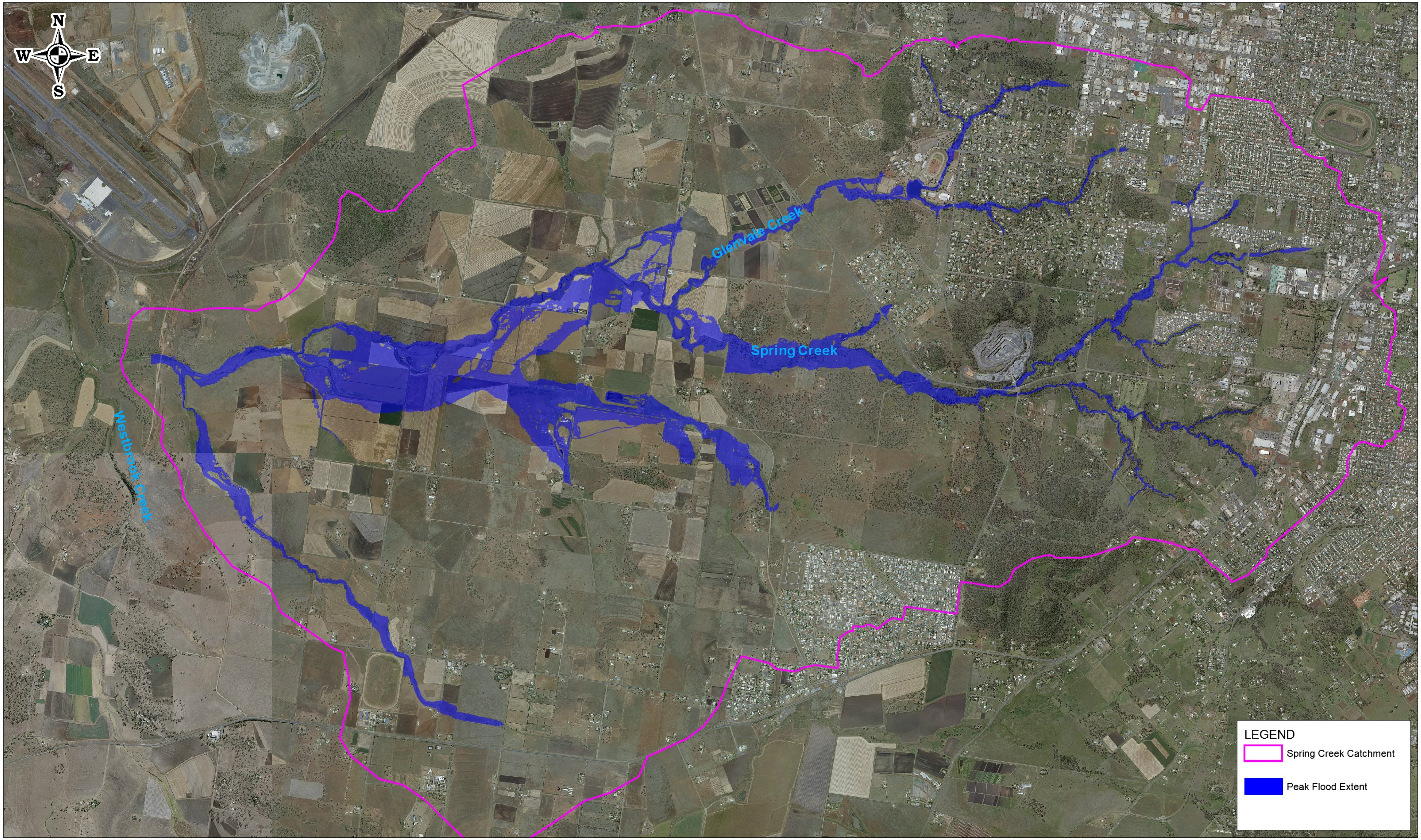
1:100 AEP Storm Event - Critical Duration and Temporal Pattern Analysis

Row Labels	Sum of 1	Sum of 2	Sum of 3	Sum of 4	Sum of 5	Sum of 6	Sum of 7	Sum of 8	Sum of 9	Sum of 10
A15	**1931.0**	**2080.0**	**1928.5**	**2101.5**	**2102.8**	**1976.4**	**1861.8**	**1985.4**	**1806.3**	**2324.9**
30	224.2	221.5	234.4	228.3	248.1	242.7	224.6	229.8	177.1	260.4
60	334.0	311.9	280.7	282.0	293.8	286.8	270.1	263.6	262.0	311.1
90	337.4	339.4	308.7	369.6	308.0	318.7	338.7	313.5	307.5	414.5
120	284.2	322.6	279.3	350.2	325.0	336.8	275.8	331.4	321.0	389.5
180	289.5	355.6	362.2	343.8	317.3	339.5	293.5	277.2	281.5	276.7
270	254.6	298.6	208.5	300.6	256.2	213.1	265.8	258.9	275.4	375.3
360	207.1	230.4	254.7	227.1	354.5	238.9	193.3	311.1	181.9	297.3
A25	**293.8**	**304.1**	**295.6**	**307.4**	**318.7**	**299.9**	**291.0**	**308.9**	**308.3**	**341.9**
30	23.0	27.0	27.7	29.0	32.3	25.6	22.1	27.4	25.3	25.1
60	39.4	35.7	31.7	40.7	31.3	31.5	35.2	34.3	33.1	32.7
90	41.9	44.9	43.1	44.5	42.9	46.7	47.2	45.0	50.6	52.3
120	46.5	43.6	46.0	45.9	47.3	59.6	55.5	48.7	55.1	50.0
180	46.1	65.8	57.3	46.7	44.2	52.3	48.6	40.2	50.1	56.2
270	53.3	52.7	45.4	56.6	48.4	37.0	38.4	50.9	54.2	65.7
360	43.5	34.4	44.4	43.9	72.2	47.1	43.8	62.2	39.9	59.9
A26	**2517.2**	**2639.8**	**2550.8**	**2662.4**	**2608.8**	**2500.3**	**2383.5**	**2572.3**	**2384.2**	**2908.4**
30	242.5	240.1	252.8	246.5	266.3	260.0	243.0	246.7	196.2	278.4
60	383.9	362.0	329.3	323.0	345.3	340.5	313.9	318.4	313.9	366.2
90	421.6	410.6	410.6	439.0	384.2	431.2	398.6	374.1	387.1	480.3
120	398.7	426.8	405.1	425.1	399.1	401.3	358.5	409.5	407.8	480.0
180	410.5	436.6	462.8	442.3	421.3	443.9	413.1	384.8	399.5	405.1
270	332.8	433.4	335.2	431.2	327.0	312.2	355.0	389.9	387.0	472.8
360	327.2	330.4	355.0	355.4	465.8	311.2	301.6	448.9	292.8	425.7
D16	**409.7**	**453.6**	**406.8**	**464.1**	**457.8**	**439.5**	**432.6**	**416.0**	**453.7**	**503.6**
30	63.3	66.0	72.9	67.2	77.4	72.0	67.4	71.5	63.8	84.7
60	82.5	77.6	65.6	79.2	66.5	64.5	71.4	58.7	70.8	66.8
90	66.0	69.1	59.0	79.4	64.2	75.7	76.9	70.0	77.9	98.2
120	56.3	61.5	52.1	72.2	65.2	76.1	72.0	64.0	80.5	75.2
180	50.4	79.1	66.6	73.5	61.6	64.5	49.8	55.8	54.4	62.5
270	54.2	52.5	39.9	50.3	51.7	39.4	60.3	39.9	61.3	69.7
360	36.9	47.8	50.7	42.4	71.2	47.3	34.7	56.1	45.1	46.4
D35	**543.2**	**561.7**	**510.4**	**582.3**	**563.5**	**545.4**	**524.6**	**497.7**	**590.7**	**654.9**
30	90.1	89.0	92.9	94.4	100.1	94.9	92.2	92.5	94.7	121.1
60	109.1	93.6	79.8	94.9	89.3	83.9	86.0	73.9	92.3	89.6
90	87.9	86.9	80.4	103.6	74.3	91.6	95.6	83.9	102.3	141.0
120	76.3	77.5	70.2	89.2	77.7	91.1	85.2	75.6	107.0	97.6
180	61.0	98.3	75.5	89.7	71.4	78.4	55.3	64.2	63.8	72.4
270	66.7	60.5	50.7	55.6	65.7	52.7	72.1	44.3	72.7	81.2
360	52.1	55.8	60.9	54.8	84.9	52.7	38.1	63.2	58.0	51.9
D40	**1864.1**	**2019.4**	**1865.5**	**2039.6**	**2049.1**	**1920.1**	**1810.7**	**1925.3**	**1746.4**	**2261.1**
30	221.8	219.0	232.1	226.0	245.8	240.5	222.3	227.8	174.4	257.9
60	328.2	306.1	275.2	278.1	287.9	280.4	265.3	257.0	256.5	304.0
90	328.2	331.5	297.6	362.1	299.6	306.6	332.3	307.4	299.8	407.1
120	269.4	311.3	271.6	342.1	317.1	330.1	270.8	322.9	312.2	379.1
180	274.4	348.1	351.6	332.9	305.3	328.7	281.0	265.2	271.3	263.6
270	248.6	283.2	194.1	287.2	248.8	202.8	256.4	244.8	263.2	366.4
360	193.4	220.3	243.4	211.4	344.6	231.2	182.6	300.2	169.1	282.8
D7	**140.4**	**143.7**	**138.2**	**149.5**	**146.8**	**154.0**	**133.4**	**124.1**	**158.0**	**136.8**
30	22.9	24.2	28.8	28.8	35.5	28.6	25.3	30.6	34.0	26.7
60	32.7	29.3	20.0	27.9	23.2	24.3	23.3	17.9	23.7	18.6
90	22.6	23.1	23.1	25.0	21.1	33.0	20.5	17.5	26.3	28.2
120	19.5	21.3	20.6	19.4	16.3	25.6	24.2	22.1	25.6	19.8
180	15.2	19.4	15.4	20.1	16.5	16.4	12.3	13.3	13.6	16.8
270	14.8	13.5	16.3	14.6	17.0	13.4	17.9	10.0	19.5	15.9
360	12.8	13.0	14.1	13.7	17.2	12.7	9.9	12.9	15.3	10.8
G31	**171.7**	**187.2**	**173.3**	**197.1**	**200.1**	**181.2**	**177.4**	**184.4**	**195.6**	**216.8**
30	23.2	20.1	26.1	25.7	28.3	27.1	24.4	28.7	21.0	29.2
60	35.5	29.6	27.5	31.8	28.0	25.9	27.3	26.3	30.4	29.4
90	29.4	30.9	26.2	35.5	28.9	27.0	33.9	31.2	35.0	43.5
120	20.8	27.0	24.5	31.1	29.4	34.2	28.7	29.5	37.0	33.9
180	22.4	36.1	30.0	32.2	28.0	28.1	22.4	24.8	25.1	26.7
270	25.3	23.5	15.4	23.4	24.5	17.0	24.9	18.4	28.9	32.7
360	15.2	20.1	23.5	17.4	33.1	21.8	15.9	25.6	18.2	21.4
R3A/7	**1185.3**	**1305.6**	**1176.7**	**1319.0**	**1328.4**	**1231.9**	**1194.1**	**1226.8**	**1143.0**	**1470.4**
30	162.1	162.7	170.7	165.3	179.9	176.9	162.0	167.5	133.5	205.5
60	222.4	210.5	185.5	195.6	194.1	187.8	180.1	171.6	168.7	203.8
90	207.6	213.2	179.2	239.7	188.5	191.4	222.8	204.7	200.8	282.4
120	162.4	189.7	166.6	220.1	202.5	217.8	190.1	202.6	210.2	227.3
180	158.6	230.5	212.4	212.0	189.2	196.1	161.5	163.0	153.6	170.5
270	162.1	162.8	110.9	162.5	157.1	119.5	168.9	136.3	166.2	222.7
360	110.0	136.3	151.4	123.7	217.1	142.5	108.7	181.1	110.0	158.2
A23	**243.4**	**254.6**	**242.4**	**254.9**	**264.4**	**249.8**	**241.0**	**252.7**	**256.4**	**284.4**
30	21.1	25.1	25.7	27.0	30.4	23.8	20.2	25.5	23.5	23.3
60	33.1	29.4	25.9	34.6	25.5	25.6	29.1	28.5	26.9	26.7
90	32.7	36.3	34.8	34.9	34.8	39.3	37.5	35.6	42.0	42.9
120	39.3	36.8	37.2	38.4	38.4	49.9	47.3	39.0	45.4	40.6
180	38.2	55.2	47.0	36.5	34.9	43.7	39.5	32.2	41.8	47.1
270	44.6	42.7	36.3	49.0	39.7	29.5	32.0	41.3	44.0	55.1
360	34.4	29.0	35.6	34.6	60.7	38.1	35.4	50.5	32.9	48.8
Grand Total	**9299.7**	**9949.7**	**9288.2**	**10077.8**	**10040.3**	**9498.3**	**9050.0**	**9493.7**	**9042.5**	**11103.2**

	AVERAGE
A15	
30	229.1
60	289.6
90	335.6
120	321.6
180	313.7
270	270.7
360	249.6
A25	
30	26.5
60	34.6
90	45.9
120	49.8
180	50.8
270	50.3
360	49.1
A26	
30	247.2
60	339.6
90	413.7
120	411.2
180	422.0
270	377.6
360	361.4
D16	
30	70.6
60	70.4
90	73.6
120	67.5
180	61.8
270	51.9
360	47.9
D35	
30	96.2
60	89.2
90	94.7
120	84.7
180	73.0
270	62.2
360	57.3
D40	
30	226.8
60	283.9
90	327.2
120	312.6
180	302.2
270	259.5
360	237.9
D7	
30	28.5
60	24.1
90	24.0
120	21.5
180	15.9
270	15.3
360	13.2
G31	
30	25.4
60	29.2
90	32.1
120	29.6
180	27.6
270	23.4
360	21.2
R3A/7	
30	168.6
60	192.0
90	213.0
120	198.9
180	184.7
270	156.9
360	143.9
A23	
30	24.6
60	28.5
90	37.1
120	41.2
180	41.6
270	41.4
360	40.0

APPENDIX C

Flood Mapping



Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
P: 07 3221 7174
F: 07 3236 2399
E: admin@engeny.com.au
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WATER MANAGEMENT

TOOWOOMBA REGIONAL COUNCIL

0 700 1400
Scale in Metres (1:35,000 @ A3)

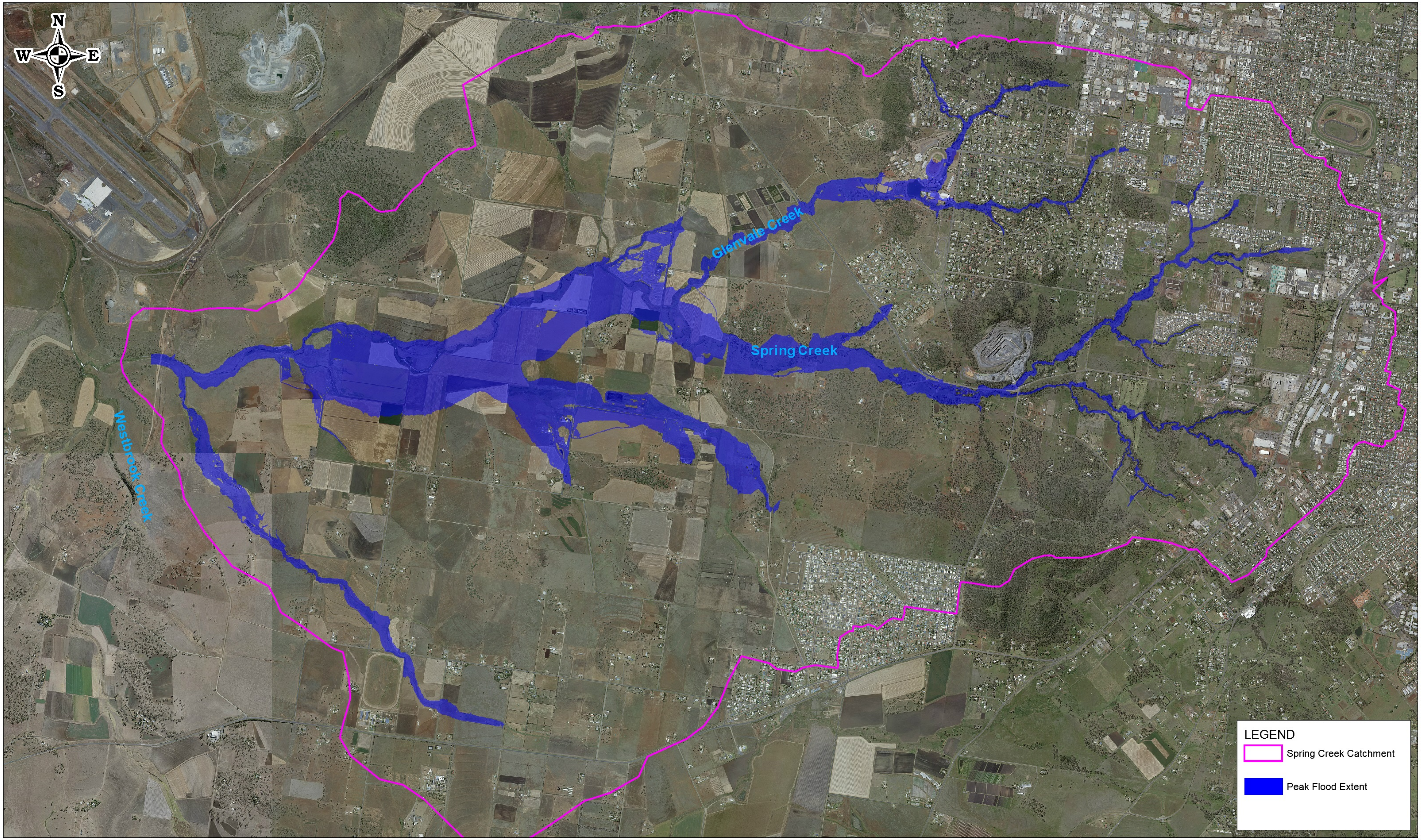
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Spring Creek Flood Study Update

Figure C1

Peak Flood Extent - 10% AEP Storm Event

Job Number: M34000_046
Revision: 1
Drawn: AJ
Date: 27 Apr 2017



Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
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F: 07 3236 2399
E: admin@engeny.com.au

ENGENY WATER MANAGEMENT

TOOWOOMBA REGIONAL COUNCIL

0 700 1400
Scale in Metres (1:35,000 @ A3)

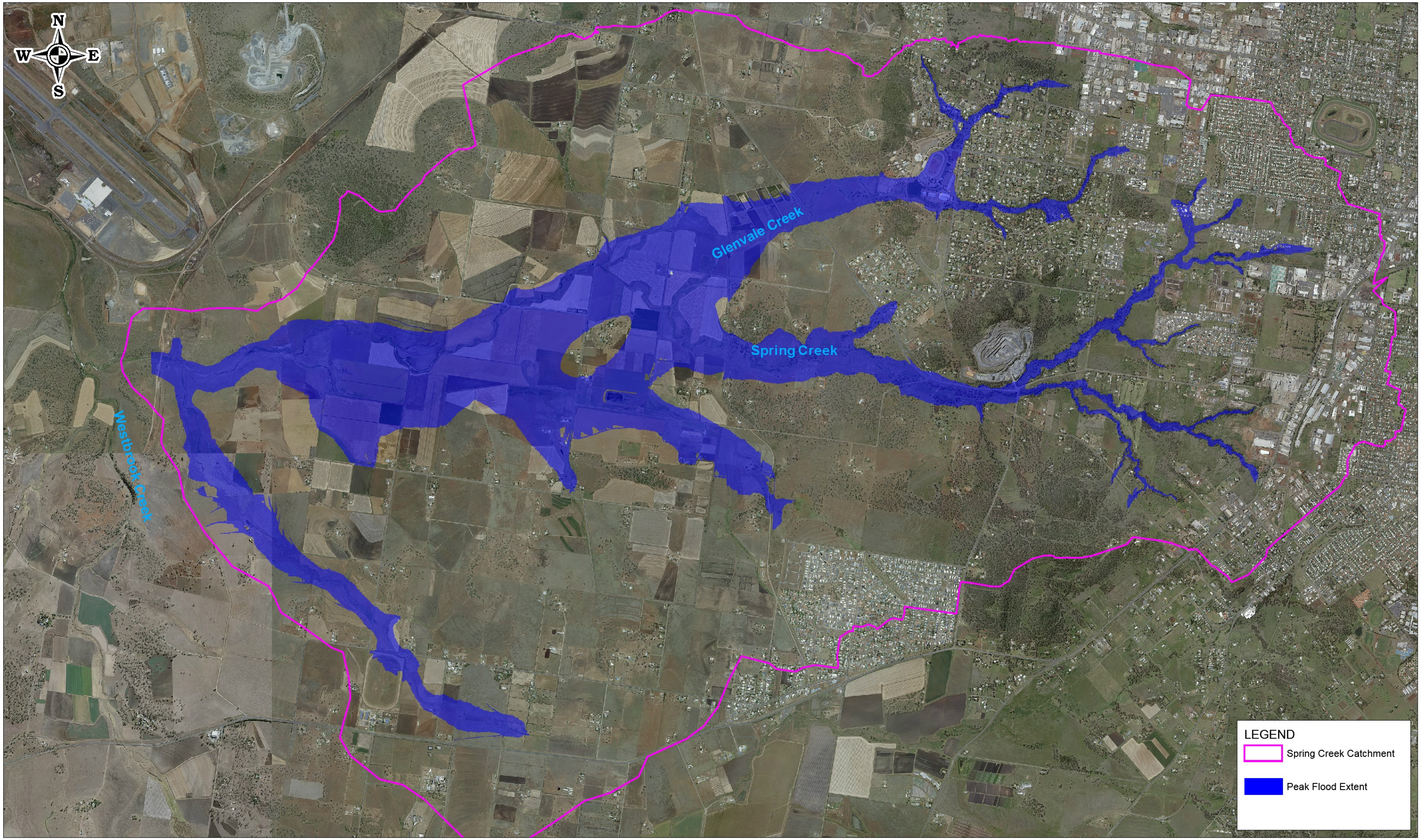
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Spring Creek Flood Study Update

Figure C2

Peak Flood Extent - 1% AEP Storm Event

Job Number: M34000_046
Revision: 1
Drawn: AJ
Date: 27 Apr 2017



Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
P: 07 3221 7174
F: 07 3236 2399
E: admin@engeny.com.au
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TOOWOOMBA REGIONAL COUNCIL

0 700 1400

Scale in Metres (1:35,000 @ A3)

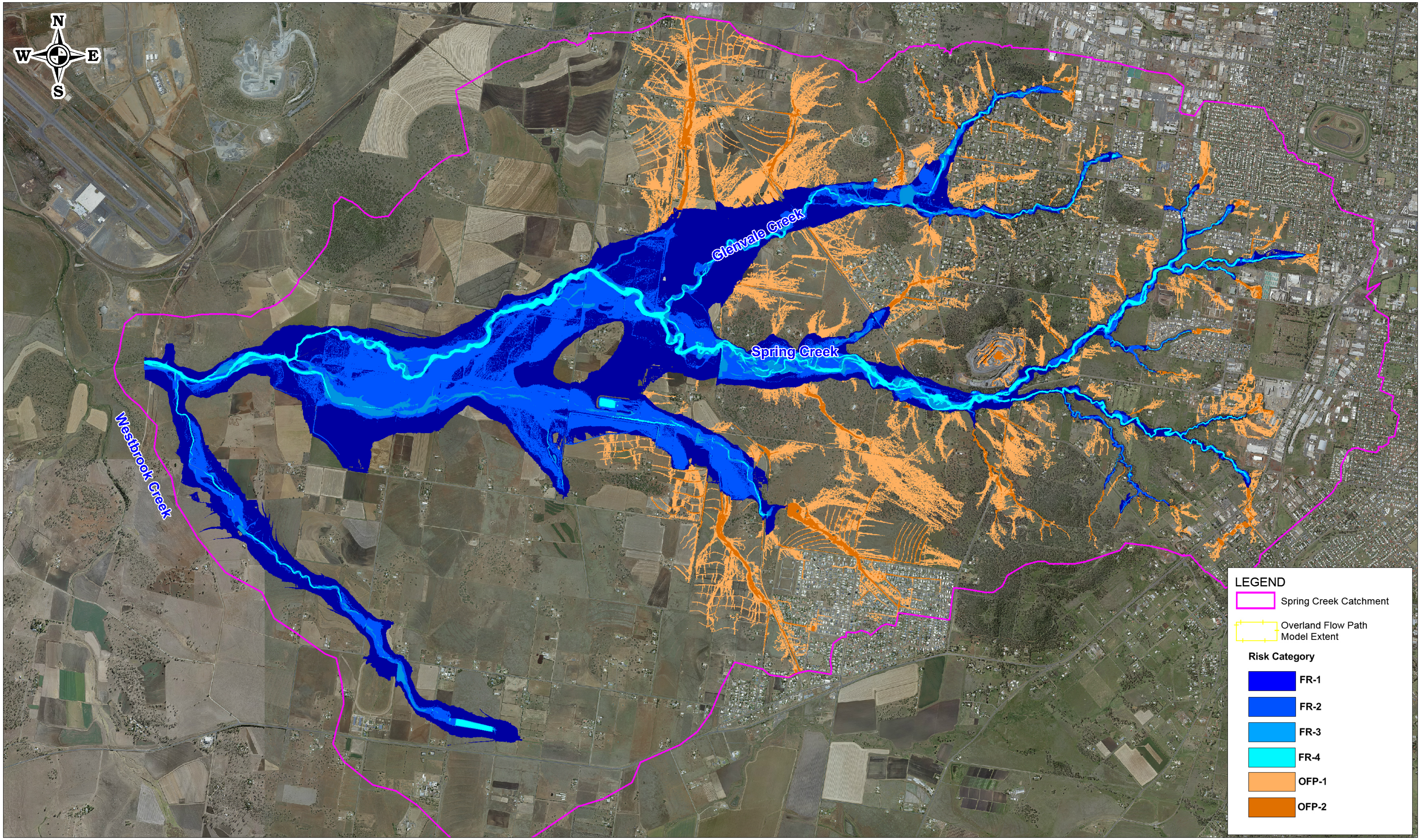
Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Spring Creek Flood Study Update

Figure C3

Peak Flood Extent - PMF

Job Number: M34000_046
Revision: 1
Drawn: AJ
Date: 27 Apr 2017



Level 11, 344 Queen St, Brisbane QLD 4000
PO Box 10183 Brisbane QLD 4000
www.engeny.com.au
P: 07 3221 7174
F: 07 3236 2399
E: admin@engeny.com.au

ENGENY WATER MANAGEMENT

TOOWOOMBA REGIONAL COUNCIL

0 700 1400
Scale in Metres (1:35,000 @ A3)

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994. (GDA94)
Vertical Datum: Australia Height Datum
Grid: Map Grid of Australia, Zone 56

Spring Creek Flood Study Update

Figure C4

Flood Risk Map

Job Number: M34000_046
Revision: 0
Drawn: GH
Date: 26 May 2017

TOOWOOMBA REGION

131 872 | info@tr.qld.gov.au | www.tr.qld.gov.au
PO Box 3021 Toowoomba QLD 4350 | Toowoomba Regional Council