Report

Flood Hydrology Technical Report

Red Hill Mining Lease EIS

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Prepared for

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URS

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Abbreviations

Acronym	Definition
ACARP	Australian Coal Association Research Program
AEP	Annual Exceedence Probabilities
ARI	average recurrence interval
AR&R	Australian Rainfall and Runoff
AUS-IFD	Australian Intensity-Frequency-Duration Program
AVM	Average Variability Method
BMA	BHP Billiton Mitsubishi Alliance
BOM	Bureau of Meteorology
DEM	Digital Elevation Model
GIS	Geographic Information Systems
GRB	Goonyella, Riverside and Broadmeadow
GRM	Goonyella Riverside Mine
GSDM	Generalised Short Duration Method
IFD	intensity-frequency-duration
MAF	Mean Annual Flood
NASA	National Aeronautics and Space Administration
PMP	Probable Maximum Flood
QRT	Quantile Regression Technique
QRT-OLS	Quantile Regression Technique based on Ordinary Least Squares
RORB	runoff-routing computer program
SRTM	Shuttle Radar Topography Mission
URS	URS Australia Pty Ltd

Executive Summary

Unit	Definition
%	per cent
hr	hour
K_c	main routing parameter for the overall catchment
km^2	square kilometre
K_{rj}	relative reach routing parameter for the specific reach
m	dimensionless exponent for non-linear routing
m^3	cubic metres
m^3/s	cubic metres per second
min	minute
mm	millimetre
mm/hr	millimetres per hour
Q	discharge (m^3/s)
S	storage in reach

Executive Summary

Background and Study Catchment

A hydrologic assessment of the defined watercourses traversing the existing Goonyella Riverside and Broadmeadow mine complex and environmental impact statement (EIS) study area was undertaken to estimate design flood flows for these watercourses. The catchments included in the assessment were Isaac River, Eureka Creek, Goonyella Creek, 12 Mile Gully, Fisher Creek and Platypus Creek. The hydrology study for the Red Hill Mining Lease (the project) was based on and further refined from previous comprehensive hydrologic assessment of the Isaac River (Alluvium 2008). Additional hydrologic modelling was conducted for the tributaries of the Isaac River within the EIS study area using similar techniques as employed by Alluvium.

To assess flood risks, design flood estimates from rare to extreme floods were evaluated. The hydrology study considered a wide range of design flood estimates with Annual Exceedence Probabilities (AEP) ranging up to the 1 in 2,000 AEP event. These included the 1 in 10, 1 in 20, 1 in 50, 1 in 100, 1 in 500, 1 in 1,000, 1 in 2,000 AEP events for Isaac River. For all other tributaries, the events considered were 1 in 2, 1 in 5, 1 in 10, 1 in 20, 1 in 50, 1 in 100, 1 in 500, 1 in 1,000 and 1 in 2,000 AEP events.

The key objective of the hydrology study was to estimate the flood hydrology to support flood modelling assessment of the EIS study area. The process included hydrological assessment of the catchments within the EIS study area and surrounding areas to estimate rainfall frequency and intensity and design peak flow rates at key locations.

Rainfall Runoff Routing Modelling

Rainfall runoff routing modelling was undertaken with RORB software to estimate peak flood flows for the 1 in 10 AEP to more extreme events up to 1 in 2,000 AEP. The models were also used to estimate more frequent flood events (1 in 2 to 1 in 20 AEP) for comparative purposes only. RORB software was selected based on the track record of its use in Australia, suitability for rural catchments, and availability of empirical methods to estimate the RORB routing parameters for catchments where calibration data is not available.

One RORB model was established for the overall Isaac River catchment to the northern lease to just beyond the southern boundary of the project to estimate flood flows for the larger streams. Separate smaller RORB models were established for four tributary systems (Eureka Creek, combined catchment of Holding, Platypus and Fisher Creeks, Goonyella Creek and 12 Mile Gully). Sub-catchment boundaries and reach networks were delineated using a combination of detailed survey data of the project lease (supplied by BHP Billiton Mitsubishi Alliance), and publicly available Queensland Government topographic Geographic Information Systems data and NASA Shuttle Radar Topography Mission data.

Rainfall design storm depths for the RORB modelling were derived from the following sources:

- Australian Rainfall and Runoff (AR&R) (Pilgrim 1987) parameters for frequent events (1 in 2 AEP and 1 in 5 AEP).
- Queensland Cooperative Research Centre for Catchment rainfall estimates for large to extreme events (1 in 100 AEP to 1 in 2,000 AEP).

Temporal patterns, loss rates and routing parameters were estimated based on current engineering hydrologic practices.

Executive Summary

Summary of Peak Flood Flow Estimates

The estimated design peak flood flows for key project locations derived from the hydrology study are summarised in Table ES-1.

Table ES-1 Summary of Peak Flow and Critical Duration Storm Event in Isaac River at Goonyella Gauge and Tributaries at Catchment Outlets

AEP	Isaac River at Goonyella Gauge (m^3/s)	Eureka Creek Outlet (m^3/s)	Holding, Fisher & Platypus Creek Outlet (m^3/s)	Goonyella Creek outlet (m^3/s)	12 Mile Gully Outlet (m^3/s)
1 in 10	810 (18hr)	220 (6hr)	180 (6hr)	280 (6hr)	190 (6hr)
1 in 20	1,070 (18hr)	330 (3hr)	280 (6hr)	400 (6hr)	280 (6hr)
1 in 100	2,030 (24hr)	640 (3hr)	530 (3hr)	770 (3hr)	500 (3hr)
1 in 500	3,410 (18hr)	1,000 (3hr)	850 (3hr)	1,200 (3hr)	800 (3hr)
1 in 1,000	4,040 (18hr)	1,200 (3hr)	1,000 (3hr)	1,400 (3hr)	970 (3hr)
1 in 2,000	5,390 (24hr)	1,400 (3hr)	1,200 (3hr)	1,700 (3hr)	1,200 (3hr)

Introduction

1.1 Background

The Red Hill Mining Lease is located adjacent to the existing Goonyella, Riverside and Broadmeadow (GRB) mine complex in the Bowen Basin, approximately 20 kilometres north of Moranbah and 135 kilometres south-west from Mackay, Queensland.

BHP Billiton Mitsubishi Alliance (BMA), through its joint venture manager, BM Alliance Coal Operations Pty Ltd, proposes to convert the existing Red Hill Mining Lease Application (MLA 70421) to enable the continuation of existing mining operations associated with the GRB mine complex. Specifically, the mining lease conversion will allow for:

- An extension of three longwall panels (14, 15 and 16) of the existing Broadmeadow underground mine (BRM). Key aspects include:
  - No new mining infrastructure is proposed other than infrastructure required for drainage of incidental mine gas (IMG) to enable safe and efficient mining.
  - Management of waste and water produced from drainage of IMG will be integrated with the existing BRM waste and water management systems.
  - The mining of the Broadmeadow extension is to sustain existing production rates of the BRM and will extend the life of mine by approximately one year.
  - The existing BRM workforce will complete all work associated with the extension.
- A future incremental expansion option of the existing Goonyella Riverside Mine (GRM). Key aspects include:
  - underground mining associated with the RHM underground expansion option to target the Goonyella Middle Seam (GMS) on mining lease (ML) 1763;
  - a new mine industrial area (MIA);
  - a coal handling and preparation plant (CHPP) adjacent to the Riverside MIA on MLA1764 and ML1900 − the Red Hill CHPP will consist of up to three 1,200 tonne per hour modules;
  - construction of a drift for mine access;
  - a conveyor system linking RHM to the Red Hill CHPP;
  - associated coal handling infrastructure and stockpiles;
  - a new conveyor linking product coal stockpiles to a new rail load-out facility located on ML1900; and
  - means for providing flood protection to the mine access and MIA, potentially requiring a levee along the west bank of the Isaac River.
- A future Red Hill Mine (RHM) underground expansion option located to the east of the GRB mine complex to target the GMS on MLA70421, as well as development of key infrastructure including:
  - a network of bores and associated surface infrastructure over the underground mine footprint for mine gas pre-drainage (IMG) and management of goaf methane drainage to enable the safe extraction of coal;
  - the proposed mine layout consists of a main drive extending approximately west to east with longwall panels ranging to the north and south;

- a ventilation system for the underground workings;
- a bridge across the Isaac River for all-weather access. This will be located above the main headings, and will also provide a crossing point for other mine related infrastructure including water pipelines and power supply;
- a new accommodation village (Red Hill accommodation village) for the up to 100% remote construction and operational workforces with capacity for up to 3,000 workers; and
- potential production capacity of 14 million tonnes per annum (mtpa) of high quality hard coking coal over a life of 20 to 25 years.

The three project elements described above are collectively referred to as 'the project'.

The proposed RHM underground longwall mine operation will be partially located under the Isaac River and several of its tributaries. The project environmental impact statement (EIS) requires assessment of potential impacts on surface water hydrology and watercourses. The watercourses through the EIS study area also pose environmental management risks to the project from flooding. The design of flood protection works for the proposed underground operations will be important aspects for both risk to the project and risks of environmental impacts. The results of the flood hydrology study will form inputs for the hydraulic flood modelling (refer to the Red Hill Mining Lease EIS Appendix I5) to estimate key flood parameters for base case and impact assessments of the project.

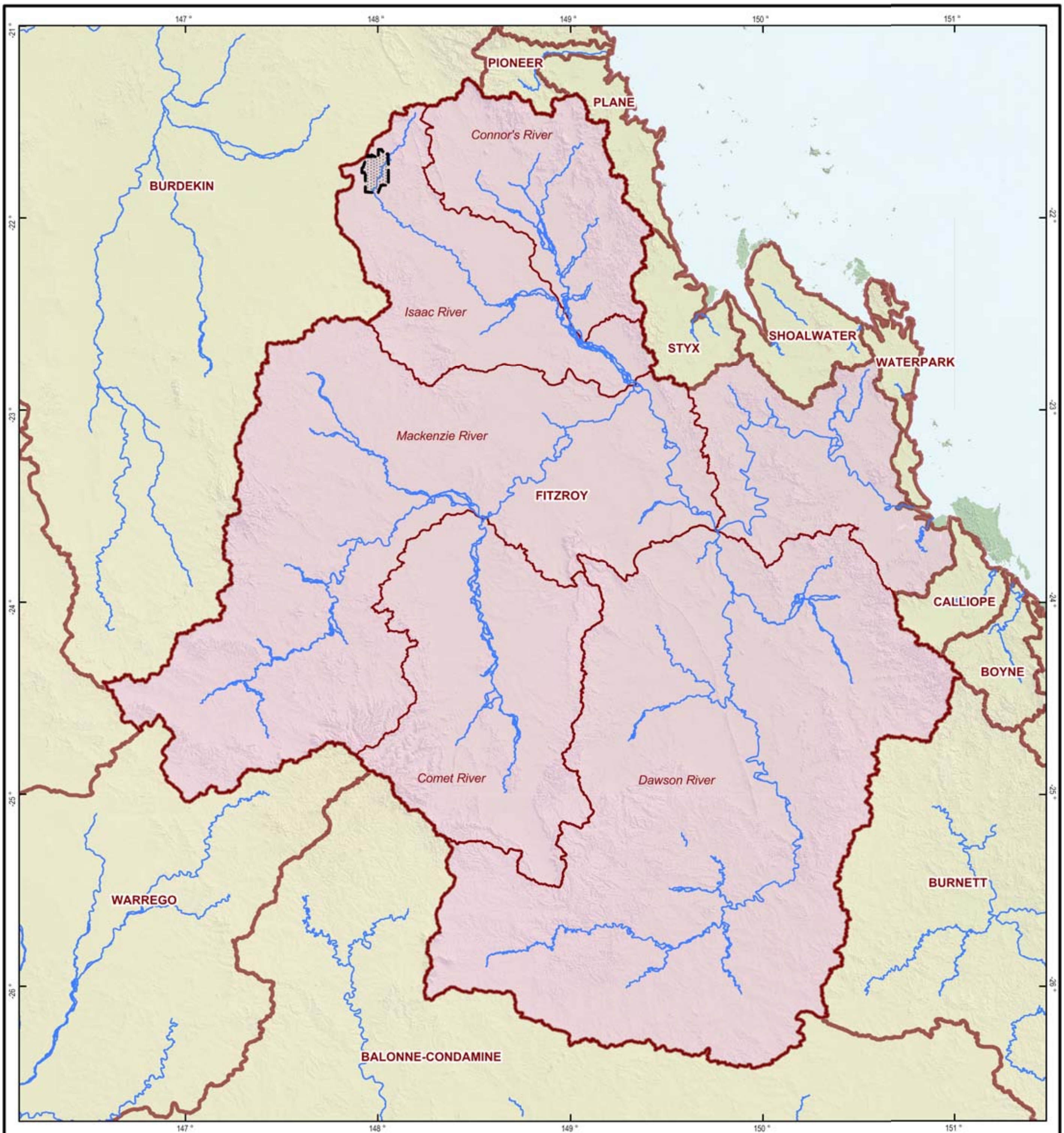
The hydrology study considered a wide range of design flood estimates with Annual Exceedence Probabilities (AEP) ranging from the 1 in 2 year to 1 in 2,000 year AEP events.

Flood hydrology predictions were modelled on the October 2011 mine sequence plan. A new mining sequence has since been developed for the RHM, Broadmeadow extension and the existing approved BRM. Further, the Broadmeadow extension footprint has been revised. This has the potential to alter flood hydrology over the life of mine. However, the mine plan and revised schedule are indicative only and sequencing of production and annual production rates may vary. Regardless of this, the changes are not anticipated to have a significant impact on modelling predictions.

1.2 Site Location and Catchment Context

The project is located within the headwaters of the Isaac-Connors sub-catchment of the greater Fitzroy Basin (refer to Figure 1-1). The Isaac River is the main watercourse traversing the EIS study area and flows south through the site, past Moranbah, and converges with the Connors and Mackenzie Rivers. It eventually joins the Fitzroy River, which flows initially north and then east towards the east coast of Queensland. The Fitzroy River flows into the Coral Sea at Port Alma (adjacent to Casuarina Island).

The Isaac River has a catchment area of approximately 1,215 km^2 at the Goonyella stream gauge located upstream of the existing rail crossing. At a broader regional scale, the greater Isaac-Connors sub-catchment area (at the junction with the Mackenzie River) is approximately 22,000 km^2 and the total Fitzroy Basin catchment area to the coast is approximately 140,000 km^2. From a broad regional context, the EIS study area represents a very small part of greater regional catchments and is located very high in the headwaters of the catchment. The elevation of the Isaac River channel bed in the EIS study area and through the existing GRB mine complex is approximately 230 to 240 m above sea level.



EIS Study Boundary

Fitzroy River Catchment

Subcatchment Boundary

Major Watercourse

0 50 100km

Scale: 1:3,000,000 (A4)

Datum: GDA94

N W E S

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HYDROLOGY TECHNICAL REPORT

REGIONAL CATCHMENT CONTEXT

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SURFACE WATER - HYDROLOGY

Figure: **1-1**

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Methodology

2.1 Overview

There was insufficient reliable stream gauge data available for the watercourses within and upstream of the EIS study area suitable for flood frequency analysis. It is noted that although there are approximately 30 years of data available for the Isaac River gauge at Goonyella (refer to Figure 2-1), this data was not considered 'stationary' for flood frequency analysis because of the influence of Burton Gorge Dam.

The flood hydrology study utilised and compared two different methodologies to estimate the design peak flood flows for the study area watercourses. The methods included:

- Rainfall runoff routing of design rainfall events for the specific EIS study area catchments using RORB modelling software, and relevant empirical methods to estimate the key RORB parameters.
- Validation of the RORB rainfall runoff modelling results with empirical peak flood flow estimation methods including:
  - the Australian Coal Association Research Program (ACARP) (2002 project C9068) empirical equations developed for Central Queensland; and
  - the recently developed Queensland Quantile Regression Technique based on Ordinary Least Squares (QRT-OLS) empirical equations for the Australian Rainfall & Runoff Revision Project (Rahman 2009).

Flood hydrologic models were developed for the larger Isaac River catchment, then for the smaller tributaries.

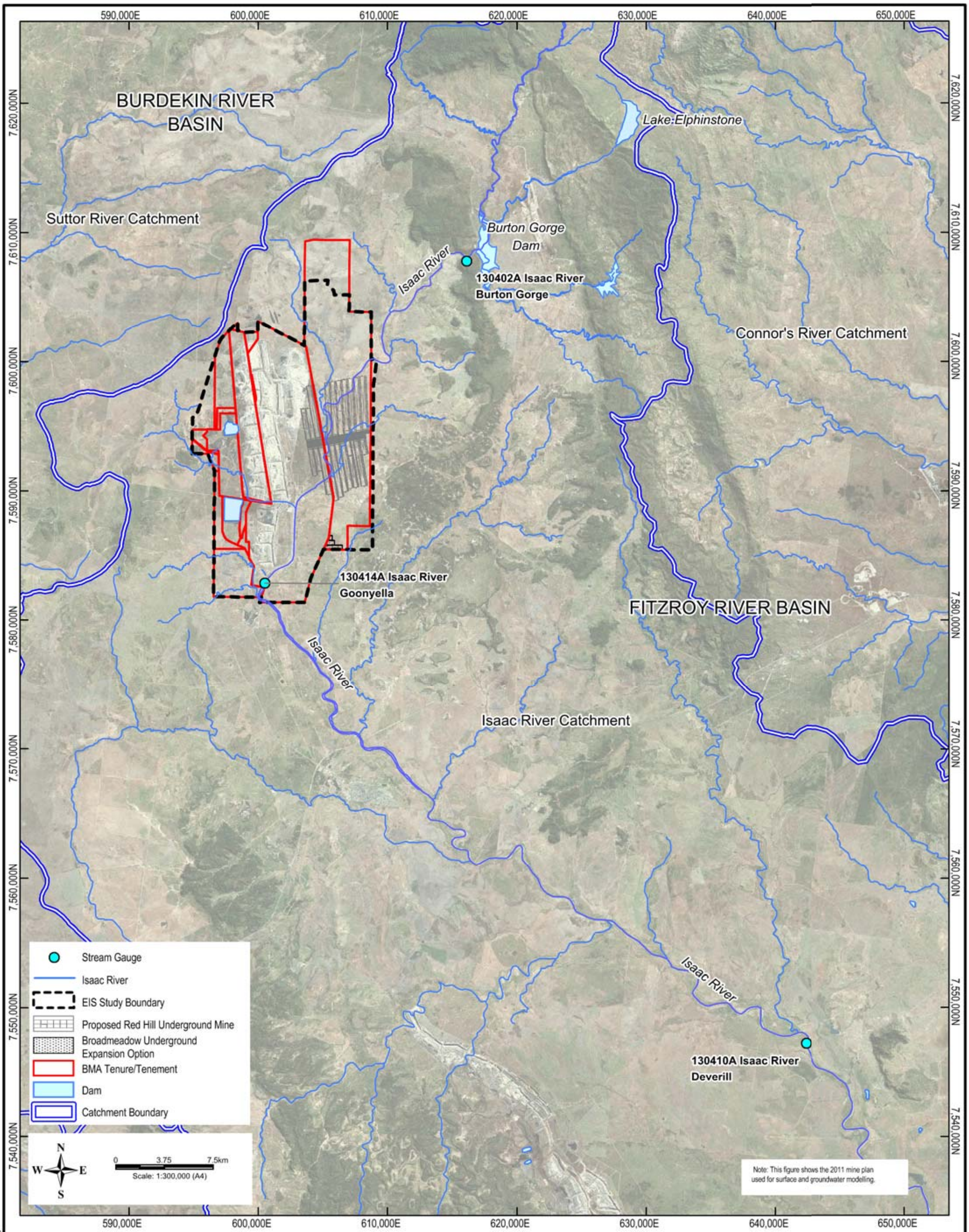
2.2 Methodology for Flood Hydrology

The methodology for estimating the flood hydrology for the Isaac River and several tributaries through the EIS study area utilised and compared a range of different methods. The methods included:

- rainfall based techniques with rainfall runoff routing modelling; and
- empirical flood estimation methods.

The methodology steps included:

1. Review of catchment characteristics and climate to guide overall understanding of flood hydrology.
2. Catchment delineation:
   a. large scale Isaac River – including tributaries subdivided into relatively uniform size sub-catchments for rainfall runoff modelling; and
   b. smaller scale tributary catchments to Isaac River in the mine lease area to allow better sub-catchment resolution for rainfall runoff modelling of the smaller streams.



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RED HILL MINING LEASE
HYDROLOGY TECHNICAL REPORT

STREAM GAUGES IN THE VICINITY OF THE PROJECT

SURFACE WATER - HYDROLOGY

Figure: **2-1**

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3. Rainfall runoff routing modelling (RORB software):
    a. RORB model setup for Isaac River catchment;
    b. RORB model setup for smaller tributaries within the EIS study area;
        i. Goonyella Creek;
        ii. 12 Mile Gully;
        iii. Eureka Creek;
        iv. Holding Creek, Fisher Creek and Platypus Creek;
    c. preparation of design rainfall storm inputs for the RORB model;
        i. Australian Intensity-Frequency-Duration Program (AUS-IFD) and Bureau of Meteorology (BoM) – point rainfall for the Isaac River; applicable to all catchment models;
        ii. Cooperative Research Centre for Catchment Hydrology (CRC-FORGE) – rainfall depths and intensities for 1 in 10 to 1 in 2000 AEPs based on catchment area (polygon);
    d. review and assumptions for rainfall losses;
    e. estimating RORB model routing parameters (K_c and m); and
    f. RORB Model simulations and reviews of results.
4. Validation of RORB results and input parameter checks:
    a. review of Weeks (1986) and URS Australia Pty Ltd (URS) derived equation for K_c parameter estimation from recent studies;
    b. ACARP peak flow estimation equations for comparison; and
    c. Queensland QRT-OLS peak flow estimation.
5. Cross-comparison review of the methods and recommendations for adopted hydrology results for the project.

2.3 Runoff-Routing Model Selection

The runoff-routing hydrologic assessment was undertaken using RORB Version 6.15 software developed by Laurenson and Mein (2010) which simulates the runoff response of a catchment area including the effects of stream routing and reservoir routing. RORB is a streamflow routing program that calculates hydrographs from rainfall input, subtracting losses from rainfall to produce runoff. It was selected for this study due to its suitability for rural catchments, and its ability to route hydrographs through an extensive network and attenuate flow.

In order to simulate the tributaries and variability of the catchment topography, the study catchment is sub-divided into smaller sub-catchments which should generally be uniform in size. Good modelling practice requires at least four to six catchments upstream of a point of interest where flow data is to be extracted from the RORB model. For this reason several RORB runoff models of different scales were developed for this study to allow estimation of flood hydrographs for the main Isaac River catchment and separately for the smaller tributary catchments traversing the EIS study area.

Nodes which represent the centre of flow accumulation in the sub-catchment were placed along the stream channels. Model reaches, for routing of the hydrographs through the catchment, are used to connect nodes to form the overall reach network of the catchment. Routing of the hydrographs through each reach has a non-linear storage-discharge relationship of the form:

$$S = 3600 * K_c * K_{ri} * Q^m$$

Where S = storage in reach (m^3)
Q = discharge (m^3/s)
K_c = main routing parameter for the overall catchment
m = dimensionless exponent for non-linear routing
K_{ri} = relative reach routing parameter for the specific reach

The exponent m is the parameter that describes the non-linearity of a catchment's storage routing. An m value of 0.8 is recommended for ungauged catchments. The K_c value is the key parameter that defines the degree of hydrograph attenuation due to storage effects of flow routing through the catchment reach network. The K_c and m values are intrinsically linked, and the m value cannot be arbitrarily modified without modifying the K_c value. For this study, the m value was set at 0.8, and the K_c parameter was estimated using empirical regional relationships.

2.4 Available Data

2.4.1 Previous Studies

The Alluvium (2008) study, which conducted a detailed flood assessment of the Isaac River including calibration of input parameters to a number of flood events, was utilised for developing a hydrologic model of the Isaac River. The Alluvium report documents a RORB model constructed for the entire Isaac River catchment. Alluvium developed three separate RORB models due to geography and geology. The RORB models utilised the 'fit' and 'design' runs as part of the calibration to the recorded stream flows at the Burton Gorge, Goonyella and Deverill stream gauges (refer to Figure 2-1).

2.4.2 Design Rainfall Data

Design rainfall estimates for the EIS study area which relate to rainfall intensity to duration and probability of occurrence were available from two sources. Design rainfall estimates were sourced from AR&R (Pilgrim 1987) parameters applied using AUS-IFD software. Design rainfall estimates were also sourced from the Queensland CRC-FORGE data and software (Hargraves 2004). The CRC-FORGE design rainfall data is considered to be the best source of design rainfall data as this was generated from longer data records (compared to Pilgrim 1987) and also allows for updated procedures to convert point rainfall estimates to catchment average rainfall (using areal reduction factors).

Further descriptions of the design rainfall data obtained for the study is presented in Section 3.2.

2.4.3 Catchment Mapping Data

The delineation of catchment sub-basins and stream reaches was sourced from two sources:

- detailed topographic and aerial photo survey of the EIS study area in December 2010, supplied by BMA, and
- SRTM Topographic Digital Elevation Model (DEM) data.

Isaac River Runoff-Routing Model

3.1 Isaac River RORB Model Development

Using the documented information from the Alluvium (2008) report, URS developed a similar RORB model of the Isaac River to estimate flows at select locations for the purpose of this study. The RORB model included similar stream length and catchment areas, as shown in Figure 2-1, to the Alluvium (2008) in order to create a catchment file for the overall Isaac River catchment, including the three stream gauging stations at Burton Gorge, Goonyella and Deverill. The purpose the model was to develop an independent model that could be used to confirm the RORB model results from the Alluvium (2008) report without extensive calibration simulation. A more detailed discussion of the Isaac River modelling background, including sub-basin delineation, calibration to storm events, and discussion on catchment parameters is presented in the Alluvium (2008) report. The differences in modelling input and results when compared to the Alluvium (2008) report are presented in this study report.

The RORB model developed for this study has two differences as compared to the Alluvium (2008) study:

- A single RORB model was developed of the entire Isaac River catchment to the Deverill stream gauge instead of three separate models. A single RORB model was developed because version 6 of the model can be specify initial and continuing losses at inter-stationary locations instead of requiring separate simulation files.
- The connectivity of the Eureka creek diversion to the Isaac River was modified so that the creek discharged through the GRM mine lease, not to the south of the mine.

3.2 Temporal Patterns

The temporal patterns that have been used for the RORB models are consistent with those recommended in AR&R (Pilgrim 1987), Table 3.2 (Zone 3 - AEP's from 1 in 10 year to 1 in 50 year). For more extreme events than this (AEPs 1 in 100 year to 1 in 2,000 year), Probable Maximum Precipitation (PMP) temporal patterns have been used from AR&R Figure 13.3 (Pilgrim 1987).

3.3 Design Rainfall Depths

The runoff-routing model was simulated for the following AEPs and durations:

- AEPs: 1 in 10, 1 in 20, 1 in 50, 1 in 100, 1 in 500, 1 in 1,000, and 1 in 2,000 year.
- Durations: 1 hour, 3 hour, 6 hour, 12 hour, 18 hour, 24 hour, 48 hour, 72 hour.

The design rainfall depths and area reduction factors for these selected AEPs and durations were extracted using the CRC FORGE methodology, as shown in Table 3-1; these were considered appropriate for this analysis and are consistent with the study by Alluvium (2008). The CRC-FORGE method, developed by the Cooperative Research Centre for Catchment Hydrology, is a statistical method for developing rainfall estimates for large and infrequent storm events for catchments less than 8,000 km^2. The CRC-FORGE method was then further developed for Queensland by Hargraves (2004).

The CRC-FORGE method produces design point rainfall estimates for durations from 15 minutes to 120 hours (in 24 hour increments), and from AEP 1 in 5 to AEP 1 in 2,000 and areal reduction factors for converting point rainfall estimates to catchment rainfall estimates. The user prepares a coordinate point file that represents the outline of the catchment boundary which is then utilised by the CRC-FORGE program to estimate catchment area, areal reduction factors, and rainfall depths for durations between 15 minutes and 120 hours.

Table 3-1 Design Rainfall Depths (mm) for Isaac River RORB Model

Isaac River Headwaters to Burton Gorge (Catchment Area of 555 km²)									
Storm Duration (hours)	1 in 5 AEP	1 in 10 AEP	1 in 20 AEP	1 in 50 AEP	1 in 100 AEP	1 in 200 AEP	1 in 500 AEP	1 in 1,000 AEP	1 in 2,000 AEP
1	60	67	75	87	100	113	132	148	165
3	82	92	105	123	141	161	188	211	234
6	99	112	129	152	175	199	233	260	290
12	120	136	159	189	217	247	288	323	359
18	135	155	182	218	251	285	334	373	415
24	147	170	200	241	277	315	369	413	459
48	207	239	281	338	386	435	502	555	610
72	236	272	320	385	442	500	581	645	713
Isaac River Burton Gorge to Goonyella Gauge (Catchment Area of 660 km²)									
1	47	52	59	68	77	87	102	113	125
3	64	71	82	95	109	123	143	159	177
6	76	86	100	117	134	151	176	196	217
12	92	105	122	144	165	187	217	242	268
18	104	120	140	168	193	218	253	282	312
24	113	131	155	187	214	242	282	314	347
48	157	182	215	260	295	331	379	417	457
72	181	209	247	299	340	382	440	485	532
Isaac River Goonyella Gauge to Deverill (Catchment Area of 2,940 km²)									
1	44	48	54	62	71	80	93	104	115
3	58	65	75	87	100	113	131	146	161
6	69	78	91	107	122	138	160	179	198
12	82	94	110	132	150	170	197	219	243
18	94	108	126	152	173	195	227	253	280
24	102	118	139	167	191	215	250	278	308
48	137	158	186	224	254	284	327	360	394
72	160	185	217	261	296	331	380	418	457

3.4 Initial and Continuing Loss Values

The initial and continual loss values adopted for this study were similar to those documented in the Alluvium (2008) report. The initial loss values were divided into areas upstream and downstream of Burton Gorge stream gauge as 90 mm and 25 mm for all storm events, respectively. The Burton Gorge catchment is much more vegetated than the catchments in the lower reaches of the Isaac. Hence a higher value for initial loss was considered appropriate for this catchment. It should be noted that a sensitivity analysis was conducted by Alluvium (2008) on the initial loss for the catchments. An initial loss of 90 mm for the Burton Gorge catchment resulted in the best fit for peak discharge at the Goonyella gauge.

A constant continual loss value of 2.5 mm/hr was used for the entire modelled area areas. Table 3-2 summarises the adopted initial and continuing losses for the RORB modelling of the Isaac River catchment.

Table 3-2 Adopted Initial and Continuing Loss Values (mm) for the Isaac River Model

RORB Model	Burton Gorge	Goonyella	Deverill
Alluvium	95/2.5	25/2.5	25/2.5
URS	90/2.5	25/2.5	25/2.5

3.5 Isaac River Runoff-Routing Verification and Model Results

As discussed earlier, the URS RORB model for this study was developed independent of the Alluvium (2008) study. 'Verification' simulations were performed by comparing the URS modelled peak flows to the Alluvium results at the Goonyella Gauge, as this is the nearest stream gauge to the study area. The model verification runs were performed by modifying the K_c value in order to produce similar results to those presented in the Alluvium (2008) report.

URS adopted an approach to the selection of the K_c value for the model that is consistent with modelling standards for RORB in Queensland. Using a standard m value of 0.8, the K_c value was calculated using the Weeks equation (RORB default method for Queensland) for the entire Isaac river catchment upstream of the Deverill Gauge. This approach was utilised to give a consistent approach to the model as opposed to breaking up the model into the three gauged areas (using three respective K_c values) as per the Alluvium (2008) study. A comparison of K_c values between the Alluvium (2008) model and the model for this study is presented in Table 3-3 which shows that the overall K_c value to the Deverill gauge is within approximately 10 per cent.

Table 3-3 K_c Value at Deverill Gauge Comparison (for m of 0.8)

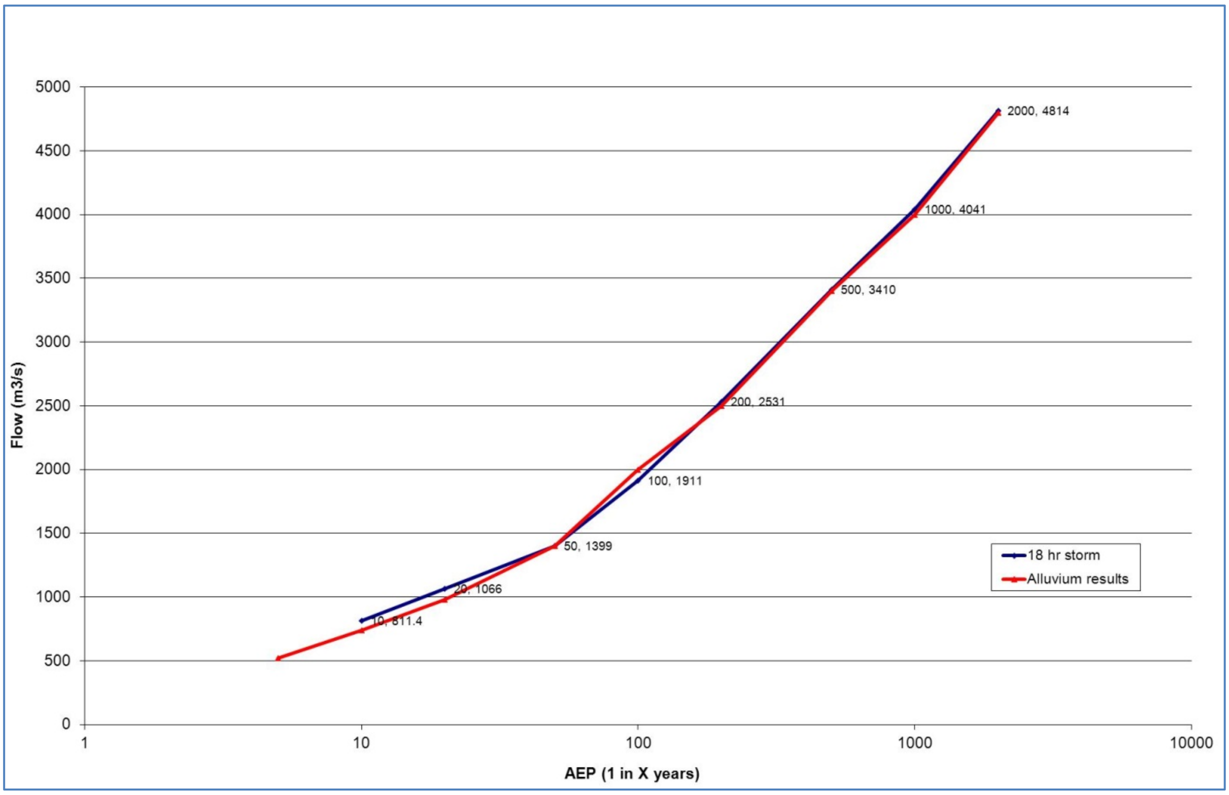
RORB Model	Deverill
Alluvium	78
URS	72.7

The RORB model of the Isaac River catchment was then simulated for the eight storm durations selected for each AEP storm event. The RORB model peak flow results were compared to the results from the Alluvium (2008) report. This is shown in Table 3-4 and illustrated in Figure 3-1 for the critical storm duration (i.e. storm duration that results in the largest peak outflow) of 18 hours (refer to Table 3-4). The results from the verification simulations show that the peak flows at the Goonyella gauge from the URS model simulations were within 4 per cent of the estimated results from the Alluvium (2008) report for events greater than the 1 in 20 AEP event, which was considered adequate for this study. The differences in peak flow for the 1 in 10 and 1 in 20 AEP events were primarily a result of the slightly lower K_c value which reduced the flood attenuation within the basin and resulted in higher discharges. The simulated peak discharges were higher than those reported in the Alluvium (2008) report and were considered conservative, and were therefore adopted for this study.

Table 3-4 Goonyella Gauge Peak Flow Comparison (18hr Storm Duration)

AEP	Alluvium (2008) Peak Flow (m^3/s) and Time to Peak	Red Hill Mining Lease Peak Flow (m^3/s) and Time to Peak	% Difference
1 in 10	740 (15 hours)	810 (15 hours)	+10%
1 in 20	980 (15 hours)	1,070 (15 hours)	+9%
1 in 50	1,400 (15 hours)	1,400 (15 hours)	0%
1 in 100	2,000 (20 hours)	1,910 (20 hours)	-4%
1 in 500	3,400 (25 hours)	3,410 (20 hours)	0%
1 in 1,000	4,000 (24 hours)	4,040 (20 hours)	+1%
1 in 2,000	4,800 (24 hours)	4,810 (18 hours)	0%

Figure 3-1 Comparison of Project RORB Peak Flows and Alluvium 2008 Results at Goonyella Gauge (18 hour storm)



3 Isaac River Runoff-Routing Model

A summary of the critical duration storm event peak flows at the Goonyella gauge location is presented in Table 3-5. It shows that the 18-hour storm typically results in the highest discharge, with the exception of the 1 in 100 and 1 in 2,000 year events which result from the 24-hour storm event.

Table 3-5 Critical Duration Storm Peak Flows at Goonyella Gauge

AEP	Critical Duration Storm Event (hours)	Peak Flow (m^3/s)
1 in 10	18	810
1 in 20	18	1,070
1 in 50	18	1,400
1 in 100	24	2,030
1 in 500	18	3,410
1 in 1,000	18	4,040
1 in 2,000	24	5,390

4 Runoff-Routing Model for Tributaries in EIS Study Area

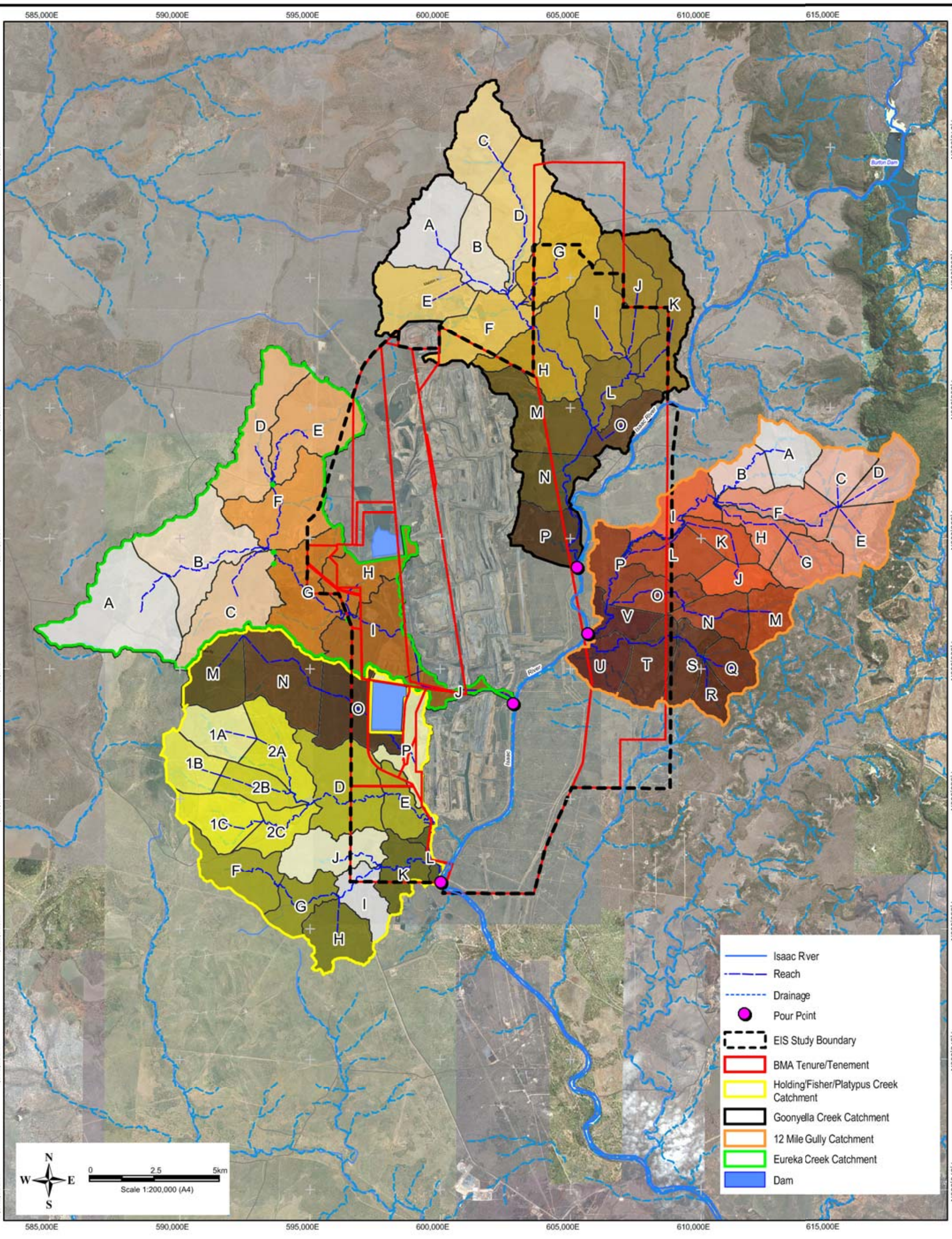
Similar to the Isaac River runoff-routing modelling, RORB modelling was conducted of the several tributaries within the EIS study area to estimate peak flood discharges for storm events between the 1 in 10 and 1 in 2,000 AEP events.

4.1 RORB Model Layout and Catchment Delineation

Four different RORB models were developed to estimate peak flows as inputs to the hydraulic models to estimate flood inundation within the EIS study area for the select storm events. Models were developed for the catchments of the four major watercourses, as shown in Figure 4-1, that contribute to the Isaac River at and downstream of the EIS study area:

- Goonyella Creek;
- Eureka Creek;
- 12 Mile Gully;
- Holding Creek, Fisher Creek, and Platypus Creeks.

The catchments of Holding, Fisher and Platypus Creeks were combined to estimate a peak flow entering the Isaac River to the South of the EIS study area. In addition peak flows were also modelled and estimated for individual creek sub-catchments; before each confluence; to allow individual hydraulic models to be created for each creek. The hydrograph output locations from the RORB models for these three creeks, prior to each confluence and prior to confluence with the Isaac River, are presented in Figure 4–2.



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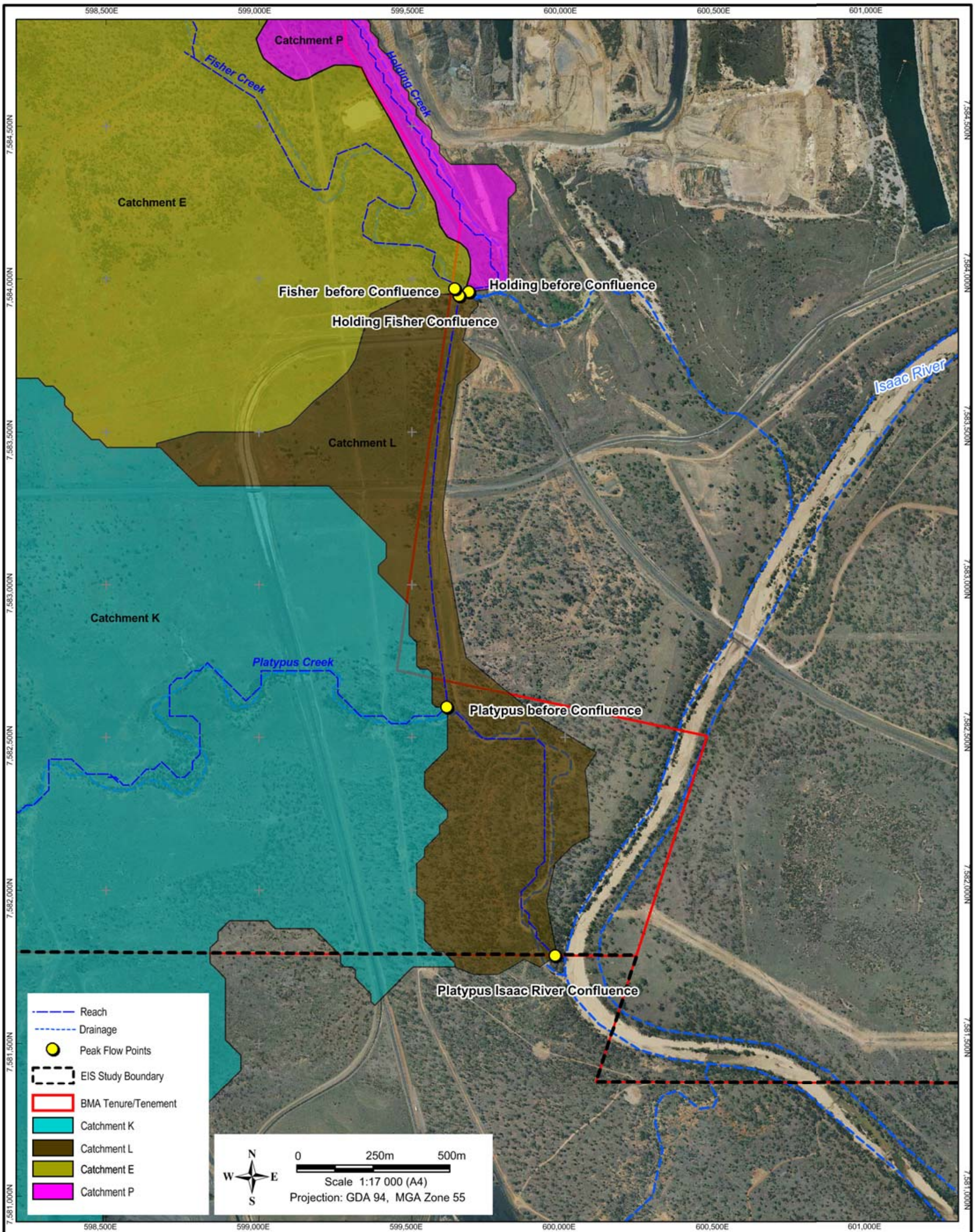
RORB MODEL
SUB-CATCHMENTS AND REACHES

URS

SURFACE WATER - HYDROLOGY

Figure: **4-1**

File No: **42627136-g-2046.wor** Drawn: **MH** Approved: **CP** Date: **24-06-2013** Rev.**A** A4



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RORB MODEL HYDROGRAPH PRINT POINTS FOR HOLDING, FISHER AND PLATYPUS CREEKS

URS

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Figure: **4-2**

File No: **42627136-g-2047.wor** Drawn: **MH** Approved: **CP** Date: **24-06-2013** Rev.**A** A4

4.2 Routing Parameters (Kc and m)

The applied K_c routing parameter for RORB is critical to the estimation of flood hydrograph routing through the catchment. A large K_c value results in greater attenuation effects and produces lower peak flood flow estimates, and conversely a low K_c value results in less hydrograph attenuation and produces higher peak flood flow estimates.

A regional relationship was developed by Weeks (1986) and recommended in AR&R (Pilgrim 1987) to estimate the K_c value for ungauged streams in Queensland with m equal to 0.8. A relationship between K_c and the catchment area was developed from the analysis of 94 calibrated RORB models for gauged catchments in Queensland. Utilising this methodology, a relationship was developed for the Eureka Creek, Goonyella Creek, 12 Mile Gully and combined Holding, Fisher and Platypus Creek catchments by scaling the K_c value reported in Appendix C of the Alluvium (2008) report. A more detailed explanation of this procedure can be seen in Appendix A.

A comparison of the K_c estimates for the RORB models based on the Weeks and equation [1] region relationships is presented in Table 4-1.

Table 4-1 Comparison of Weeks and URS K_c Derived Values for Tributaries to Isaac River

Catchment Name	Catchment Area (km^2)	Reach Length (km)	K_c (Weeks Equation)	K_c (URS Equation)	m
Eureka Creek	86.4	34.6	9.4	7.4	0.8
Holding Fisher & Platypus Creeks	95.4	50.9	9.9	7.8	0.8
Goonyella Creek	106.9	45.6	10.5	8.3	0.8
12 Mile Gully	84.4	56.1	9.2	7.4	0.8

As discussed in Section 4.6.2 and Section 4.6.3, the K_c value based on the URS derived equation was considered to be the most suitable based on comparisons of:

- RORB vs ACARP peak flow estimate.
- RORB vs Quantile Regression Technique based on Ordinary Least-Squares (QRT-OLS) peak flow estimate.

4.3 Design Rainfall Estimates and Areal Reductions

Rainfall depths and intensities for the various EIS study area catchments were estimated and compared to regional type methodologies:

- Small events (1 in 2 to 1 in 10 AEP event):
  - AR&R (Pilgrim 1987) using AUSIFD software
  - Verified with BoM
- Small to Rare events (1 in 10 to 1 in 2000 AEP):
  - Queensland CRC-FORGE (Hargraves 2004)
  - Verified with BoM (up to 1 in 100 AEP)

The AR&R and BOM rainfall intensities were used in conjunction with the ACARP and QRT-OLS methodologies to verify RORB peak flow estimates.

4.3.1 Rainfall Estimate from Australian Rainfall and Runoff (Pilgrim 1987)

Point rainfall intensity-frequency-duration (IFD) data for the catchments, for events up to the 1 in 100 AEP were derived using the AUS-IFD version 2.0 computer program, developed at Griffith University. AUS-IFD is a computer program that calculates IFD tables from parameters sourced from maps in AR&R (Pilgrim 1987). The input parameters for the EIS study area were estimated for the approximate geographic location of the mine site, and are presented in Table 4-2. The design IFD rainfall intensities estimated using the AUS-IFD program are summarised in Table 4-3.

Table 4-2 AUS-IFD Input Parameters for Goonyella-Riverside Mine Site

1 in 2 AEP Intensity		1 in 50 AEP Intensity		Geographic factors and skew	
1hr (mm/hr)	44	1hr (mm/hr)	74	Skewness G	0.13
12hr (mm/hr)	6.6	12hr (mm/hr)	13	F2	4.1
72hr (mm/hr)	1.7	72hr (mm/hr)	3.9	F50	17

Table 4-3 AR&R 1987 Intensity-Frequency-Duration rainfall for Goonyella-Riverside Mine Site

	AEP (mm/hr)						
DURATION	1 in 1 AEP	1 in 2 AEP	1 in 5 AEP	1 in 10 AEP	1 in 20 AEP	1 in 50 AEP	1 in 100 AEP
5mins	99	127	162	182	210	246	274
6mins	93	120	152	171	196	231	257
10mins	78	100	125	141	161	188	210
20mins	58	74	93	103	118	137	152
30mins	48	62	76	84	96	111	123
1hr	34	43	53	58	66	76	83
2hrs	20	26	32	36	41	47	52
3hrs	15	19	24	27	30	36	39
6hrs	8.6	11	14	16	19	22	24
12hrs	5.0	6.5	8.5	9.7	11	14	15
24hrs	3.1	4.0	5.3	6.1	7.2	8.6	9.8
48hrs	1.8	2.4	3.2	3.7	4.4	5.4	6.1
72hrs	1.3	1.7	2.3	2.7	3.3	4.0	4.6

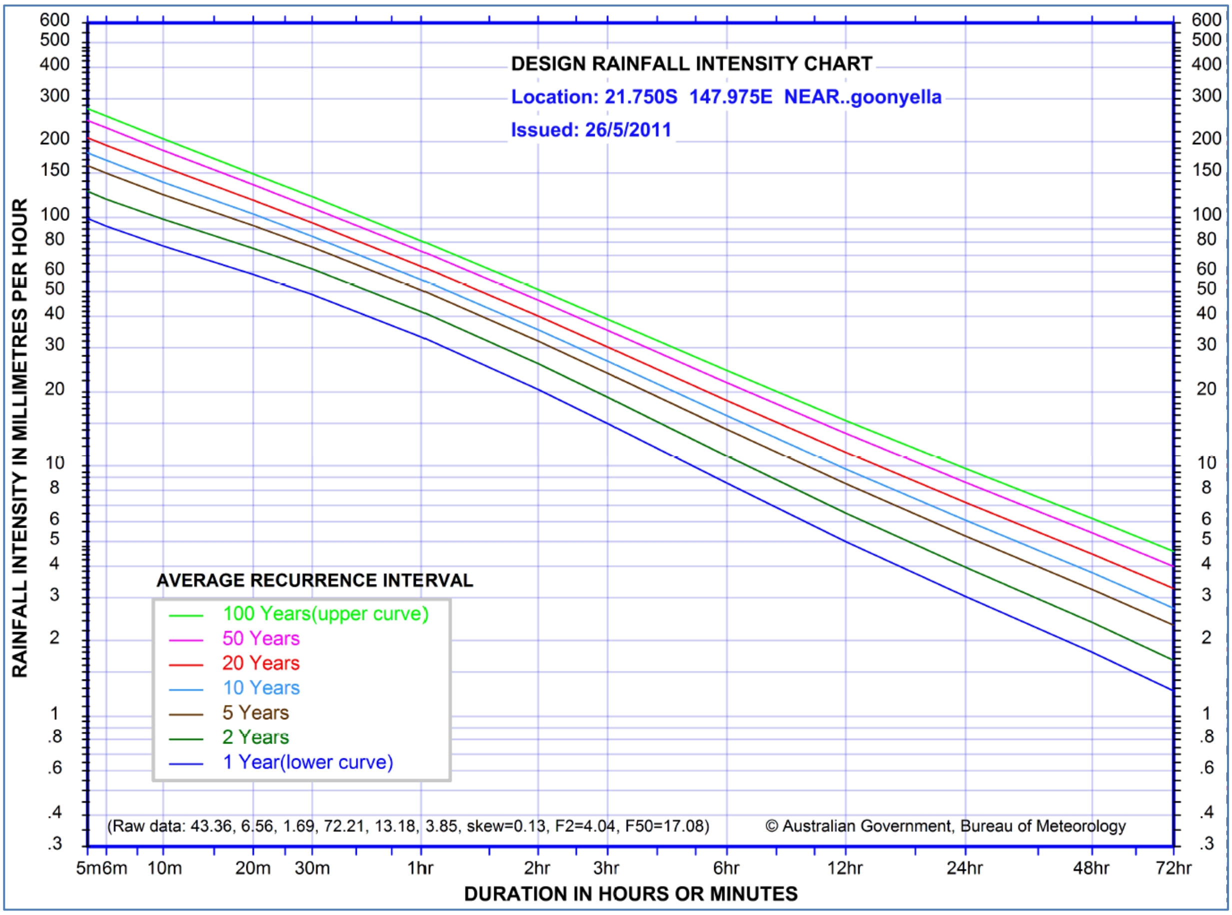
4.3.2 IFD from the Bureau of Meteorology

To verify the rainfall intensities from AR&R (Pilgrim 1987), point rainfall intensities were also sourced from the BoM website for the same geographic location (21.75˚ south, 147.975˚ east). The BoM website uses a spatial interpolation routine to estimate the same input parameters as the AUS-IFD program. The results from the BoM computer program are presented in Table 4-4 and Figure 4-3. The BoM and AUS-IFD program estimates of AR&R (Pilgrim 1987) rainfall results compare well and are generally within three per cent. An intensity-frequency-duration curve based on the BoM data is presented in Figure 4-3.

Table 4-4 Bureau of Meteorology Intensity-Frequency-Duration Rainfall for Goonyella-Riverside Mine Site

	AEP (mm/hr)						
DURATION	1 in 1 AEP	1 in 2 AEP	1 in 5 AEP	1 in 10 AEP	1 in 20 AEP	1 in 50 AEP	1 in 100 AEP
5mins	99	127	161	181	208	244	272
6 mins	92	118	150	169	194	228	254
10 mins	77	98	123	138	159	185	206
20 mins	59	75	93	103	117	135	149
30 mins	49	62	76	84	95	109	121
1hrr	33	42	51	56	64	73	80
2hrs	20	26	32	35	40	47	51
3hrs	15	19	24	27	30	35	39
6hrs	8.6	11	14	16	18	22	24
12hrs	5.0	6.5	8.5	9.7	11	14	15
24hrs	3.0	3.9	5.3	6.1	7.2	8.6	9.8
48hrs	1.8	2.4	3.2	3.8	4.5	5.4	6.2
72hrs	1.3	1.7	2.3	2.7	3.2	4.0	4.6

Figure 4-3 Bureau of Meteorology Intensity-Frequency-Duration Rainfall for Goonyella Mine Site



4.3.3 IFD from CRC-FORGE

The CRC-FORGE method, developed by the Cooperative Research Centre for Catchment Hydrology, is a statistical method for developing rainfall estimates for large and infrequent storm events for catchments less than 8,000 km^2. The CRC-FORGE method was then further developed for Queensland by Hargraves (2004).

The CRC-FORGE method produces design point rainfall estimates for durations from 15 minutes to 120 hours (in 24 hour increments), AEPs from 1 in 5 to AEP 1 in 2,000, and areal reduction factors for converting point rainfall estimates to catchment rainfall estimates. The user prepares a coordinate point file that represents the outline of the catchment boundary. This is then utilised by the CRC-FORGE program to estimate catchment area, areal reduction factors, and rainfall depths for durations between 15 minutes and 120 hours. The BoM, AUS-IFD program and CRC-FORGE estimates of rainfall results compare well and are generally within five per cent. The CRC-FORGE design rainfall data was adopted for this study because it is considered to be the best source of design rainfall data as this was generated from longer data records (compared to AR&R (Pilgrim 1987)). Further, it allows for updated procedures to convert point rainfall estimates to catchment average rainfall (using Areal Reduction Factors).

The areal reduction factors obtained from CRC-FORGE are presented in Table 4-5, and the derived CRC-FORGE catchment rainfall intensities for the three RORB models are presented in Table 4-6

Table 4-5 CRC-FORGE Catchments Areas and Areal Reduction Factors

Areal reduction factor for different durations						
Catchment	Area (km^2)	24 hr	48 hr	72 hr	96 hr	120 hr
Eureka Creek	86.4	0.938	0.965	0.976	0.983	0.987
Holding Fisher & Platypus Creeks	95.4	0.935	0.963	0.975	0.981	0.985
Goonyella Creek	106.9	0.933	0.961	0.973	0.980	0.984
12 Mile Gully	84.4	0.939	0.966	0.977	0.983	0.987

Table 4-6 CRC-FORGE Catchment Rainfall Depths (mm) for RORB Model

Eureka Creek	Storm Event (AEP)							
Duration (hrs)	1 in 2[1]	1 in 5[1]	1 in 10[2]	1 in 20[2]	1 in 50[2]	1 in 100[2]	1 in 1000[2]	1 in 2000[2]
0.25	na	na	28	32	38	43	63	69
0.5	na	Na	41	46	53	61	89	98
1	42	51	56	63	72	83	120	133
3	52	64	76	87	101	115	168	186
6	57	71	91	105	123	141	205	227
12	66	85	110	128	151	173	252	278
18	Na	Na	126	147	177	202	294	325
Eureka Creek	Storm Event (AEP)							
24	78	102	138	163	196	224	327	361
48	95	126	184	217	262	296	417	456
72	114	154	209	246	297	337	476	521
96	120	166	225	265	320	362	515	564
120	na	na	235	277	334	379	539	591
Holding, Fisher & Platypus Creeks	Storm Event (AEP)							
Duration (hrs)	1 in 2[1]	1 in 5[1]	1 in 10[2]	1 in 20[2]	1 in 50[2]	1 in 100[2]	1 in 1000[2]	1 in 2000[2]
0.25	Na	na	28	32	37	42	62	68
0.5	Na	Na	40	46	53	60	87	97
1	42	51	55	62	71	81	119	131
3	52	64	75	85	99	114	165	183
6	57	71	90	103	122	139	202	223
12	66	85	108	125	149	170	248	274
18	Na	Na	123	144	173	198	288	318
24	78	102	135	159	192	219	319	353
48	95	126	180	211	255	288	405	442
72	114	154	204	240	290	328	462	505
96	120	166	220	259	312	353	499	546
120	Na	na	230	271	326	369	523	573

Goonyella Creek	Storm Event (AEP)							
Duration (hrs)	1 in 2[1]	1 in 5[1]	1 in 10[2]	1 in 20[2]	1 in 50[2]	1 in 100[2]	1 in 1000[2]	1 in 2000[2]
0.25	na	na	30	34	40	46	68	75
0.5	na	na	43	49	57	65	95	105
1	42	51	59	67	77	88	129	142
3	52	64	81	93	108	124	182	201
6	57	71	98	113	134	153	224	249
12	66	85	119	139	165	189	277	307
18	Na	Na	137	160	193	221	324	359
24	78	102	150	177	215	246	360	399
48	95	126	203	240	291	329	468	512
72	114	154	230	271	329	374	53	590
96	120	166	248	293	354	404	584	643
120	na	na	259	307	371	423	612	674
12 Mile Gully	Storm Event (AEP)							
Duration (hrs)	1 in 2[1]	1 in 5[1]	1 in 10[2]	1 in 20[2]	1 in 50[2]	1 in 100[2]	1 in 1000[2]	1 in 2000[2]
0.25	na	na	31	35	41	47	68	76
0.5	na	Na	43	49	57	65	96	107
1	42	51	60	67	77	88	130	144
3	52	64	82	94	109	125	184	204
6	57	71	99	118	135	155	228	252
12	66	85	121	141	167	192	282	312
18	Na	Na	138	162	195	223	329	364
24	78	102	152	179	217	248	365	405
48	95	126	205	242	292	332	472	517
72	114	154	233	275	332	378	543	596
96	120	166	251	297	358	408	591	651
120	na	na	263	310	375	428	620	684

Notes: 1 Based on BoM IFD Data

2 Based on CRC-FORGE IFD data

4.4 Temporal Patterns of Design Rainfall Events

Three sets of temporal patterns were considered for the rainfall runoff routing (RORB) simulations for different events.

For the more frequent floods up to the 1 in 100 AEP events, the temporal patterns from AR&R (Pilgrim 1987) for Zone 3 were used. It should be noted, that the rainfall runoff routing modelling undertaken for the frequent events 1 in 20 and 1 in 50 AEP was for the purposes of comparison to ACARP and QRT-OLS only.

For large to extreme storm events from 1 in 100 AEP events up to 1 in 2,000 AEP, the generalised temporal patterns from the Generalised Short Duration Method (GSDM) publication (BoM) for durations 1 to 6 hours was utilised. The temporal patterns sourced from the publication were for the generalised coastal Average Variability Method (AVM) temporal patterns standard area of 100 km^2 for the all RORB models.

For durations between 6 and 72 hours AR&R Volume 2 (Pilgrim 1987) Procedures for Estimating Large and Extreme Floods (Section 13, Figure 13.3) were utilised. This methodology provides temporal patterns for generalised tropical storms for the Queensland coastal zone for extreme rainfalls from 1 in 500 AEP event to the PMP.

4.5 Catchment Losses

The initial loss and constant continuing loss method was applied for the rainfall runoff routing modelling. The continuing loss rate was applied at 2.5 mm/hr for all events in accordance with the recommendations of AR&R Book VI (Nathan and Weinmann 1999).

The assumed initial loss is based on engineering judgement, however the effect of an error in initial loss of say 20 mm is relatively insignificant since the initial loss rate represents less than 10 per cent of the 1 in 100 AEP 72 hour storm rainfall total. The initial loss values for more extreme events were assumed to gradually decrease to no initial loss for the PMP rainfall event. Higher initial loss values were assumed for smaller events up to 1 in 20 AEP which were only modelled for comparative purposes.

A summary of the assumed loss values for the RORB model is presented in Table 4-7.

Table 4-7 Adopted Rainfall Loss Values for RORB Model

AEP events	Initial Loss (mm)	Continuing Loss (mm/hr)
1 in 10	40	2.5
1 in 20	35	2.5
1 in 100	25	2.5
1 in 1,000	15	2.5
1 in 2,000	10	2.5

4.6 RORB Results

4.6.1 Eureka Creek Catchment Results

The RORB model simulation results for the Eureka Creek catchment (86 km^2) show that the critical duration storm event is approximately three hours. A summary of the RORB model simulation peak flood flows in Eureka Creek are presented in Table 4-8. The results for 1 in 10 to 1 in 20 AEP events are presented for completeness only, as these results were only used for the purpose of comparison with ACARP and QRT-OLS peak flow estimates.

Table 4-8 Eureka Creek RORB Model Peak Flow Results

AEP	Peak Duration (hrs)	RORB Estimated Peak Flow (m³/s)
1 in 2	30	90
1 in 5	9	167
1 in 10	6	220
1 in 20	3	330
1 in 100	3	640
1 in 500	3	1,000
1 in 1,000	3	1,200
1 in 2,000	3	1,400

4.6.2 Holding, Fisher and Platypus Creek Catchment Results

The RORB model simulation results for the Holding, Fisher and Platypus Creek catchments (97 km^2) show that the critical duration storm event is approximately three hours. A summary of the RORB model simulation peak flood flows is presented in Table 4-9. The results for 1 in 10 to 1 in 20 AEP events are presented for completeness only, as these results were only used for the purpose of comparison with ACARP and QRT-OLS peak flow estimates.

The contributing flows from each individual catchment; at locations previously identified (Figure 4-3); were modelled and a summary of the results are presented in Table 4-10 below.

Table 4-9 Holding, Fisher and Platypus Creeks RORB Model Peak Flow Results

AEP	Peak Duration (hrs)	RORB Estimated Peak Flow (m³/s)
1 in 2	30	90
1 in 5	30	150
1 in 10	6	180
1 in 20	6	280
1 in 100	3	530
1 in 500	3	850
1 in 1,000	3	1,000
1 in 2,000	3	1,200

Table 4-10 Summary of RORB Model Peak Flow Results for Individual Creeks

AEP	Fisher Creek Before Confluence (m³/s)	Holding Ck Before Confluence (m³/s)	Holding Fisher Cks Confluence (m³/s)	Platypus Creek Before Confluence (m³/s)
1 in 2	40 (30hr)	20 (30hr)	60 (30hr)	30 (30hr)
1 in 5	70 (30hr)	40 (30hr)	100 (30hr)	50 (6hr)
1 in 10	80 (6hr)	506 (3hr)	130 (3hr)	60 (6hr)
1 in 20	130 (6hr)	70 (3hr)	200(3hr)	100 (3hr)
1 in 100	240 (3hr)	130 (3hr)	370 (3hr)	190 (3hr)
1 in 500	390 (3hr)	210 (3hr)	600 (3hr)	310 (3hr)
1 in 1,000	460 (3hr)	260 (3hr)	720 (3hr)	360 (3hr)
1 in 2,000	540 (3hr)	300 (3hr)	850 (3hr)	420 (3hr)

4.6.3 Goonyella Creek Catchment Results

The RORB model simulation results for the Goonyella Creek catchment (107 km^2) show that the critical duration storm event is approximately three hours. A summary of the RORB model simulation peak flood flows in Goonyella Creek are presented in Table 4-11. The results for 1 in 10 to 1 in 20 AEP events are presented for completeness only, as these results were only used for the purpose of comparison with ACARP and QRT-OLS peak flow estimates.

Table 4-11 Goonyella Creek RORB Model Peak Flow Results (m^3/s)

AEP	Peak Duration (hrs)	RORB Estimated Peak Flow (m^3/s)
1 in 2	30	100
1 in 5	30	170
1 in 10	6	280
1 in 20	6	410
1 in 100	3	770
1 in 500	3	1,200
1 in 1,000	3	1,400
1 in 2,000	3	1,700

4.6.4 12-Mile Gully Catchment Results

The RORB model simulation results for 12 Mile Gully catchment (84 km^2) show that the critical duration storm event is approximately three hours. A summary of the RORB model simulation peak flood flows is presented in Table 4-12. The results for 1 in 10 to 1 in 20 AEP events are presented for completeness only, as these results were only used for the purpose of comparison with ACARP and QRT-OLS peak flow estimates.

Table 4-12 12 Mile Gully RORB Model Peak Flow Results (m^3/s)

AEP	Peak Duration (hrs)	RORB Estimated Peak Flow (m^3/s)
1 in 2	30	80
1 in 5	30	130
1 in 10	6	190
1 in 20	6	280
1 in 100	3	510
1 in 500	3	810
1 in 1,000	3	970
1 in 2,000	3	1,100

4.7 Empirical methods for Flood Estimates

4.7.1 Overview of Empirical Methods

Empirical flood estimation methods were undertaken to provide an independent means to validate the flood estimates derived from rainfall runoff routing modelling of the EIS study area tributary catchments to the Isaac River. Empirical flood estimation methods are generally based on regional regression assessments to derive formulae for direct estimation of the magnitudes of floods based on key catchment parameters. The empirical methods considered were:

- The flood estimation method outlined in the ACARP report for *Maintenance of Geomorphic Process in Bowen Basin River Diversions*'(ACARP project No. 9068, 2002).
- The QRT-OLS recently developed by Weeks as part of the Engineers Australia (Water Engineering Committee) activities for the AR&R Revision Project – Project 5 Stage 1 *Regional Flood Methods* (Rahman, et al 2009).

4.7.2 ACARP Stream Diversion Guidelines

ACARP developed guidelines for the design and maintenance of stream diversions in the Bowen Basin in 2002. This included an empirical flood estimation method, herein referred to as the ACARP method.

The ACARP method is based on data for catchments up to 4,000 km^2. The method is similar to that reported by Meigh *and* Farquharson (1997), which computes a Mean Annual Flood (MAF), and then factor to scale the MAF to different AEP flood estimates.

The MAF is calculated using the equation:

- MAF = $2.95\times10^{-4}\ A^{0.83}\ R^{4.26}$, where
  - — A is the catchment area in km^2; and
  - — R is the 2-year ARI 12-hour rainfall intensity in mm/hr, (6.49 mm/hr for the EIS study area).

The calculated MAF for a specified catchment area is then multiplied by a factor from charts plotted in the ACARP report. The results of the ACARP method for each catchment area modelled are summarised in Table 4-13.

Table 4-13 ACARP Empirical Method Peak Flow Estimates

Estimated Peak Flow (m^3/s)					
Catchment	Catchment Area (km^2)	APF (m^3/s)	1 in 10 AEP	1 in 20 AEP	1 in 100 AEP
Eureka Creek	86	110	180	280	520
Holding, Fisher & Platypus Creeks	97	120	190	290	550
Goonyella Creek	110	130	200	310	590
12 Mile Gully	84	110	180	270	510

4.7.3 Queensland QRT-OLS (AR&R Revision Project 5)

Engineers Australia (Water Engineering Committee) is revising and updating the AR&R publication which is widely regarded as the key reference source for flood estimation in Australia. The Revision Project 5, Stage 1 Report (*Regional Flood Estimation Methods;* Rahman et. al 2009) focused on collating '… techniques and guidelines for peak flow estimation at ungauged sites across Australia.' The report describes the recently developed QRT-OLS as a methodology that fits the gauged data sets well.

Different methods are applicable for different states, and the method for Queensland is reported to be applicable for catchments up to 1,000 km^2. Several 'catchment' variables were tested using the QRT-OLS method for Queensland, and the analysis showed that catchment area is the most significant variable, and the 1 in 50 AEP 72-hour rainfall intensity is the second most significant variable.

The relevant QRTL-OLS prediction equations for Queensland are:

- $\log(Q10) = 0.159 + 0.688 \log(area) + 1.164 \log(i_{50,72})$
- $\log(Q20) = 0.412 + 0.674 \log(area) + 1.064 \log(i_{50,72})$
- $\log(Q50) = 0.681 + 0.657 \log(area) + 0.957 \log(i_{50,72})$
- $\log(Q100) = 0.855 + 0.645 \log(area) + 0.888 \log(i_{50,72})$
  - note: Qx is a flood flow with 1 in X AEP probability, *area* is in km^2, and $i_{50,72}$ is the 1 in 50 AEP 72-hour rainfall intensity (mm/hr).

Using the above equations, with a 1 in 50 AEP 72-hour event rainfall intensity of 3.97 mm/hr from the CRC-FORGE IFD curve, peak flow estimates were calculated for the project catchment areas and are summarised in Table 4-14.

Table 4-14 QRT-OLS Empirical Method Peak Flow estimates

Estimated Peak Flow (m³/s)				
Catchment	Catchment Area (km²)	1 in 10 AEP	1 in 20 AEP	1 in 100 AEP
Eureka Creek	86	150	230	430
Holding, Fisher & Platypus Creeks	97	170	240	460
Goonyella Creek	107	180	260	500
12 Mile Gully	84	150	220	430

4.7.4 Comparisons

The results from the two different flood estimation methods were compared to identify the most suitable flood flow estimates for a wide range of floods of interest for the project. For comparing the results to identify the most suitable estimates the following high level objectives were considered:

- For the project interests related to assessing geomorphologic stability of the stream channels through the EIS study area, small to large floods in the range up to 1 in 50 AEP are the most significant. For this range of floods, un-necessary conservatism should be avoided as it is important that qualitative geomorphologic assessment of channel conditions and influencing processes can be related to realistic estimates of flood magnitude and frequency.

- For the project interests related to design and impacts of flood protection works (including adequate floodplain corridors through the site), rare to extreme floods in the range of 1 in 100 AEP to 1 in 2,000 AEP are considered the most significant. For this range of floods, the potential uncertainty of extreme flood estimation needs to be considered. Consequently a reasonable degree of conservatism should be applied to identify the most suitable flood estimates for assessment and design purposes.

4.7.5 Comparisons and Discussion

A comparison of flood estimates from the different flood estimation methods is presented in Figure 4-4 to Figure 4-7. The comparisons of the different peak flow estimation methods for various AEP events were used to draw the following conclusions:

- The ACARP empirical method flood estimates generally plot above the QRT-OLS empirical method flood estimates for 1 in 100 AEP. This likely reflects that the ACARP method is more specifically applicable for central Queensland catchments compared to the QRT-OLS method which is more generally applicable to broader diversity of Queensland catchments.
- The 1 in 100 AEP rainfall based (RORB) flood estimates for each catchment modelled appeared reasonable when compared with the QRT and ACARP estimates. The RORB estimates for Eureka Creek and Goonyella Creek are approximately nine per cent greater than the ACARP estimates. The ACARP estimates for 12 Mile Gully and the combined catchment of Holding, Fisher and Platypus Creeks were approximately 12 per cent and 20 per cent larger respectively, than the RORB estimates.
- However, for Eureka Creek, Goonyella Creek and 12 Mile Gully; the RORB estimates for the 1 in 10 AEP and 1 in 20 AEP peak flows are larger by approximately 30 to 50 per cent when compared to the QRT-OLS method and approximately 60 per cent larger when compared to ACARP.

The ACARP empirical method is considered more applicable to Central Queensland catchments, particularly in the Bowen Basin compared to QRT-OLS empirical method. Because the rainfall based estimates (RORB) for 1 in 10 AEP and 1 in 20 AEP events plot notably higher than the ACARP empirical method, it is considered that the RORB estimates are more conservative for the more frequent floods. As stated before the 1 in 10 and 1 in 20 AEP peak flows are for comparative purposes only and not used as inputs for any hydraulic modelling.

4 Runoff-Routing Model for Tributaries in EIS Study Area

Figure 4-4 RORB, QRT & ARCAP Estimated Peak Flows versus AEP for Eureka Creek

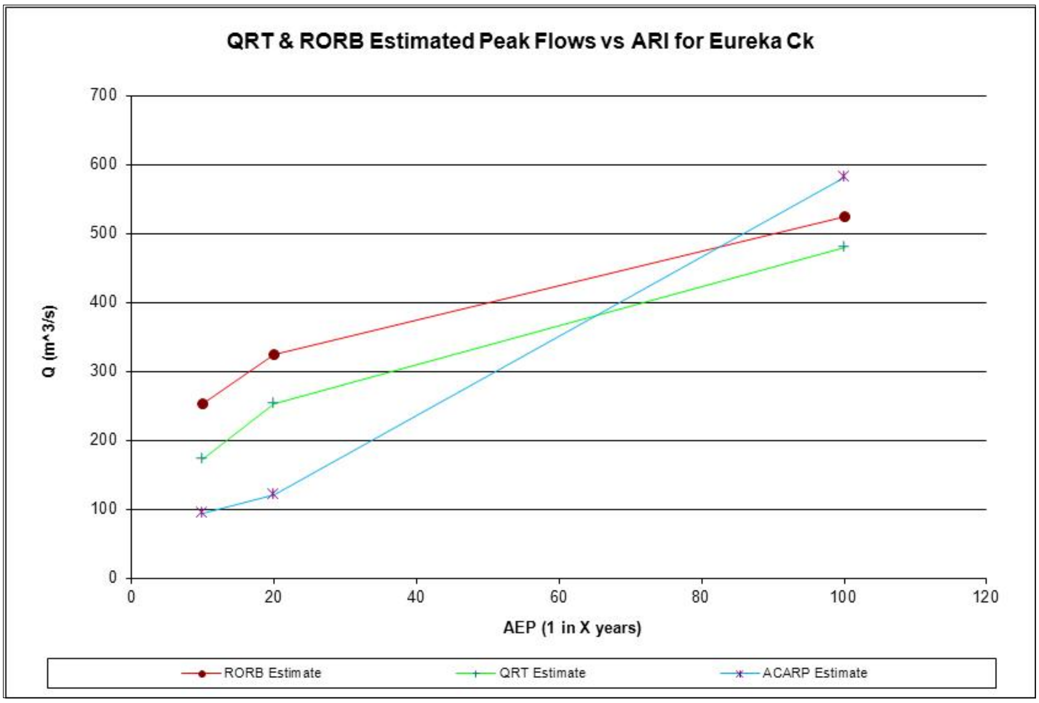


Figure 4-5 RORB, QRT & ARCAP Estimated Peak Flows versus AEP for Holding, Fisher & Platypus Creeks

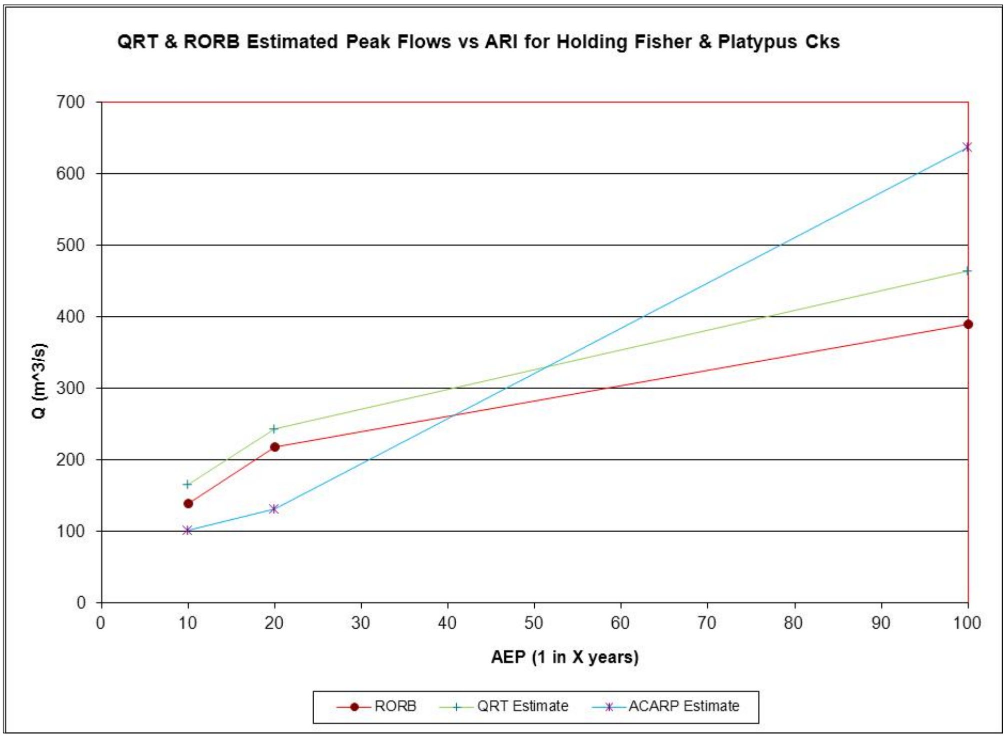


Figure 4-6 RORB, QRT & ARCAP Estimated Peak Flows versus AEP for Goonyella Creek

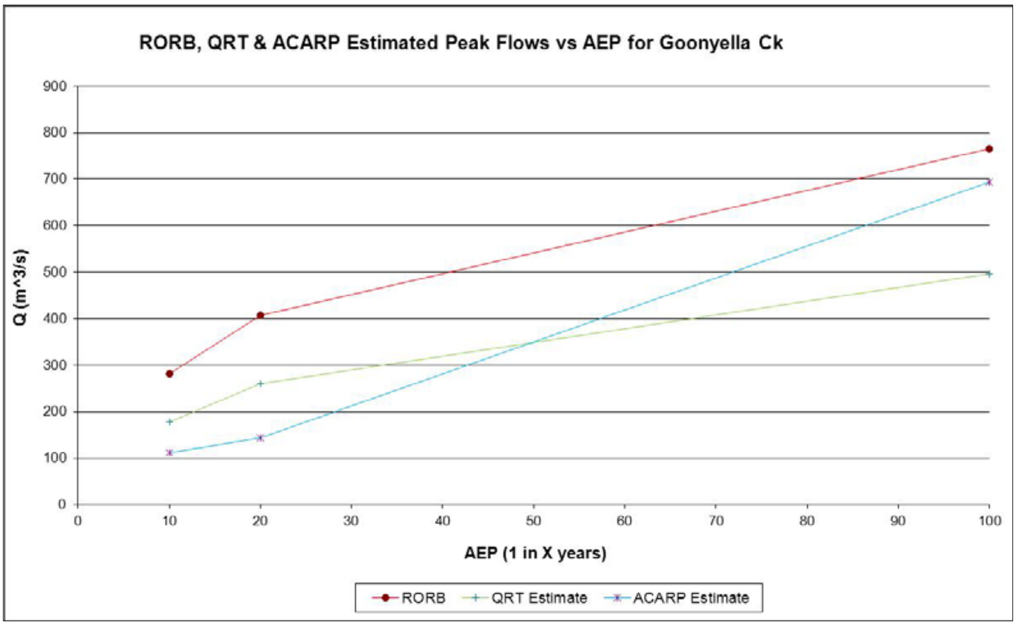
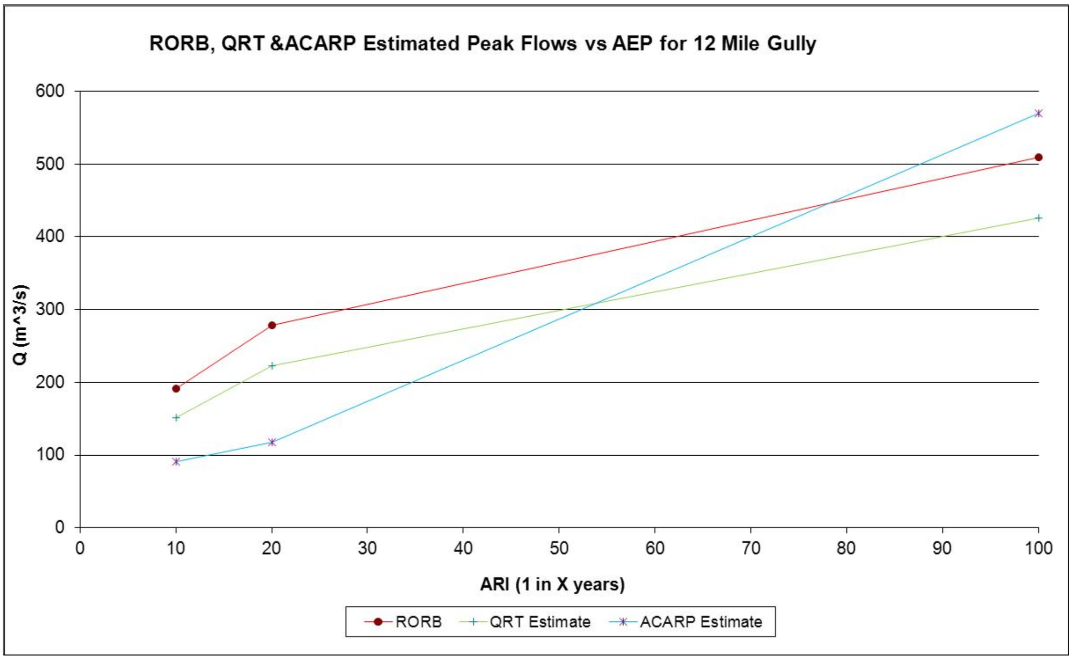


Figure 4-7 RORB, QRT & ARCAP Estimated Peak Flows versus AEP for 12 Mile Gully



4.8 Recommended Flood Estimates

Based on the analysis above, the flood estimates from the rainfall runoff routing modelling (RORB results) were adopted for the range of events from the 1 in 10 to the 1 in 2,000 AEP events.

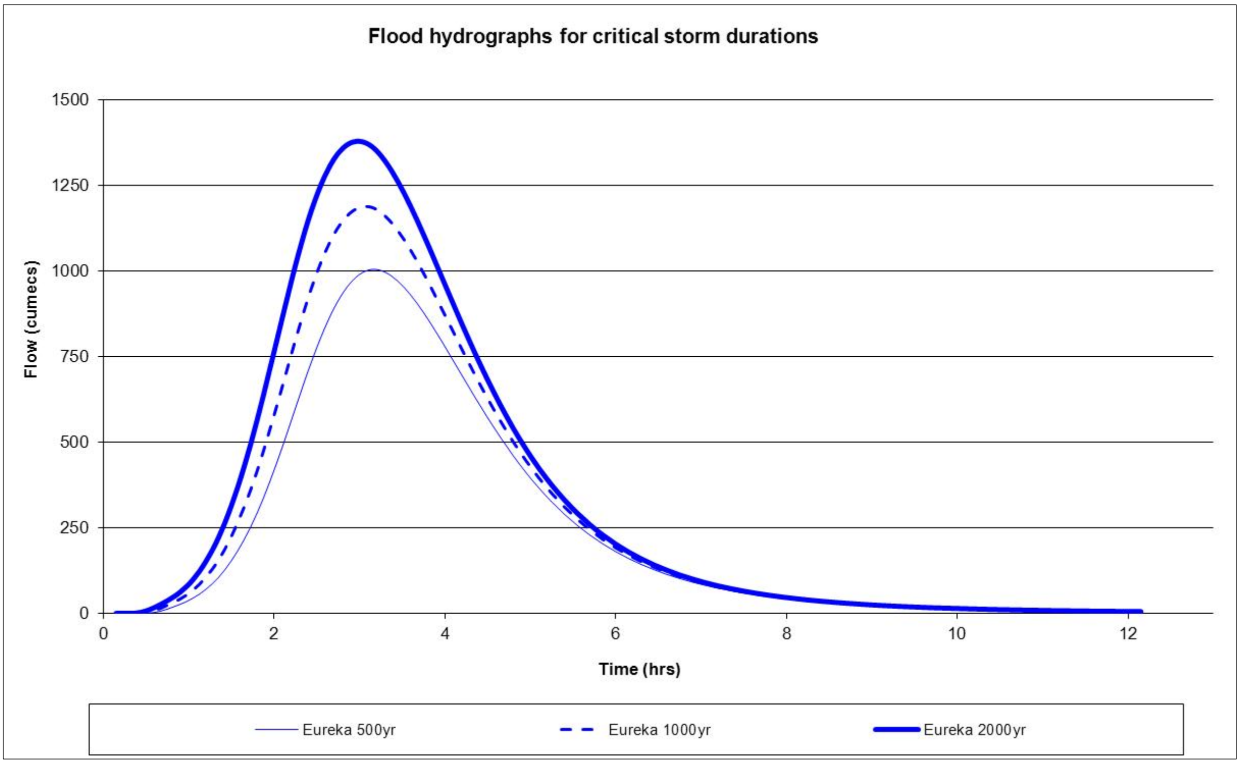
A summary of the adopted flood estimates is presented in Table 4-15, along with their associated hydrographs in Figure 4-8 to Figure 4-11.

4 Runoff-Routing Model for Tributaries in EIS Study Area

Table 4-15 Summary of Peak Flow and Critical Storm Duration at Catchment Outlet

AEP	Eureka Creek Outlet (m^3/s)	Holding, Fisher & Platypus Creek Outlet (m^3/s)	Goonyella Creek outlet (m^3/s)	12 Mile Gully Outlet (m^3/s)
1 in 10	220 (6hr)	180 (6hr)	280 (6hr)	190 (6hr)
1 in 20	330 (3hr)	280 (6hr)	400 (6hr)	280 (6hr)
1 in 100	640 (3hr)	530 (3hr)	770 (3hr)	500 (3hr)
1 in 500	1,000 (3hr)	850 (3hr)	1,200 (3hr)	800 (3hr)
1 in 1,000	1,200 (3hr)	1,000 (3hr)	1,400 (3hr)	970 (3hr)
1 in 2,000	1,400 (3hr)	1,200 (3hr)	1,700 (3hr)	1,200 (3hr)

Figure 4-8 Flood Hydrographs of Critical Storm Durations for Eureka Creek Catchment at Outlet



4 Runoff-Routing Model for Tributaries in EIS Study Area

Figure 4-9 Flood Hydrographs of Critical Storm Durations for Holding Creek Catchment at Outlet

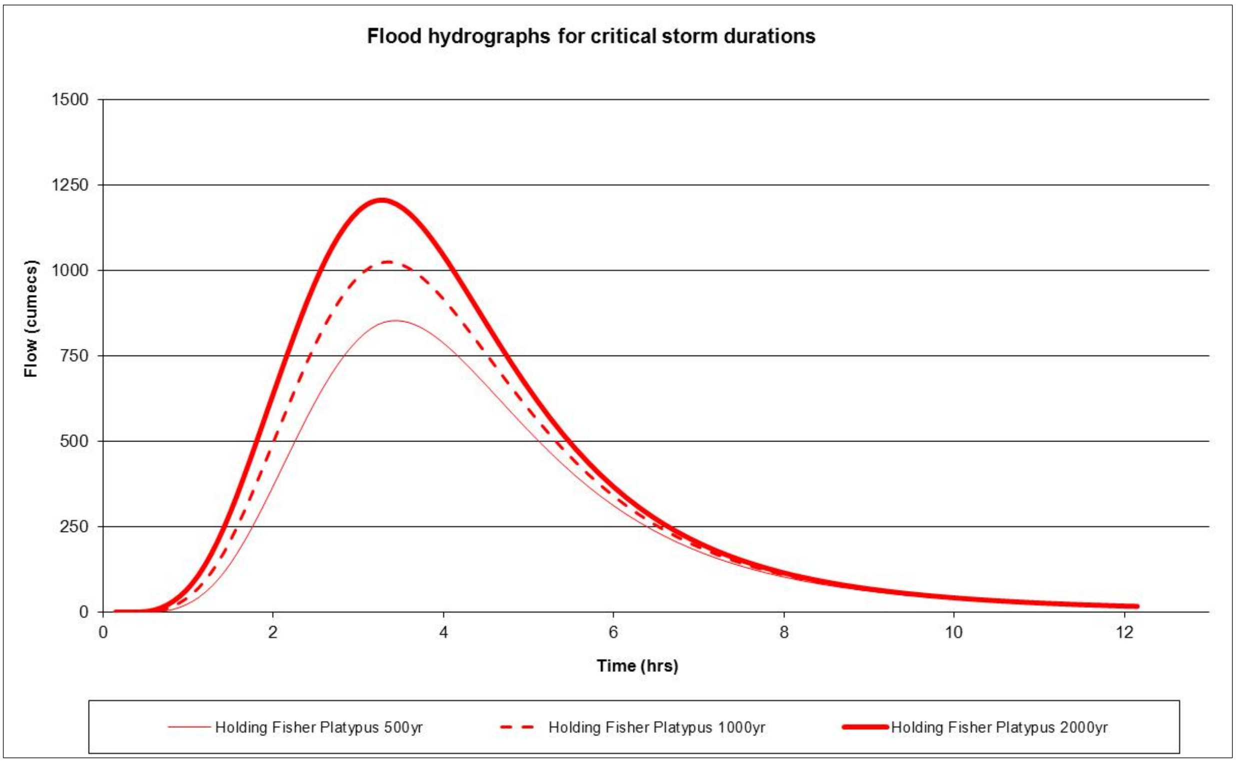
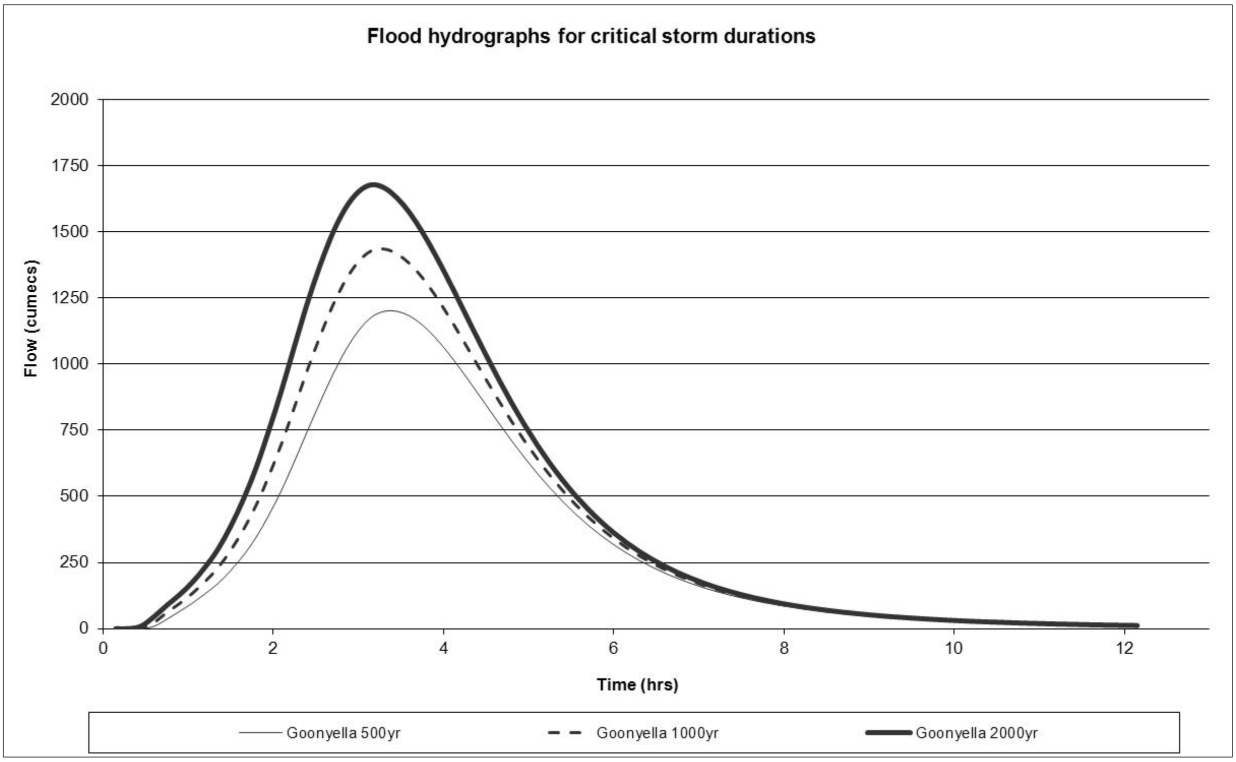
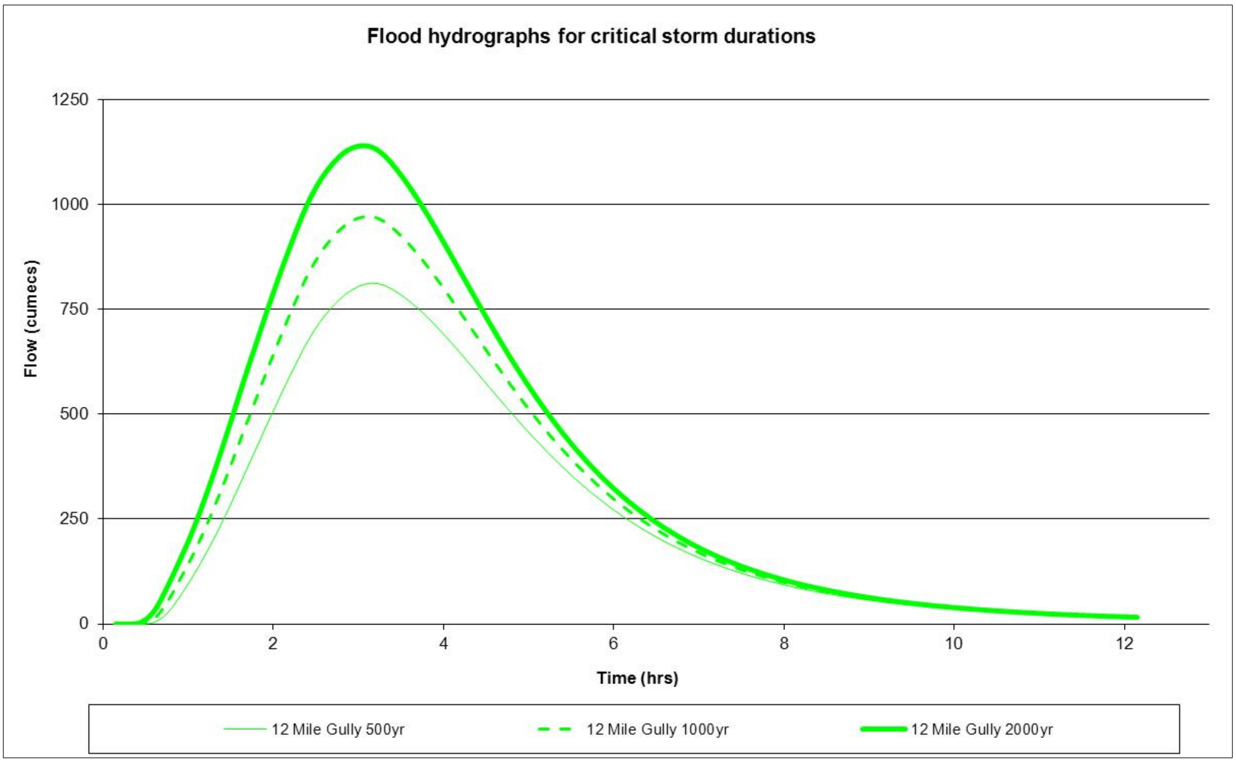


Figure 4-10 Flood Hydrographs of Critical Storm Durations for Goonyella Creek Catchment at Outlet



4 Runoff-Routing Model for Tributaries in EIS Study Area

Figure 4-11 Flood Hydrographs of Critical Storm Durations for 12-Mile Gully Catchment at Outlet



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Appendix A URS Scaled K_c Methodology

This spread sheet was originally prepared for Caval Ridge EIS - Supplement -
J:\Jobs\42626420\5 Works\Flood Analysis\7.5 RORB\RORB FILES1\PARAMETER

Rare and extreme flood analysis for risk of flooding of mine pits
Flood Hydrology
Derivation of RORB runoff-routing model parameters
Prepared by: Michel Raymond

Purpose
Determine RORB Kc parameters for creeks specific to GCE project site

Reference Information
Isaac River Flood Study reported in Appendix C of Isaac River Cumulative Impact Assessment of Mine Developments - August 2008 Version 3
Note: Overall Report prepared by Alluvium Consulting, however Appendix C prepared by Sargent Consulting

Basis Sargent Consulting Flood Study of Isaac River has calibrated RORB model and reports Kc Values at various locations along the River
In absence of recorded floods to calibrate a RORB model of creeks through proposed Caval Ridge mine, use scaling of Isaac River parameters
Common empirical equations relate to Kc to Area ^ approx 0.5 to 0.6, hence test fit for this function

Data From Sargent Consulting Report | **Calculation**

			Fit Kc = X . Area $^{0.5}$
Location	**Catchment Area (km^2)**	**Calibrated RORB Kc value**	Parameter X =
Isaac River at Burton Gorge	555	20	0.85
Isaac River at Goonyella	1215	27.5	0.79
Isaac River at Deverill	4155	78	1.21

Interpretation
Isaac River upstream of Burton Gorge has distinctly different geology to downstream around Goonyella and Deverill
Goonyella Gauge is closest to GCE Site, has similar local geology and is probably most relevant
Deverill Gauge catchment is much larger than subject GCE creek catchments
On balance fit for Goonyella Gauge is likely to be most relevant

Adopt Kc = 0.8 x Area $^{0.5}$

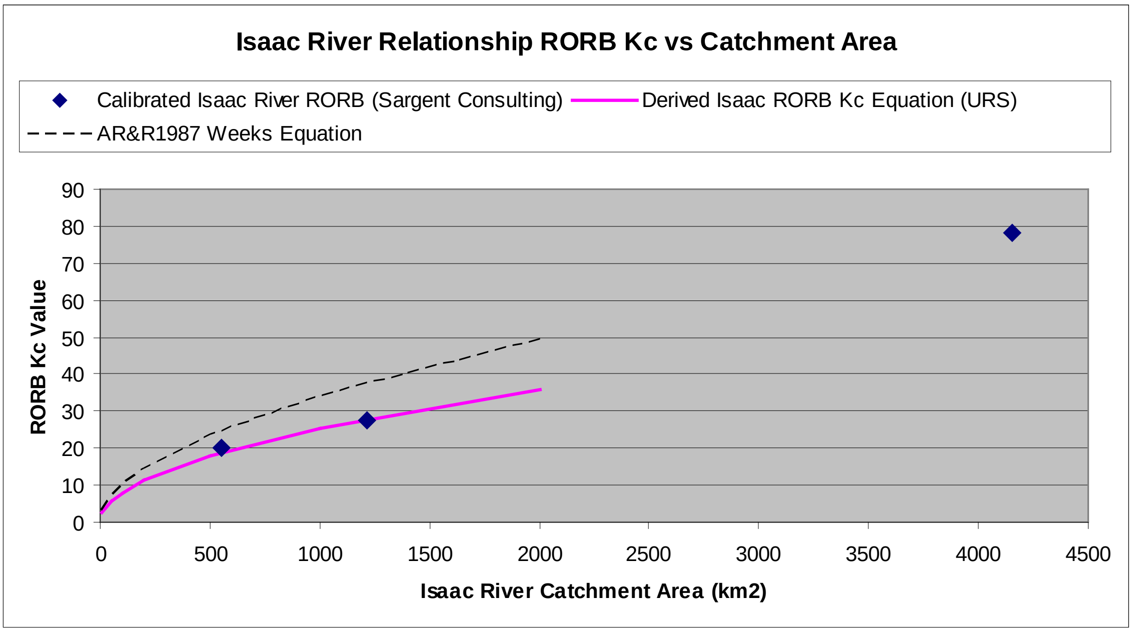
Test and Compare with Weeks (1986) equation reported in AR&R 1987 (Kc = 0.88 Area^$^{0.53}$)

Area (km2)	Kc derived from calibrated Isaac RORB	Kc derived from Weeks Equation
10	2.5	3.0
50	5.7	7.0
100	8.0	10.1
200	11.3	14.6
500	17.9	23.7
1000	25.3	34.2
2000	35.8	49.4

Review and Conclusion
Plot shows reasonable fit of derived equation to Calibrated Isaac River RORB for catchment areas in range of 200 to 1500 km^2
Derived equation estimates lower value Kc than empircal equation reported by Weeks
Lower Kc value produces higher peak flood estimates which will be conservative and appropriate for the flood analysis
Hence, adopt derived equation:- Kc = 0.8 Area $^{0.5}$ (where area is in km^2)

Appendix A - URS Scaled Kc Methodology

Figure Appendix A-1 Isaac River Relationship RORB K_c vs Catchment Area



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