Report

Caval Ridge Environmental Impact Statement Supplementary Flood Modelling

30 OCTOBER 2009

Prepared for

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1

Introduction

This report has been prepared as part of the Supplementary EIS to provide additional information on flood inundation of the project during extreme events. This report builds on information provided in the flood assessment provided in Section 6 and Appendices I2 and I4 of the EIS and its purpose is to:

- Address comments that were raised in government agency submissions on the EIS

1.1 Background

The flood assessment provided in the Caval Ridge EIS considered inundation that would likely occur for up to a 1 in 100 year ARI event for the existing case i.e. no future development was modelled. Submissions were received from DERM regarding the flood inundation potential during extreme events. Specifically the following submissions were received:

- "For the operational phase, the EIS should provide a detailed assessment of the effects of inundation of the proposed project site from at least 1 in 500 year ARI event."
- "The EIS should include conceptual designs for the pits and levees, and more detailed consideration of flood immunity at the impacted site. It should provide commitments in the Draft EM plan to demonstrate that mitigation of potential environmental impacts will be delivered to an acceptable standard during the operational mine life, and for the foreseeable future after decommissioning and rehabilitation".

In order to address these comments additional flood modelling and assessment has been undertaken for events up to a 1 in 3000 AEP for the 30 year mine operational phase. The results of this assessment are presented in this report.

2 Hydrology

2.1 RORB

RORB Vers.6 was used to derive peak flows for the developed case for 1 in 500, 1000, 2000 and 3000 AEP events. More specifically RORB was used to derive peak flows for input into a hydraulic model which determines the depth and spatial extents of flooding and other hydraulic parameters for design of flood protection levees.

The RORB model is considered to be superior to a Flood Frequency Analysis (FFA) due to its ability to route hydrographs through an extensive network and attenuate flow. Furthermore, extensive RORB modelling has been undertaken on a regional scale (by Sargent Consulting) which provides a source for determining catchment response to rainfall.

Due to the extents of hydraulic modelling two RORB models were constructed; Horse Creek Diversion and Caval Creek Diversion. The extents of catchment delineation for these models are illustrated in Appendix A.

2.2 Input Parameters

2.2.1 Rainfall Losses

RORB includes a loss model to account for rainfall losses, allowing for an initial loss followed by continual loss. The loss parameters were derived from AR&R (1998) - Book IV Estimation of Large and Extreme Floods and as shown in Table 2-1 Rainfall loss values The process followed for the derivation of loss parameters is provided in Appendix C.

Table 2-1 Rainfall loss values

ARI (Years)	Initial Loss (mm)	Continuous Loss(mm/hr)
500	5	2.0
1000	4	1.5
2000	3	1.0
3000	2.6	1.0

2.2.2 Catchment Lag Coefficient- kc

The catchment lag coefficient, kc, is the principal calibration tool for RORB models. In the absence of regional stream gauge data with which to calibrate the models, kc scaling relationships were derived from a RORB model constructed by Sargent Consulting and documented in the Isaac River Cumulative Impact Assessment report (Alluvium 2008). This process is detailed in Appendix C and the derived kc values are provided in Table 2-2. It should be noted that different kc values were derived for each models due to the large proportional difference in catchment size.

Table 2-2 Parameter kc

Catchment	Kc Value
Horse Creek Diversion	5.16
Caval Creek Diversion	22

2.3 Design Temporal Distribution

Temporal pattern distributions for each model were derived using pluviograph traces recorded for major Australian storms as referenced from the Estimation of Probable Maximum Precipitation in Australia- Generalised Short Duration method, Figure 5, Section 4. The graph used to derive the pluviograophs for RORB input is provided in Appendix C.

2.4 Peak Flow Adoptions

Peak flow RORB outputs as adopted for the hydraulic modelling are presented in Table 2-2 and Table 2-3. Smaller catchments (such as the Horse Creek diversion catchment) had a critical storm duration of 1hr while larger catchments (such as the Cherwell Creek catchment) had a critical storm duration of 3hrs. In order to provide consistency of boundary conditions within the hydraulic models a single critical storm duration was required. This was calculated by identifying locations regional to the areas of interest and applying the critical storm duration for these locations to all contributing catchments. These locations were determined to be the downstream extent of the Horse Creek catchment and the confluence between Caval and Cherwell Creeks for Horse Creek Diversion and Caval Creek Diversion models respectively.

Table 2-3 Caval Creek Diversion - RORB Peak FlowsCaval Creek Diversion - RORB Peak Flows

Caval Creek Diversion				
Description	Flow (3hrCSD)(m^3/s)			
	500	1000	2000	3000
Caval Creek Inflow	220	250	282	293
Caval Diversion	168	190	214	223
Cherwell Creek Inflow	2568	2958	3378	3525
Nine Mile Creek Inflow	861	981	1111	1157
Cherwell Nine Mile Confluence	3325	3826	4368	4560
Cherwell Caval Confluence	3454	4000	4587	4795
Cherwell Harrow Confluence	5086	5913	6809	7119

Table 2-4 Horse Creek Diversion - RORB Peak Flows

Horse Creek Diversion				
Description	Flow (1hrCSD))(m^3/s)			
	500	1000	2000	3000
Horse Creek Inflow	931	1076	1235	1323

2.5 Results Verification

The Rational Method was used to verify peak flow outputs from the Horse Creek Diversion RORB model. This was done in order to verify the kc value used for smaller catchments since the scaling relationships were derived from much larger catchments. Assumptions and formula's used in the calculation are detailed in Appendix C.

Table 2-5 Comparison Between RORB and Rational Method

Rorb Model	Peak Flows (m^3/s)							
	1 in 500 AEP		1 in 1000 AEP		1 in 2000 AEP		1 in 3000 AEP	
	RM	RORB	RM	RORB	RM	RORB	RM	RORB
Horse Creek	1020	931	1135	1076	1255	1234	1326	1323

NOTE : RM = Rational Method

The results in Table 2.5 show that there is a good correlation between the RORB outputs and the Rational Method particular for the 1 in 2000 and 1 in 3000 AEP events.

Hydraulics

3.1 Hydraulic Modelling Objectives

The objective of the hydraulic modelling was to assess the potential for inundation of Heyford and Horse pits for the 30 year operational phase of the mine during extreme events.

3.2 Hydraulic Model Selection

HEC-RAS was selected due to its ability to calculate water surface profiles for steady gradually varied flow. The steady flow component of HEC-RAS if run in mixed flow mode is capable of calculating subcritical and supercritical flow in which this project is modelled. Some other attributes which make HEC-RAS suitable for the pit inundation hydraulic analysis are:

- HEC-RAS utilises one-dimensional energy equations
  - Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head)
- HEC-RAS utilises momentum equations in situations where the water surface profile varies rapidly i.e. river confluences (stream junctions) and hydraulic structures
- HEC-RAS is capable of modelling a large network of streams
- Results can be exported and flood inundation determined for each return period
- Flow changes can be added at any cross section chainage

3.3 Model build

Two HEC-RAS models were constructed for the study; Horse Creek Diversion and Caval Creek Diversion. The Horse Creek Diversion model was used to assess inundation of Horse pit whereas the Caval Creek Diversion model was used to assess inundation of Heyford pit, Caval Creek diversion and mine infrastructure. Levees were included within the models to avoid pit inundation and to determine the required levee heights for conceptual design.

3.3.1 Description of Geometry Data

Figures 1 and 2 illustrate the HEC-RAS geometry schematic for Horse Creek Diversion and Caval Creek Diversion models respectively. The HEC-RAS geometry files were created using 12d software, which is a 3D terrain and design model capable of constructing HEC-RAS projects. Figure 3 shows an aerial photo of the existing surface, 30 year operational phase pit extents and mine plant included in the developed topography, and the HEC-RAS cross sections and river strings used to create the models.

3.3.2 Hydraulic structures

Hydraulic structures were incorporated within the Caval Creek Diversion model at five locations as described below.

Caval Ck Crossing Haul Rd (Caval Ck - Ch 6940)

- 3 circular concrete pipe culvert barrels
- 1.8m diameter

Peak Downs Highway Crossing (Caval Ck – Ch 4770)

- 4 circular concrete pipe culverts
- 2.1m diameter

Caval Creek Crossing (Caval Ck – Ch 4644)

- 4 circular concrete pipe culvert barrels
- 1.8m diameter

Cherwell Creek Crossing (Cherwell Ck – Ch 20694)

- 7 box concrete barrels
- 1.8m rise; 2.1m span

Nine Mile Creek Crossing (Nine Mile Ck – Ch 1340)

- 4 box concrete barrels
- 1.8m rise; 2.1m span

The length and invert levels of the culverts were assumed for modelling purposes based on the proposed design and existing information available to URS.

3.3.3 Roughness Values

Manning's roughness values were assigned to the left overbank, right overbank and main channel for each cross section. The roughness values were estimated from aerial photograph taking into account the proposed mine infrastructure as referenced in AR&R Vol 1 (1987). The adopted roughness values are shown in Table 3.1 below.

Table 3-1 Manning's N Values

Drainage Feature	Manning's N Values		
	Left Overbank	Channel	Right Overbank
Cherwell Creek	0.07 (Natural Ground)	0.045	0.07 (Natural Ground)
Caval Creek	0.07 (Natural Ground)	0.045	0.07 (Natural Ground)
Horse Creek	0.07 (Natural Ground)	0.045	0.07 (Natural Ground)
Mine Infratructure	0.035	0.045	0.035

3.3.4 Steady Flow Data and Boundary Conditions

Steady flow data was derived from RORB modelling conducted for this assessment. Both HEC RAS models were run for mixed flow conditions. As a conservative measure peak flows at the downstream end of each river reach were input as the upstream boundary condition.

The Horse Creek Diversion downstream boundary was input as a known water level. This is because the model terminates at a dam just upstream of the confluence with Grosvenor Creek. The spillway invert was used as the water surface elevation under the conservative assumption that the dam was full at EL 219.8m AHD.

The downstream boundary for the Caval Creek HEC RAS model was defined as the junction at creek confluences-

- Nine Mile Ck and Cherwell Ck confluence

and

- Caval Ck and Cherwell Ck confluence)

The downstream boundary of Cherwell Ck (Downstream of Ch 15580) was defined as normal depth.

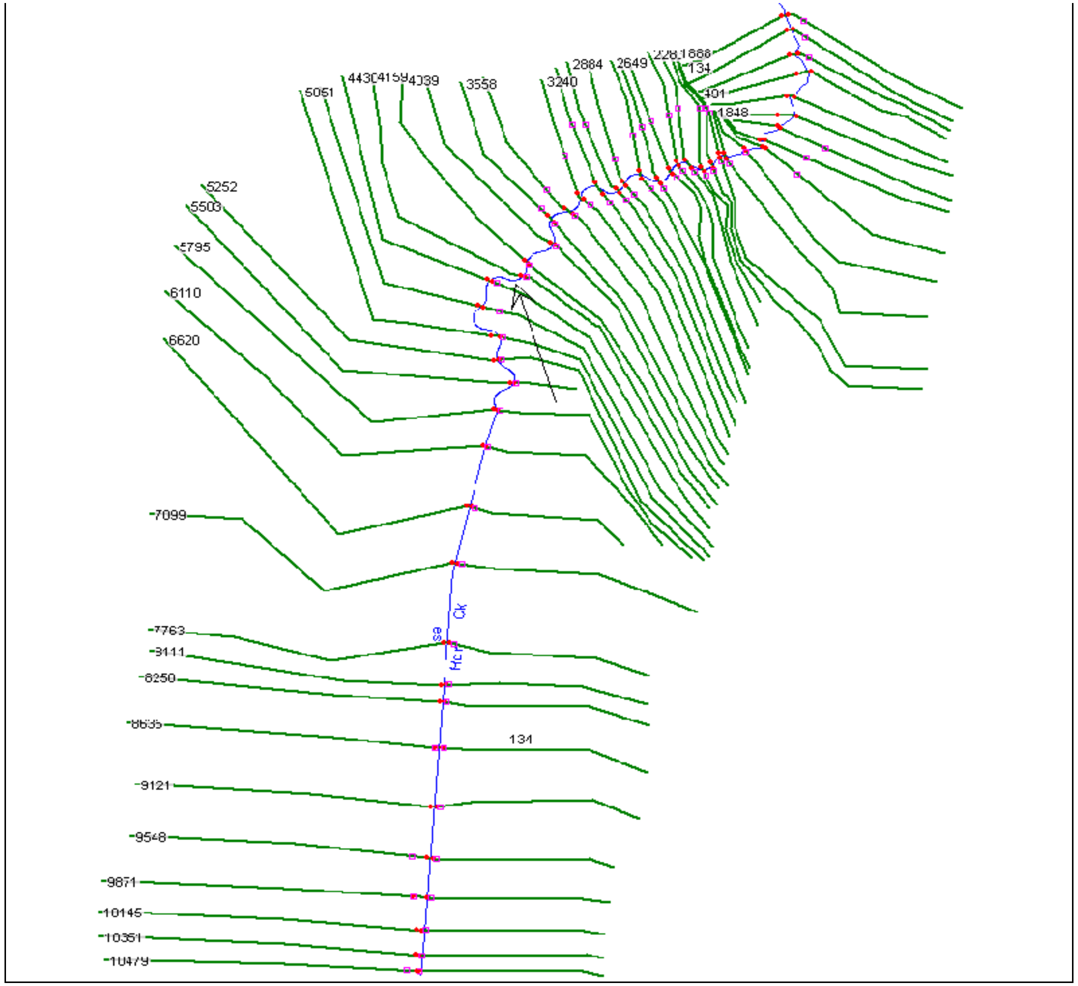


Figure 1

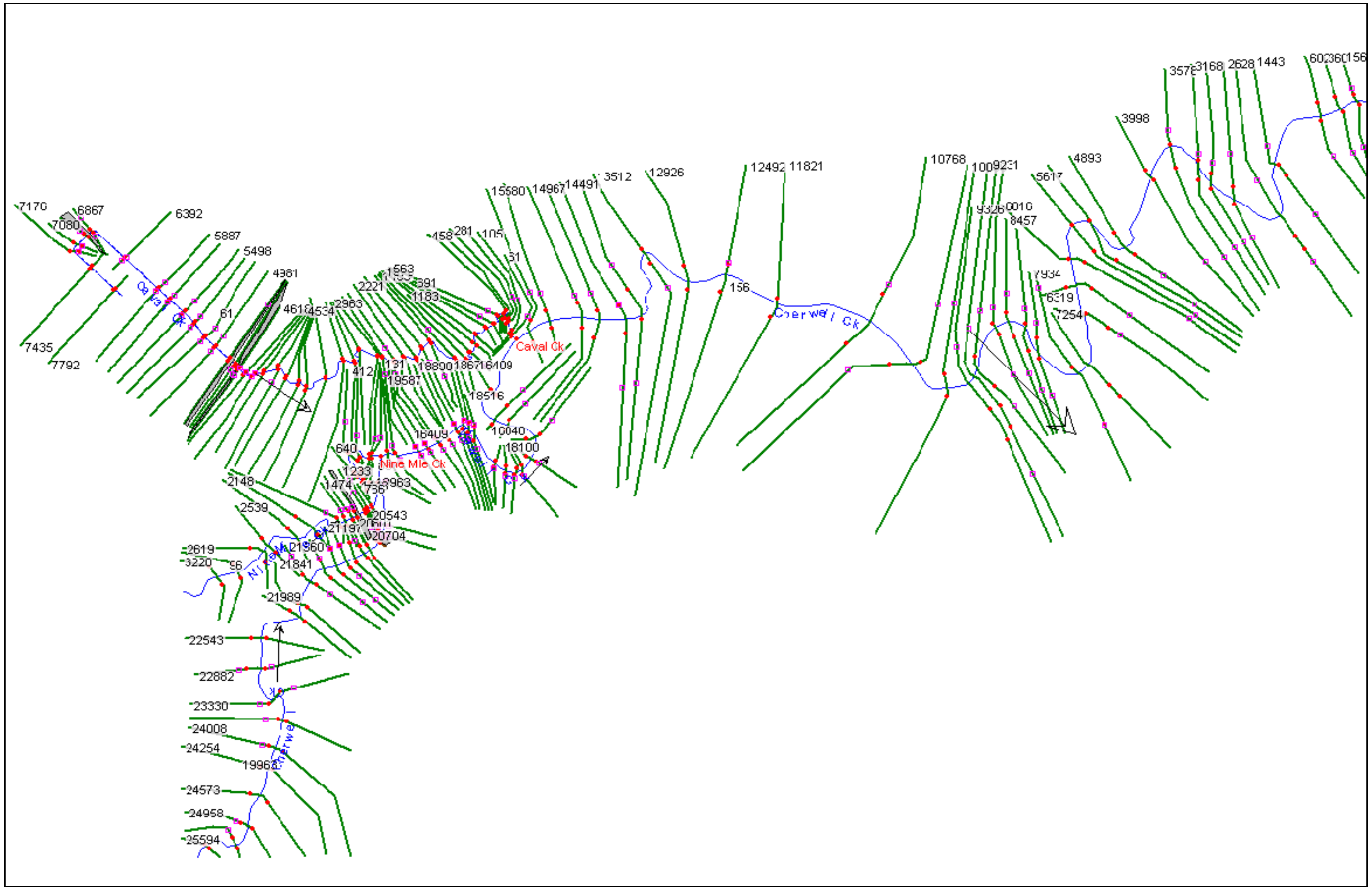


Figure 2

3 Hydraulics

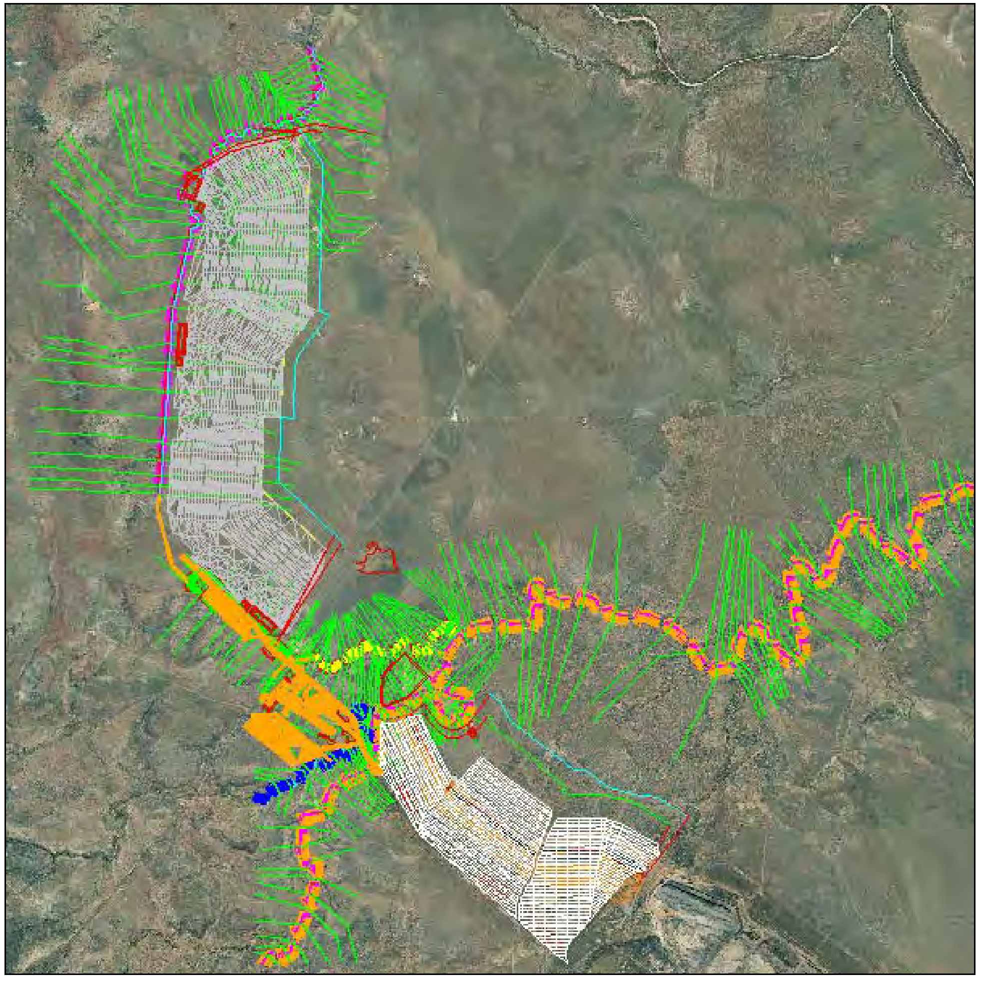


Figure 3

The flood inundation levels from the HEC RAS modelling software are shown in Figure_Appendix 2,3,4 and 5 in Appendix A for 500, 1000, 2000, and 3000 AEP events. These inundation levels are based on levees being present for both the Heyford and Horse pits such that pit inundation does not occur during the AEP 3000 event.

It should be noted that the hydraulic modelling identified three critical locations in the designed and natural channels where there is a potential for erosion and engineered protection may be required. These locations are:

- Horse creek diversion just upstream of its confluence with the natural channel (Ch 1848).
- Caval creek diversion downstream of the proposed culvert under the haul road to its confluence with the natural drainage channel at chainage 2344
- Cherwell Creek at chainage 16409

The table below outlines the flow velocities and chainages at these critical locations for the Horse and Caval Ck Hydraulic models for each design event.

Table 3-2 Horse Ck

Design Event	Chainage	Average Velocity (m/s)	Minimum Velocity (m/s)	Maximum Velocity (m/s)
ARI 3000	10479-1848	3.38	1.27	6.1
ARI 2000	10479-1848	3.36	1.29	5.91
ARI 1000	10479-1848	3.27	1.3	5.59
ARI 500	10479-1848	3.17	1.35	5.24

Table 3-3 Caval Ck

Design Event	Chainage	Average Velocity (m/s)	Minimum Velocity (m/s)	Maximum Velocity (m/s)
ARI 3000	6867- 2344	1.56	0.09	4.53
ARI 2000	6867- 2344	1.57	0.09	4.74
ARI 1000	6867- 2344	1.57	0.08	5.21
ARI 500	6867- 2344	1.48	0.06	4.02

Table 3-4 Cherwell Ck

Design Event	Chainage	Average Velocity (m/s)	Minimum Velocity (m/s)	Maximum Velocity (m/s)
ARI 3000	20582- 16409	3.17	1.42	5.58
ARI 2000	20582- 16409	3.12	1.36	5.43
ARI 1000	20582- 16409	3.01	1.34	5.03
ARI 500	20582- 16409	2.91	1.32	4.65

References

Alluvium Isaac River Cumulative Impact Assessment (2008) S Lovejoy, D Sargent

Institution of Engineers, Australia (1998) Extracted from Australian Rainfall and Runoff: Book 1V Estimation of Large and Extreme Floods R J Nathan and P E Weinmann

Institution of Engineers, Australia (1987) Australian Rainfall and Runoff: Book A Guide To Flood Estimation Vol 1 Editor in Chief D.H Pilgram Revised Edition 1987 Reprinted Edition 1998 Barton ACT

Limitations

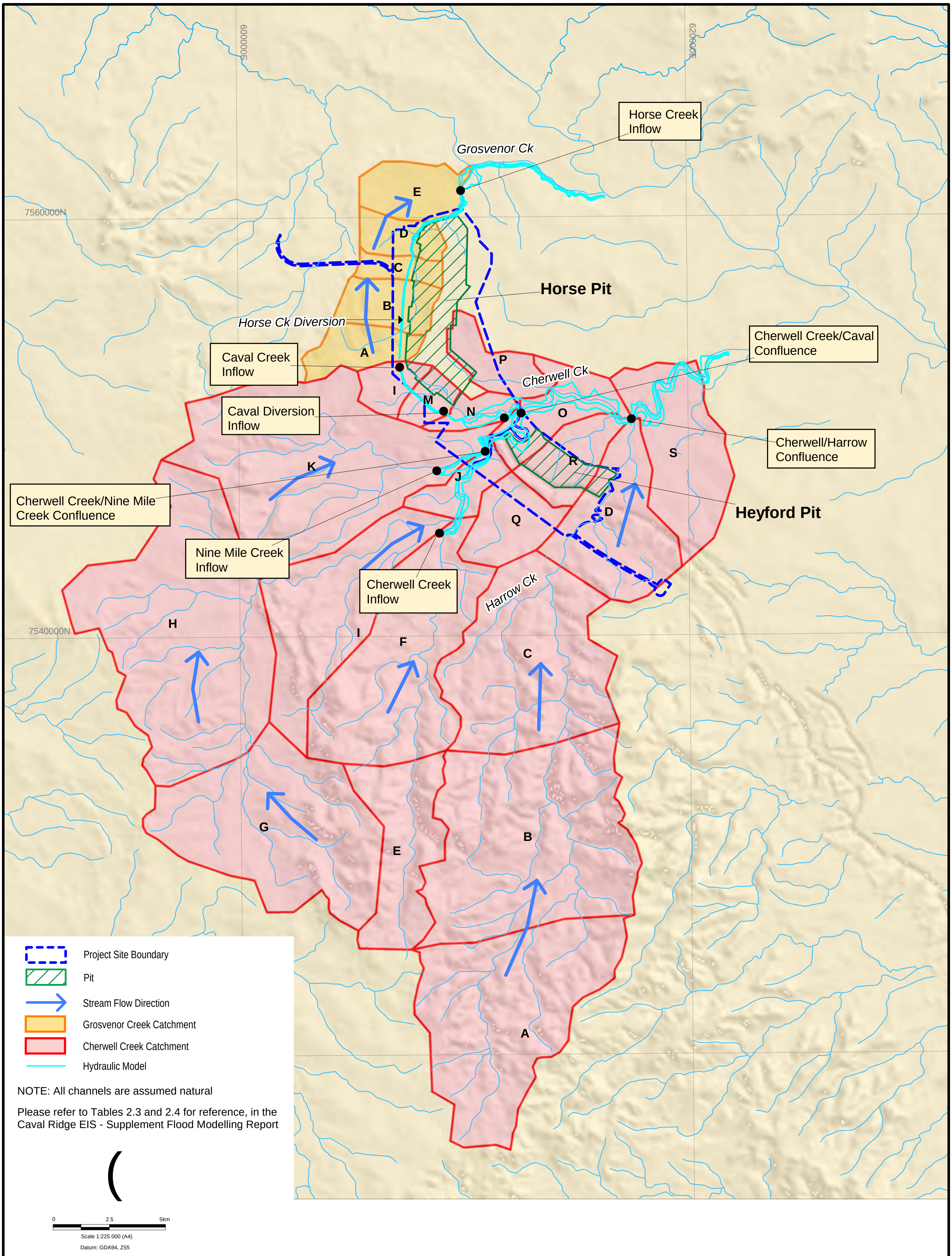
URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of BMA and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 15 September 2009. The work has been undertaken using operational infrastructure details and locations provided by BMA.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between 21 September and 27 October 2009 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Appendix A Figures

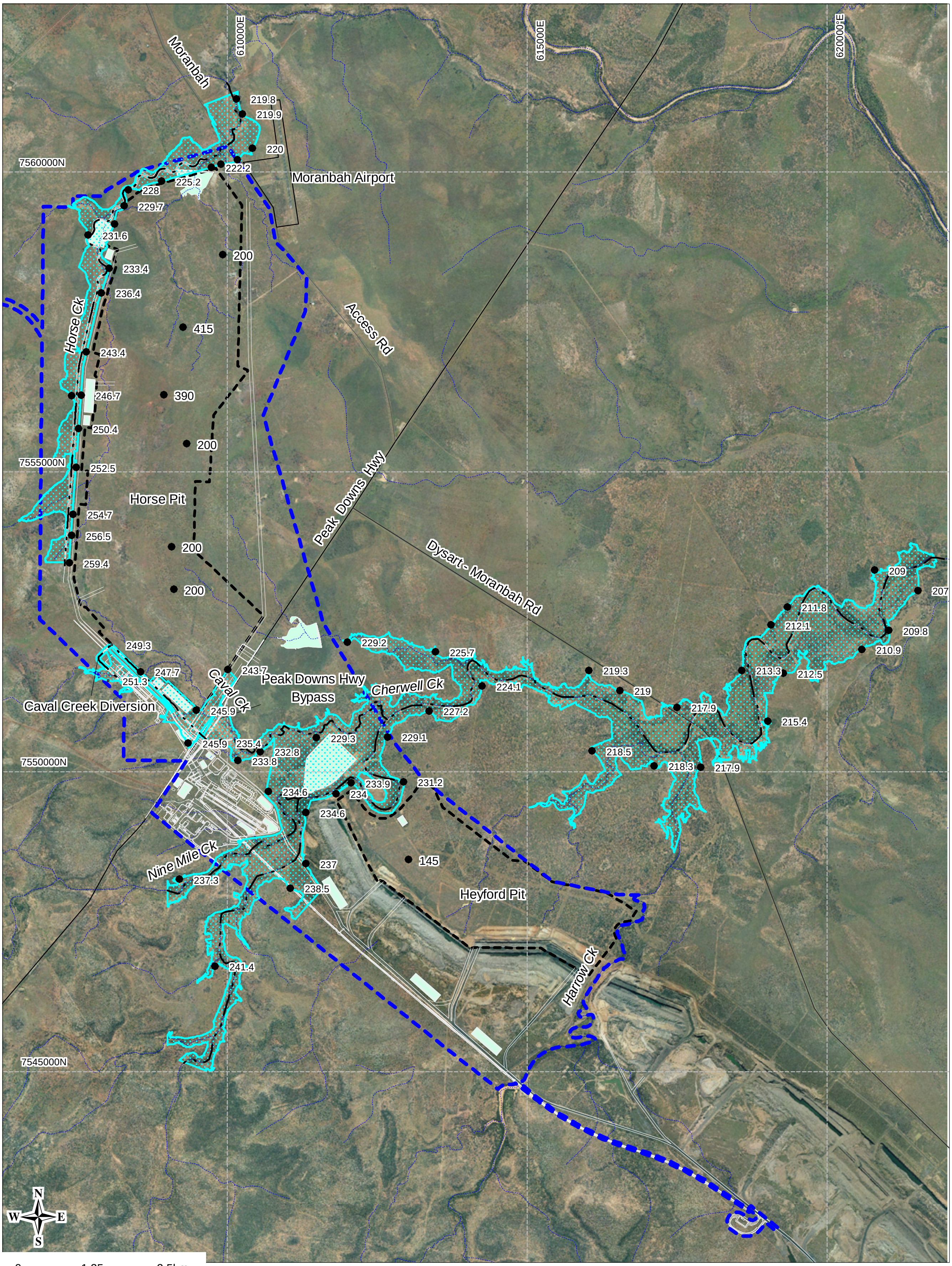


NOTE: All channels are assumed natural

Please refer to Tables 2.3 and 2.4 for reference, in the Caval Ridge EIS - Supplement Flood Modelling Report

Source: Qld Dept. NRW

Client	Project	Title
BMA BHP Billiton Mitsubishi Alliance	CAVAL RIDGE PROJECT ENVIRONMENTAL IMPACT STATEMENT SUPPLEMENT FLOOD ASSESSMENT	**RORB SUBCATCHMENT**
URS	Drawn: AA Approved: VV Date: 26-10-2009	Figure: **Appendix 1** Rev:B
	Job No: **42626420** /6158 File No: 42626158-g1523b.wor	A4



0 1.25 2.5km

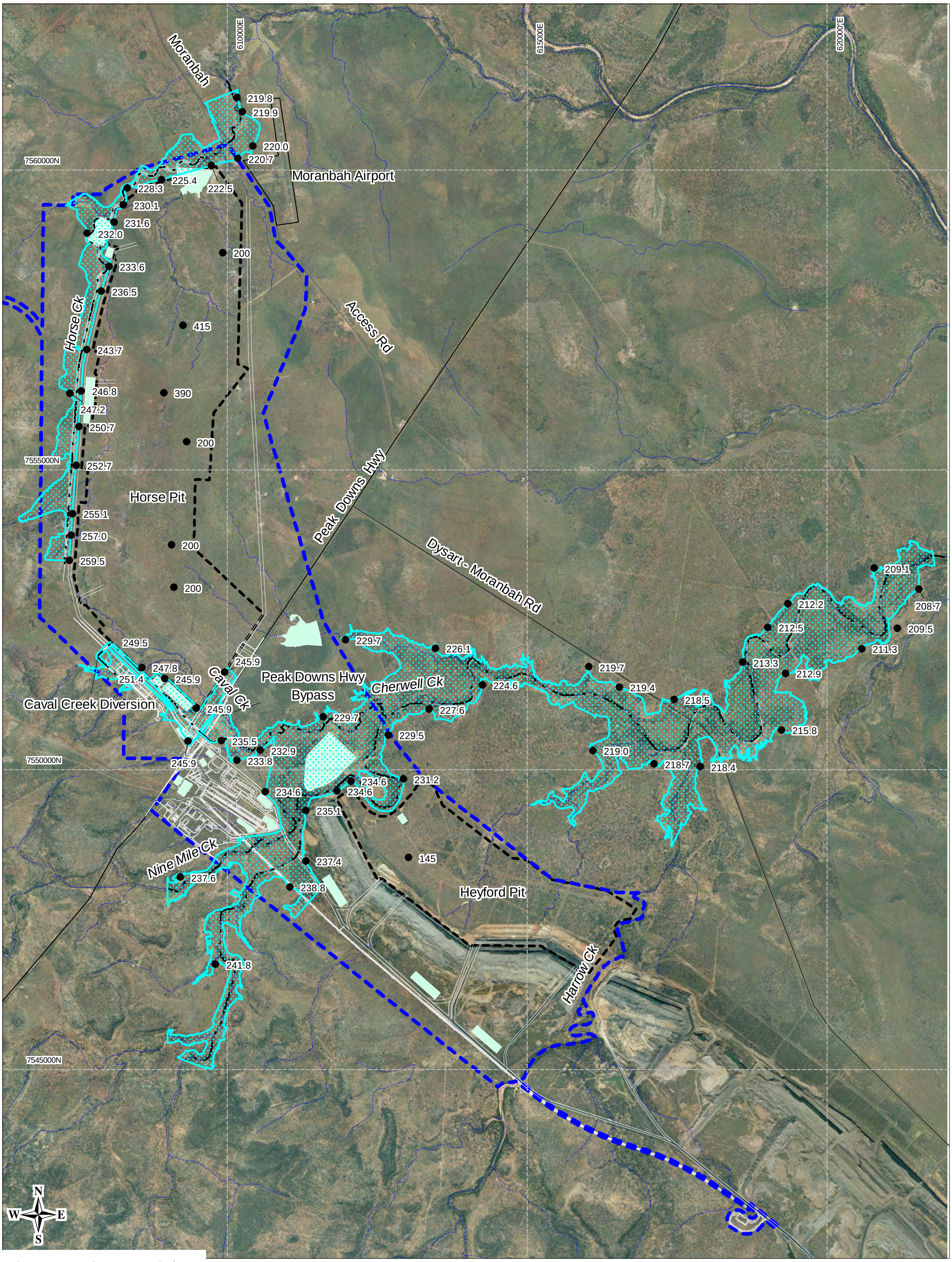
Scale 1:90 000 (A4)

Datum: AGD84, AMG Zone 55

Source: BMA Supplied Data

Legend	
Project Site	Open Cut Pit
AEP 500 Flood Extent	Dam
Proposed Mine Infrastructure	Spot Heights
Stream Centre Line	

Client	Project	Title
BMA BHP Billiton Mitsubishi Alliance URS	CAVAL RIDGE PROJECT ENVIRONMENTAL IMPACT STATEMENT SUPPLEMENT FLOOD ASSESSMENT	**AEP 500 FLOOD EXTENTS**
	Drawn: VH / Approved: PS / Date: 29-10-2009	Figure: **Appendix 2** — Rev:C
	Job No: **4262 6420** /6158 / File No: 42626158-g-1519c.wor	A4



0 1.25 2.5km

Scale 1:90 000 (A4)

Datum: AGD84, AMG Zone 55

Source: BMA Supplied Data

Legend	
Project Site	Open Cut Pit
AEP 1000 Flood Extent	Dam
Proposed Mine Infrastructure	Spot Heights
Stream Centre Line	

Client

BMA
BHP Billiton Mitsubishi Alliance

URS

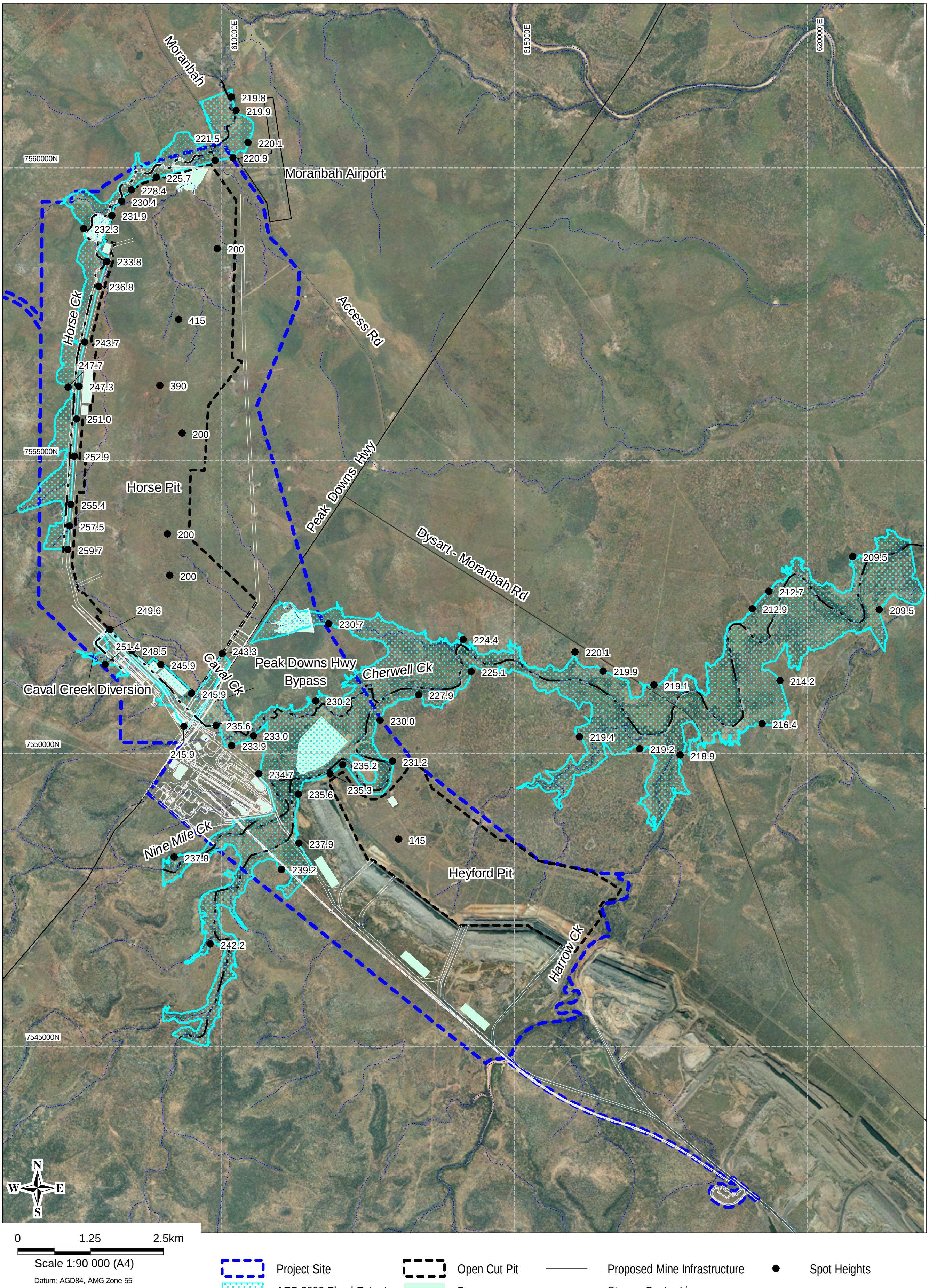
Project

CAVAL RIDGE PROJECT
ENVIRONMENTAL IMPACT STATEMENT
SUPPLEMENT
FLOOD ASSESSMENT

Title

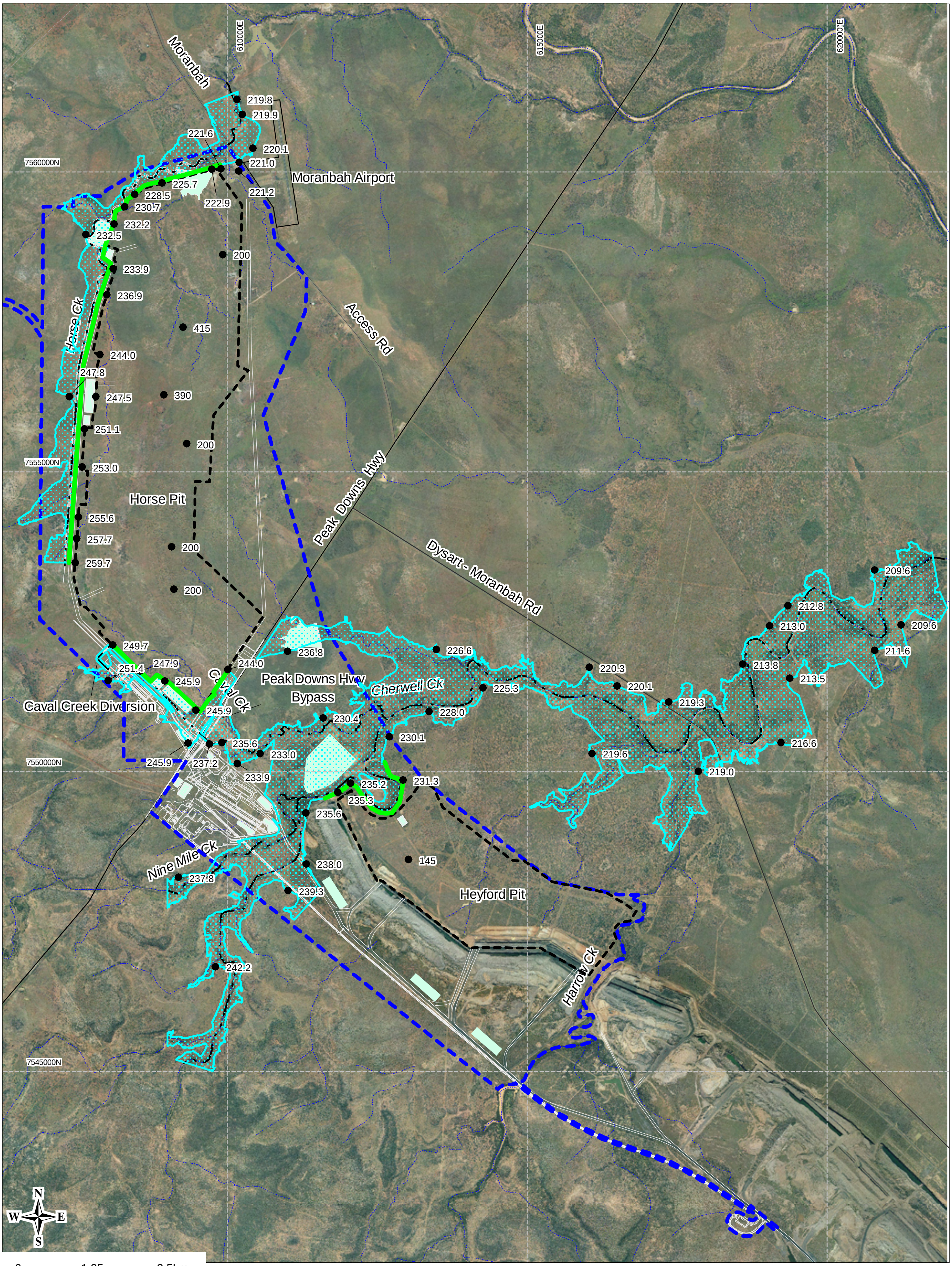
AEP 1000 FLOOD EXTENTS

Drawn: VH	Approved: PS	Date: 29-10-2009	Figure: **Appendix 3**	Rev:C
Job No: **4262 6420** /6158	File No: 42626158-g-1520c.wor			A4



Source: BMA Supplied Data

Client	Project	Title
BMA BHP Billiton Mitsubishi Alliance	CAVAL RIDGE PROJECT ENVIRONMENTAL IMPACT STATEMENT SUPPLEMENT FLOOD ASSESSMENT	**AEP 2000 FLOOD EXTENTS**
URS	Drawn: VH — Approved: PS — Date: 29-10-2009 Job No: **4262 6420** /6158 — File No: 42626158-g-1521c.wor	Figure: **Appendix 4** — Rev:C — **A4**



0 1.25 2.5km

Scale 1:90 000 (A4)

Datum: AGD84, AMG Zone 55

Source: BMA Supplied Data

Legend	
Project Site	AEP 3000 Flood Extent
Open Cut Pit	Dam
Proposed Mine Infrastructure	Stream Centre Line
Spot Heights	Extent of Levee (3000 year ARI flood immunity to pit)

Client

BMA
BHP Billiton Mitsubishi Alliance

URS

Project

CAVAL RIDGE PROJECT
ENVIRONMENTAL IMPACT STATEMENT
SUPPLEMENT
FLOOD ASSESSMENT

Title

AEP 3000 FLOOD EXTENTS

Drawn: VH	Approved: PS	Date: 29-10-2009
Job No: **4262 6420** /6158	File No: 42626158-g-1522c.wor	

Figure: **Appendix 5**

Rev:C

A4

Appendix B Tables

Table_Appendix 1 Horse Creek Diversion Catchment Parameters

Basin ID	Catchment Area (km2)
A	9.2
B	9.8
C	4.5
D	6.9
E	11.3

Reach #	Length (km)
1	1.2
2	1.2
3	1.3
4	0.7
5	0.6
6	1.1
7	1.2
8	2.6
9	1.3

Table_Appendix 2 Caval Creek Catchment Parameters

Basin ID	Catchment Area (km2)
A	62.0
B	75.5
C	54.5
D	29.3
E	25.8
F	52.9
G	60.4
H	85.6
I	38.4
J	7.8
K	75.4
L	5.7
M	4.7
N	4.8
O	14.0
P	9.5
D1	12.9
R	11.9
S	29.1

Reach #	Length (km)
1	7.0
2	5.2
3	4.5
4	5.4
5	4.5
5A	2.4
6	4.6
7	9.1
8	6.0
9	6.8
10	4.3
11	6.8
12	2.1
13	4.2
14	6.8
15	1.6
16	2.3
17	10.2
18	2.5
19	2.1
20	1.1
21	1.2
22	1.6
23	0.8
24	1.5
25	0.6
26	2.5
27	4.0
28	2.4
29	2.9
30	3.4
31	2.4
32	14.0

Table_Appendix 3 Horse Creek Diversion Catchment – Rainfall Depth Results (CRC-FORGE)

Duration (hrs)	Total Rainfall Depth (mm)			
	1 in 500 AEP	1 in 100 AEP	1 in 2000 AEP	1 in 3000 AEP
15 min	57	64	70	74
30 min	81	90	99	105
1 hour	110	122	135	143
3 hours	154	172	190	200
6 hours	190	211	233	245
12 hours	233	260	287	301
18 hours	267	297	328	344
24 hours	292	326	360	377
48 hours	360	396	432	451
72 hours	409	449	489	511
96 hours	438	482	526	549
120 hours	455	500	546	568

Table_Appendix 4 Caval Creek Diversion Catchment – Rainfall Depth Results (CRC-FORGE)

Duration (hrs)	Total Rainfall Depth (mm)			
	1 in 500 AEP	1 in 100 AEP	1 in 2000 AEP	1 in 3000 AEP
15 min	55	61	67	70
30 min	78	86	95	100
1 hour	106	118	130	136
3 hours	147	163	180	187
6 hours	179	198	219	228
12 hours	218	242	267	277
18 hours	249	277	306	317
24 hours	274	304	336	348
48 hours	337	371	406	419
72 hours	382	419	456	469
96 hours	407	446	487	501
120 hours	421	461	502	525

Note: 1) Reference : AR&R 1997 Procedures for interpolating between 1 in 100 AEP and PMP depths

Appendix C Hydrologic Modelling

C.1 Rainfall Losses

RORB includes a loss model to account for rainfall losses, allowing for an initial loss followed by continual loss. Loss parameters were derived from AR&R (1998) - Book IV Estimation of Large and Extreme Floods. Initial loss was derived by interpolating between an upper and lower limit according to a log normal probability distribution as shown in in **Figure_Appendix 1**. A median continual loss value of 2.0 mm/hr was adopted for the 1 in 500 AEP event and gradually reduced for more rare events.

C.2 Model Parameters Catchment Lag Coefficient - k_c

The catchment lag coefficient, kc, is the principal calibration tool for RORB models. In the absence of regional stream gauge data in which to calibrate to, kc scaling relationships were derived from a RORB model constructed by Sargent Consulting and documented in the Isaac River Cumulative Impact Assessment report (Alluvium 2008).

The Sargent Consulting RORB model provides $\mathbf{k_c}$ values for all sub-catchments of the Isaac River. Three sub-catchments (Burton Gorge, Goonyella and Deverill) were considered for catchment scaling to calculate the k_c value to be applied in RORB models.

A fit test was carried out using a common empirical equation relating kc to Area using equation (2) to establish the appropriate value for the parameter X with data provided in the Sargent report.

$\mathbf{k_c}$ = X. Area $^{0.5}$……………………………………………………………………………………… (2)

where $\mathbf{k_c}$ = the catchment lag coefficient

Table C-5-1 Derivation of Parameter X- Fit Test

Location	Catchment Areas (km^2)	Calibrated RORB k_c Values	Fit k_c = X. Area 0.5
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

The X value of 0.8 obtained from Goonyella catchment was adopted as the most suitable parameter for the study area as the Goonyella catchment was determined as the most appropriate for catchment scaling due to its similar geology and regional location to the study area. Furthermore, the Burton Gorge catchment has distinctly different geology and the Deverill catchment size is far larger than the study area. The Weeks formula as shown below and reported in AR&R (1987) was plotted against the derived equation to test the suitability of the parameter against the study area as shown in **Figure_Appendix 2** .

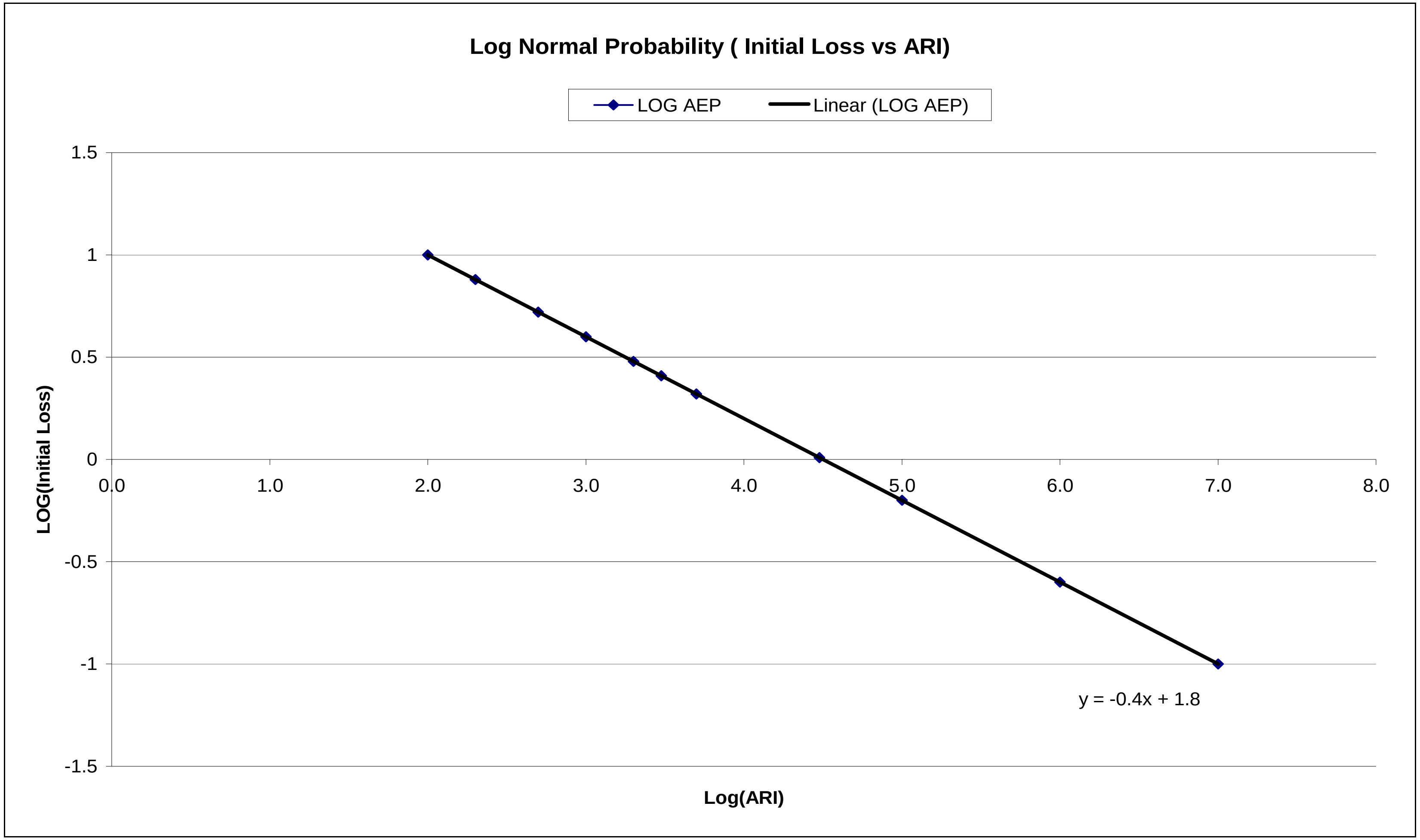
$k_c = 0.88.\ \text{Area}^{0.5}$……………………………………………………………………………………(3)……

The plot shows a reasonable fit between the derived equation and Weeks equation for catchment areas ranging from 200 km^2 to 1500 km^2. The derived equation estimates lower Kc values than the empirical equation reported by Weeks. A lower kc value produces higher peak flow estimates and is therefore more conservative.

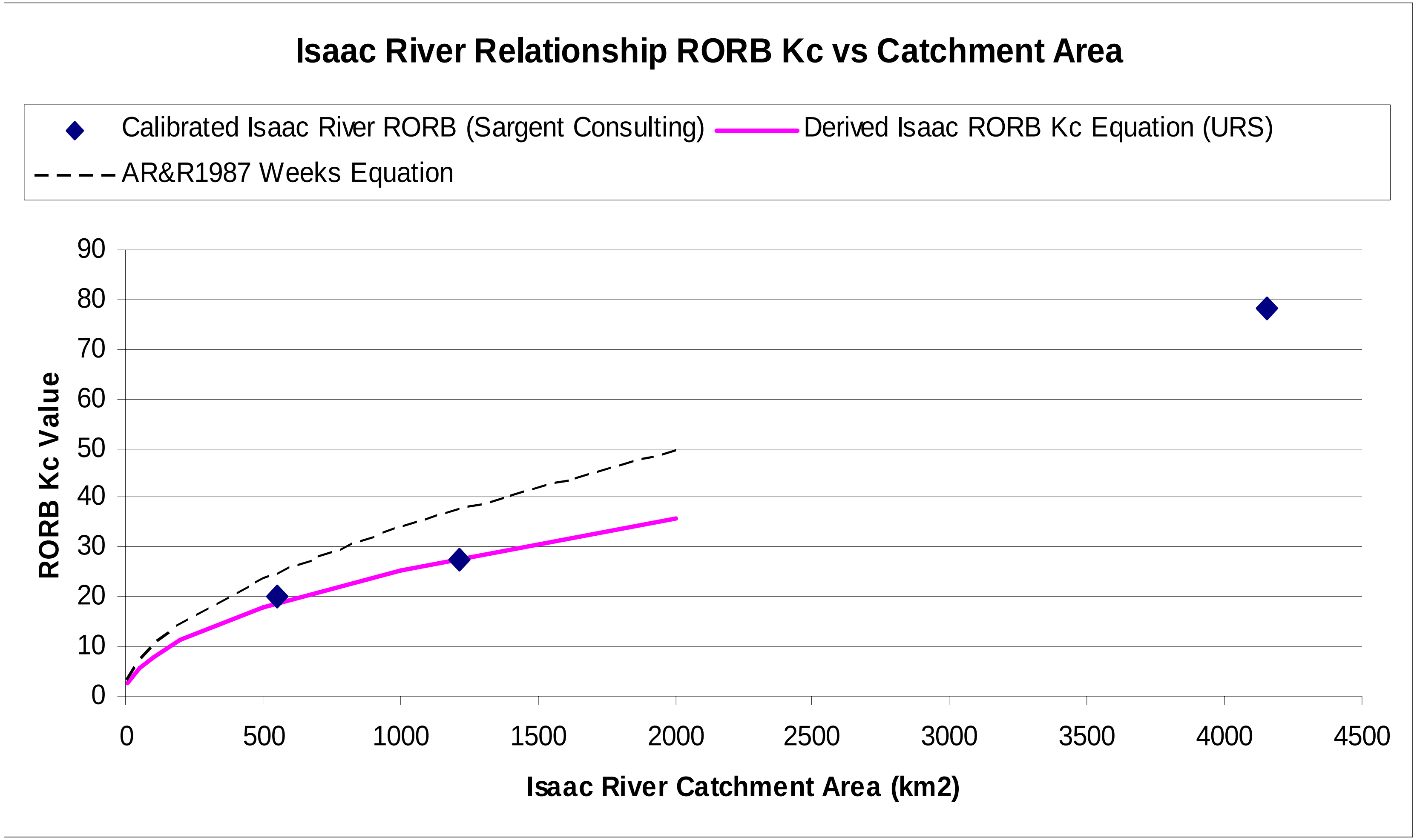
Table C-5-2 Derived Kc Values From Calibrated Isaac RORB and Weeks Equation

Kc Values and Weeks Equation

Area (km2)	k_c derived from Calibrated Isaac RORB	k_c 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



Figure_Appendix 1 Log Normal Probability(Initial Loss vs ARI)



Figure_Appendix 2 RORB Kc vs Catchment Area

5. DESIGN TEMPORAL DISTRIBUTION OF PMP

A design temporal distribution was derived using pluviograph traces recorded in major Australian storms. This pattern is shown in Table 1 with figures rounded to 1% and presented as a mass curve in Figure 9.

Table 1: Design Temporal Distribution of Short Duration PMP

% of time	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
% of PMP	0	4	10	18	25	32	39	46	52	59	64	70	75	80	85	89	92	95	97	99	100

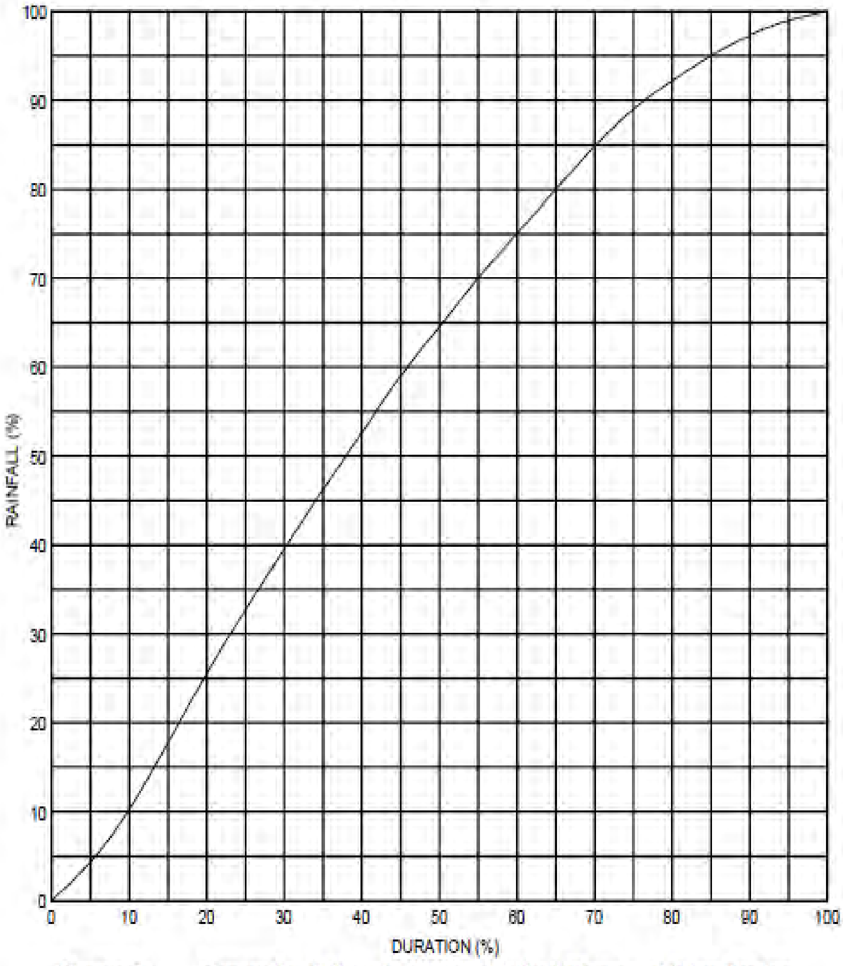


Figure 5: Generalised Short Duration Method Temporal Distribution

Figure_Appendix 3 : Generalised Short Duration Method Temporal Distribution

C.3 RATIONAL FORMULA

As used in the design, the formula of Rational Method is

$Q_Y = 0.278 . C_Y . I_{TC,Y} . A$ **(AR & R 1987)**

$Q_{Y} =$ peak flow rate (m^3/s) of average recurrence interval (ARI) of Y years

C_Y = runoff coefficient (dimensionless) for ARI of y years

A= area of catchment (km^2)

I_{TC} = average rainfall intensity (mm/hr) for design duration of tc hours and ARI of y years

The runoff coefficient was assumed to be 0.8 as the catchment would be saturated during extreme events.

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