Austar Coal Mine Pty Ltd

Flooding Assessment: Longwalls A3, A4 and A5

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Umwelt
Environmental Consultants

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Prepared by

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on behalf of

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1.0 Introduction

1.1 Background

Austar Coal Mine is an aggregate of the former Ellalong, Pelton, Cessnock No.1 (Kalingo) and Bellbird South Collieries near Cessnock (refer to **Figure 1.1**). The mine is to be developed in three stages. A modification to Consent was granted for Stage 1 in September 2006. The modification allowed the use of the new technology of the top coal caving method. The approval process for the mining of Stage 2 using the top coal caving method is yet to be confirmed. Regardless of this process, a Subsidence Management Plan (SMP) for the first workings and initial longwall is required. This Plan is currently being prepared by Austar Coal Mine.

This document contains information regarding the flooding assessment for Austar Coal Mine's SMP for Stage 2 of the mine's longwall mining operations.

1.2 Scope of Assessment

The primary aims of this flood assessment are to:

- define the 100 year Average Recurrence Interval (ARI) flood; and

- define the potential future impacts on flooding resulting from underground mining of Longwalls A3, A4 and A5 (refer to **Figure 1.1**).

1.3 Modelling Approach

This flooding assessment uses the XP-Storm one dimensional (1D) hydrodynamic model and the RMA-2 two dimensional (2D) hydrodynamic model to produce a description of flood behaviour and potential impacts from subsidence associated with underground mining.

The XP-Storm model has been specifically developed to gain an initial understanding of flood behaviour in the upper reaches of the valley and to provide inputs and boundary conditions to the 2D model. The RMA-2 model has been developed to model the floodplain area using inputs and boundary conditions derived using the XP-Storm model.

The modelling has been undertaken in four stages:

1. define the landform and drainage features;

2. define the inflows into the floodplain region for historical storm events, the 100 year ARI storm event and the 1 year ARI storm event;

3. define the existing flood extents, depths and velocities in the valley for historical storm events (when data is available), the 100 year ARI storm event and the 1 year ARI storm event; and

4. determine potential impacts of subsidence associated with underground mining on the 100 year ARI storm event and the 1 year ARI storm event flood extents, depths and velocities.

2.0 Catchment Description

2.1 Physical Setting

The Stage 2 mining area is located with the Quorrobolong Creek / Cony Creek drainage system (also known as the Quorrobolong Valley) (refer to **Figure 2.1**). The Quorrobolong Valley upstream of Ellalong Lagoon (including Quorrobolong and Cony Creeks) is approximately 87 km^2 and mainly comprises state forest and cleared agricultural land. The drainage system through the valley conveys runoff from the Broken Back and Myall Ranges to the west, past the township of Ellalong and into Ellalong Lagoon (approximately 6 kilometres downstream of the mining area). Overflows from Ellalong Lagoon flow into Congewai Creek which flows in a westerly direction until meeting Wollombi Brook. Wollombi Brook flows in a northerly direction into the Hunter River 10 kilometres upstream of Singleton. Further details of the valley drainage system are contained in **Section 2.2** below.

2.2 Topography and Drainage

The mining area is located immediately to the south of Broken Back Range and to the north of the Myall Range (refer to **Figure 2.1**).

The highest elevation in the catchment area is 445 metres AHD and forms part of the Myall Range on the southern catchment boundary. The catchment area of the valley upstream of Ellalong Bridge is approximately 78 km^2 (refer to **Figure 2.1**).

The north westerly portion of the mining area is characterised by gentle to moderate slopes of a spur which extends from the Broken Back Range. This area has also been cleared for grazing and vineyards.

Quorrobolong Creek has an extensive floodplain associated with it except where it hugs the base of the spur. The central and eastern portions of the mining area are characterised by alluvial flats approximately 500 metres wide. These have been cleared for cattle grazing and vineyards and contain a number of dams. In the eastern portion of the mining area immediately downstream of the junction of Cony Creek and Quorrobolong Creek the floodplain is constricted. Another natural constriction in the floodplain is evident at the western boundary of the mining area.

Quorrobolong and Cony Creek are joined from the north and the south by a number of smaller order drainage lines that originate from the southern slopes of Broken Back Range and the northern slopes of the Myall Range. Many sections of these creeks have been dammed both within the mining area and higher in the catchment.

2.3 Flooding Regime

The floodplain modelling indicates that there are three different flooding regimes in the Quorrobolong Valley:

- flooding within the narrow channels in the upper catchment. Flooding is confined by the relatively steep sides of the channels (these channels lie within the domain of the 1D model);

- overland flow flooding, which affects the majority of the floodplain areas. This flow is governed by the characteristics of the creek channels and overland flow areas (these areas lie within the domain of the 2D model); and

- backwater flooding due to natural and man-made constrictions (e.g. bridges). Flooding in these areas is defined by the hydraulic capacities of the constrictions and available flood storage zones upstream (these areas lie within the domain of the 2D model).

In the proposed mining area only two types of flooding are generally seen in major storm events: overland flow flooding and backwater flooding.

3.0 Available Data

3.1 Previous Flooding Investigations

Investigations indicate that two previous flood studies have been carried out in the region of the Quorrobolong Valley.

The first, Ellalong Flood Study (Wayne Perry and Associates Pty Limited, 1993) was prepared for Cessnock City Council. The Ellalong Flood Study investigated flooding on a minor tributary of Quorrobolong Creek in the northwest section of Ellalong Village. The domain of this flood study does not overlap the area of flood impact assessment for the Stage 2 Mine Plan.

The second study is the Wollombi Creek Flood Study (Patterson Britton & Partners Pty Ltd, 2005) prepared also for Cessnock City Council. This study focused on flooding regimes in Wollombi Brook and Congewai Creek. The study has been accepted by Council to set development flood level in the village of Wollombi. The Quorrobolong Valley forms part of the flood model. However, the Quorrobolong Valley upstream of Ellalong Lagoon is modelled as a single catchment node in XP-RAFTS. It is considered that this will describe the flooding behaviour in the valley in a simplistic manner and not provide suitable information regarding flood levels for comparison to the current assessment. The Wollombi Creek Flood Study does however explore regional loss rates for the Wollombi Creek system. As such these loss rates have been incorporated into the flood impact assessment for Austar Mine (refer to **Section 5.1**).

3.2 Survey Data

Topographic survey data is required to describe the geometry of the land surface as used in the hydraulic model. In the simplest 1D model, a channel and its floodplain are represented by a series of cross sections orientated at right angles to the direction of flow. In more sophisticated hydrodynamic models, such as the RMA-2 model used in this assessment, the geometry of the land surface is represented by a series of triangles or quadrilateral elements. For these models it is necessary to obtain detailed survey data to determine the level at the corner of each element. In this situation, the accuracy with which the land surface can be represented is governed by the accuracy of the topographic survey.

3.2.1 Aerial Laser Survey

Aerial laser scanning (ALS) survey data was collected by AAM Hatch during August 2006. This survey captured approximately 80 million survey points describing the land and channel system of the Quorrobolong Valley. The ALS survey captured a dense swathe of points with an average horizontal accuracy of < 0.55 metres (AAM Hatch 2006).

Verification of the vertical accuracy of the ALS was undertaken by AAM Hatch as part of the quality assurance procedures. Levels derived from ALS on areas of open ground were compared with ground based survey. For 182 comparison points the standard deviation of the error was found to be approximately 40 mm (AAM Hatch 2006).

3.3 Meteorological Data

3.3.1 Daily Rainfall Data – Bureau of Meteorology

Several Bureau of Meteorology (BOM) daily rainfall stations area located within the surrounding region (refer to **Figure 3.1**). These stations are listed in **Table 3.1**.

Table 3.1 – BOM Daily Rainfall Stations

Station Number	Name	Period of Record
061103	Ellalong	1895 – 1931
061048	Mulbring	1932 – present
061174	Millfield Composite	1959 – 1983
061141	Quorrobolong (Emmavale)	1959 – 1971
061152	Congewai (Greenock)	1959 – present
061154	Eglinford	1959 – 1970
061289	Quorrobolong Post Office	1959 – 1981
061238	Pokolbin (Somerset)	1962 – present
061056	Pokolbin (Ben Ean)	1905 – 2002
061242	Cessnock (Nulkaba)	1966 – 2000

Only two of these stations lie within the catchment area of the Quorrobolong Valley (refer to **Figure 3.1**).

An analysis of daily rainfall data for the stations listed above shows very little spatial variability in rainfall records between Ellalong, Mulbring, Millfield, Quorrobolong and Congewai. This indicates that the rainfall stations with longer periods of record, i.e. at Congewai and Mulbring have rainfall data that suitably represents the rainfall that occurred in the valley.

Analysis of daily rainfall data indicates that major storm events have occurred in the region at the following times:

- 16 April 1927 – equivalent to 100 year 24 hour ARI design storm event;
- 18 June 1930 – equivalent to 100 year 48 hour ARI design storm event;
- 18 June 1949 – equivalent to 100 year 24 hour ARI design storm event; and
- 3 February 1990 – equivalent to 200 year 48 hour ARI design storm event.

There have been other large storm events that have occurred over the valley of smaller equivalent average recurrence intervals over the period of record. However, in terms of major storm events (i.e. 100 year ARI or greater) there have been only four recorded major storm events since 1920.

3.3.2 Pluviographic Data

There are three BOM stations in the local area that have pluviographic rainfall data (i.e. rainfall measured in 6 minute intervals). These stations are shown on **Figure 3.1** and listed in **Table 3.2**. None of these stations are located with the Quorrobolong Valley catchment area.

Table 3.2 – BOM Pluviograph Rainfall Stations

Station Number	Name	Period of Record
061238	Pokolbin (Somerset)	1962 - present
061152	Congewai (Greenock)	1959 - 1971
061174	Millfield Composite	1958 - 1981

Analysis of the pluviographic rainfall data for Congewai and Millfield indicates that these locations have similar temporal rainfall patterns. As such it is considered that pluviographic or daily rainfall data for Congewai and Millfield would be representative of storm events in the Quorrobolong Valley.

Unfortunately no pluviograph data is available for the major storm events of 1927, 1930 or 1949. Pluviograph data is available for the 1990 storm event, however this data is only available for Station 061238 Pokolbin which is considered to be spatially isolated from the catchment area (refer to **Section 7.3.1**).

3.4 Streamflow Data

No streamflow data was able to be sourced for within the Quorrobolong Creek / Cony Creek catchment areas.

3.5 Flood Level Data

Cessnock City Council (Council) has indicated that they hold no flood observation data for the Quorrobolong Valley upstream of Ellalong. Council has however indicated that Sandy Creek Road would be inundated across the floodplain of Quorrobolong Creek in the vicinity of Forbes Bridge (correspondence with Cessnock City Council, 2006).

Council (correspondence with Cessnock City Council, 2006) has also indicated that design work undertaken by Tricad Pty Ltd in May 2001 indicated that the following calculated water levels at Forbes Bridge over Quorrobolong Creek at Sandy Creek Road:

- maximum headwater of 129.94 mAHD; and
- maximum tailwater level of 129.70 mAHD.

Council did not provide details of how these levels were calculated.

As part of the flood assessment, Umwelt met with two residents in the valley who observed the February 1990 flood event. These residents, John Reid and Bill Jones, provided historical flood level data for four locations for this storm event (refer to **Section 7.4**).

4.0 Design Flood Estimation

Design flood flows for Cony Creek and Quorrobolong Creek have been estimated using regional flood frequency methods, based on the Probabilistic Rational Method and the Index Flood Method. The findings of this analysis are presented below. The 100 year ARI design flow estimates were subsequently compared the XP-Storm and RMA-2 model results (refer to **Section 5.0** and **Section 7.0**).

4.1 Probabilistic Rational Method

The Probabilistic Rational Method (PRM) for peak flood estimation in eastern NSW is outlined in Australian Rainfall and Runoff (AR&R) (IEAust, 1997). This peak flood estimation method was applied to the Quorrobolong Creek catchment downstream of the confluence with Cony Creek and at the bridge upstream of Ellalong. The results of the analysis are shown in **Table 4.1**.

Table 4.1 - Peak Flow Estimates – Probabilistic Rational Method – 100 year ARI

Location	Area (km^2)	tc (hours)	C10	Design Discharge (m^3/s)
Quorrobolong Creek downstream of confluence with Cony Creek	53	3.4	0.33	288
Quorrobolong Creek at Ellalong Bridge	78	4.0	0.33	362

4.2 Regional Flood Frequency Analysis

As part of the flood study for an adjacent valley, Hughes Trueman (2004) carried out a regional flood frequency analysis for small catchments located within the Central Coast and Lower Hunter regions. The regional flood frequency analysis was carried out using the Index Flood Method, as outlined in AR&R (IEAust, 1997).

The derived average, maximum and minimum design discharges for the Quorrobolong Creek catchment downstream of the confluence with Cony Creek and at the bridge upstream of Ellalong were derived using data from this analysis and are shown in **Table 4.2**.

Table 4.2 - Regional Flood Frequency Results – 100 year ARI

Location	Design Discharge (m3/s) 100 year ARI		
	Min	Avg	Max
Quorrobolong Creek downstream of confluence with Cony Creek	126	189	378
Quorrobolong Creek at Ellalong Bridge	156	468	819

4.3 Comparison of 100 year ARI Design Discharge Estimates

The regional methods listed above give a wide range of estimates for the 100 year ARI design discharge. The values are dependant on the two different methodologies and the parameters and inputs used. Due to the lack of gauged data for the catchment, it is difficult to provide a firm estimate. However, in order to overcome the uncertainties associated with the 100 year ARI design discharges for the valley sensitivity analyses were carried out for the for both the 1D hydrodynamic model (refer to **Section 5.0**) and the 2D hydrodynamic model (refer to **Section 7.0**).

5.0 One Dimensional Hydrodynamic Modelling

A 1D hydrodynamic model of the catchment area was developed using XP-Storm. This model was developed to serve the following purposes:

- gain an preliminary understanding of the flood behaviour of the valley;
- determine the inflows into the 2D hydrodynamic model;
- investigate and determine the outlet boundary conditions for the 2D hydrodynamic model; and
- estimate flood elevations to allow initial sizing of 2D RMA-2 network.

XP-Storm version 9.1, is a one-dimensional hydrodynamic model which can be used to model stormwater flows in watercourses, culverts and street drainage systems. XP-Storm is suitable to calculate overland runoff generated from large natural or developed catchments and is capable of predicting flood levels as a result of backwater effects. Consequently XP-Storm is a suitable model to gain an understanding of the flood behaviour in the valley and in particular in the mining area, and to determine the boundary conditions for the 2D hydrodynamic model.

5.1 Model Setup

XP-Storm models a watercourse as a series of nodes along a channel, connected by drainage links. Nodes are the locations at which sub-catchment information may be entered into the model, including sub-catchment area, slope and percentage impervious area. Drainage links are characterised by a channel length, slope, cross section, maximum water depth, upstream and downstream channel inverts, and Mannings ‘n’. The XP-Storm model layout is shown in **Figure 5.1**.

The critical parameters used in the XP-Storm analyses were:

- Laurenson Equation $S = BQ^{n+1}$

  Where, S = volume of storage (m^3)
  B = Storage Delay Parameter
  Q = instantaneous rate of runoff (m^3/s)
  n = -0.285

- Initial and Continuing Loss Rates

  Where, Initial Loss Rate of 20 mm/hr
  Continuing Loss Rate of 2.5 mm/hr

The initial and continuing loss rates are sourced from the Wollombi Valley Flood Study (Patterson Britton & Partners Pty Ltd, 2005) and are consistent with values recommended by AR&R (IEAust, 1987).

The values of Mannings ‘n’ were sourced from information gathered during site inspections and from aerial photographs. The values used for Mannings ‘n’ to represent the different catchment elements are listed in **Table 5.1**.

Table 5.1 - Mannings 'n' values for Different Catchment Elements

Element	Mannings 'n'
Natural Channel Sections	0.060
Pervious Catchment Areas	0.35*
Impervious Catchment Areas	0.014*

* Represents Mannings 'n'* which is used in the XP-Storm model for overland flows and is considerably higher than Mannings 'n'

There are numerous culverts and two major bridges within the Quorrobolong Valley. Data was collected regarding the size, configuration and locations of these structures during a field inspection in October 2006.

5.2 Design Flows

5.2.1 Design Rainfall Intensities and Temporal Patterns

Design rainfall data and temporal patterns were derived for the catchment area using the principles set out in Chapter 2 of AR&R (IEAust, 1997). These design rainfall intensities were translated into absolute rainfall depths for each ARI and storm duration for input into XP-Storm.

5.2.2 Areal Reduction Factors

Rainfall intensities derived using the processes outlined AR&R (IEAust, 1997) are only suitable to be used for areas up to 4 km^2. For larger areas an areal reduction factor may be used to take into account changes in rainfall intensity over larger areas.

Values for areal reduction factors (ARF) are presented in Figure 2.6 of AR&R (IEAust, 1997). The information presented is based on data from the United States of America and covers storm durations up to a maximum of 24 hours and catchment areas up to a maximum of 1000 km^2. The ARF are recommended by AR&R (IEAust, 1997) to be used for recurrence intervals up to 100 years.

Interpolation of Figure 2.6 (IEAust, 1997) provides the following factors for a 78 km^2 area for up to a 24 hour storm event.

Table 5.2 - Areal Reduction Factors (ARF) for 78 km^2 Catchment

Storm Duration (h)	ARF
3	0.957
6	0.966
12	0.978
24	0.980

It can be seen that due to the small catchment size relative to 1000 km^2 these factors would provide a negligible reduction in the point rainfall values and hence have not been used for this current assessment.

5.3 Results

Upon review of the XP-Storm model and comparison of flow rates from other flow estimation methods (refer to **Section 4.3**) it is considered that the peak flows through the model are underestimated. This is due to the nature of a 1D model and the complexity of the floodplain regions. The 1D model is suited to model flows in constrained creek systems, such as the upper reaches of the Quorrobolong Valley. However, when the creeks spill over the banks or overland flows, such as across a floodplain occur, a 1D model is not always easily able to model these characteristics. This is considered to be the case in the middle and lower reaches of the Quorrobolong Valley. A review of the model indicates that the 1D model is filling significant portions of the floodplain and overbank areas earlier within the modelled storm events compared to what occurs within the valley. As such these areas are overestimating the flood storage and detention of the valley and resulting in modelling of lower discharges than those expected.

In order to utilise the XP-Storm model to determine flood extents and flows a significant number of additional cross sections would need to be inserted into the model. It is considered that this is unfeasible. As such the 1D model has been used as a tool to determine the critical storm duration for the valley, the inflows to the RMA-2 model (refer to **Section 5.4.1**) and the downstream boundary condition of the RMA-2 model (refer to **Section 5.4.2**).

5.4 Input to RMA-2 Model

5.4.1 Inflow Hydrographs

The XP-Storm model was used to determine the inflow hydrographs to the RMA-2 model. Inflow hydrographs were extracted from the XP-Storm model at 29 nodes positioned at the boundary of the RMA-2 model.

5.4.1.1 Sensitivity Analysis

The sensitivity of the RMA-2 inflow hydrographs generated by XP-Storm to changes in initial loss rate was examined. Initial loss rates of 10 mm and 35 mm were modelled and the total inflow hydrograph to the RMA-2 model compared to that with an initial loss of 20 mm (refer to **Figure 5.2**).

This analysis indicated that a change in the initial loss rate will have minimal effect on the inflow hydrographs to the RMA-2 model after the initial steady state flow period (refer to **Section 6.2.7**).

5.4.2 Downstream Boundary Condition

In flood modelling the nature of the downstream boundary of the flood model is very important to ensure that flood flows are not impacted upon by the location or definition of this boundary. In the Quorrobolong Valley there are two natural constrictions. One constriction is located immediately downstream of the mining area and the other over the chain pillar between the proposed Longwalls A4 and A5 immediately downstream of the junction of Cony Creek and Quorrobolong Creek. These constrictions are considered to control the flow regimes through the mining area. In addition, the Ellalong Bridge, approximately 3 kilometres downstream the mining area also forms a flow constriction. At the bridge the flows are initially constricted by the bridge alone, however there is a secondary flow path to the south of the bridge at a low point in Sandy Creek Road.

The Ellalong Bridge was chosen as the RMA-2 model boundary as it is a considerable distance from the assessment area and provides a well defined location to determine a stage discharge relationship for use as a boundary condition.

The stage discharge relationship at Ellalong Bridge was found to be independent of the flows in the downstream reaches of the creek. To be conservative it was assumed that Ellalong Lagoon was full and that flows from Quorrobolong Creek had limited ability to cause back flow up the tributaries between the bridge and the lagoon. As such a stage storage relationship for the combined bridge and road flows was developed for flows up to 400 m^3/s.

6.0 Two Dimensional Hydrodynamic Model Setup

6.1 Topographic Data

6.1.1 Derivation of RMA-2 Network

The RMA-2 two dimensional hydrodynamic model represents that land surface as a series of triangular and quadrilateral shaped planes of variable size. Aerial laser scanning (ALS) survey was undertaken for the entire domain of the 2D model. This survey provided a grid of spot levels at an average 0.9 metre spacing. The availability of this high resolution data allows the RMA-2 network to incorporate additional detail into the definition of the landform and specific features such as houses, access tracks, creeks, etc.

The initial digital terrain model created using the ALS data was simplified to create a triangulated mesh of the data. As RMA-2 has a practical upper limit of approximately 50,000 elements the triangulated terrain model was simplified using a program called QSLIM (Garland & Heckbert, 1995). QSLIM uses an algorithm whereby survey points are removed one by one, based on the introduction of least error into the model, until the specified model size is achieved.

Checks were undertaken to ensure that the simplified landform was representative of the existing topography, with particular attention paid to hydrologically significant features such as creek channels, drains and roads.

Detailed topographical features, including creek channels, houses, access tracks, roads and race tracks were identified based on 100 mm contours derived from the ALS data. These features were represented as breaklines in the RMA-2 model topographic data. The creation of a breakline forces the model to define a series of elements that have one side running along the breakline and thereby define the level along that line (e.g. along the top of the creek bank). Insertion of breaklines into the mesh is important when defining features such as roads that act as a barrier to flow. Additional detailed information was then defined for areas such as creeklines, swamps and culverts (refer to **Section 5.1**). The additional vertices and breaklines were incorporated into the RMA-2 network. An example of the network created around a house, access road and road are shown in **Figure 6.1**.

Element structures suitable to allow inflows and outflows from the model need to be defined during the development of the RMA-2 network. These structures are defined at each of the 29 inflow points and at the outlet of the model. The structures are only created to assist in the mathematical calculations of the model. As such any model results in these areas should be disregarded. For example, any indicated model results downstream of Sandy Creek Road at Ellalong Bridge do not represent the true flood behaviour at this location.

The hydrodynamic model was run to determine an improved approximation of the flood extent during the 100 year ARI storm event. This initial flood extent was used to identify elements that would not be required in the RMA-2 network, thereby allowing a further reduction in the number of elements required to simulate flood events in the valley. Additionally, the elements where dwellings are located were removed, thus forming a “no-flow” barrier within the network.

The final RMA-2 network uses approximately 32,000 elements and 17,000 nodes to define the landform, hydraulic structures and inflow points of the valley floodplain (see **Figure 6.2**).

6.2 Model Setup

6.2.1 Channel Definition

The channels were defined using the processes outlined in **Section 6.1.1**.

6.2.2 Hydraulic Structures

Significant hydraulic structures that occur in the 2D model domain include roads, access tracks, culverts and bridges. These structures have been incorporated into the RMA-2 network as features defined by the surface levels extracted from the ALS and field inspections (refer to **Section 5.1** and **6.1.1**).

6.2.3 Downstream Boundary Conditions

The downstream boundary of the RMA-2 model has been defined by a flow rating curve at downstream of the Ellalong Bridge. The rating curve at this location was established using the XP-Storm model (refer to **Section 5.4.2**). This rating curve was applied to the element outflow structure defined in the RMA-2 network (refer to **Section 6.1.1**).

6.2.4 Hydrograph Inputs

Hydrograph inputs at 29 sub-catchment inflow points were extracted from the XP-Storm model as discussed in **Section 5.4.1**. For purposes of sensitivity analysis, the XP-Storm model was run with a range of initial and continuing losses. Details of this analysis are set out in **Sections 5.3.2** and **7.2**.

6.2.5 Hydraulic Roughness

The hydraulic roughness values used in the RMA-2 model have been sourced from *Australian Rainfall & Runoff* (1998). In order to test the sensitivity of the model to different values of hydraulic roughness, 'low', 'medium' and 'high' Mannings "n" values were used for each of the land use types defined in the RMA-2 model. Details of the adopted values of Mannings "n" are set out in **Section 7.2.2**.

6.2.6 Influence of Marsh Elements

The RMA-2 model uses the concept of 'marsh elements' to assist in achieving a numerical solution in areas of the finite element mesh where wetting and drying occurs during the flood event. The 'marsh element' method treats the flow as an integration of both surface flow and shallow sub-surface flow. When the water surface elevation drops below the ground surface, rather than an element suddenly being turned off, which may cause numerical instability and poor convergence of the numerical solution, the flow is presumed to occur in a low-porosity shallow sub-surface flow zone. To implement the 'marsh element' solution, the porosity in the sub-surface zone is gradually varied over a transitional zone from the surface to sub-surface. The depth of the subsurface zone is set to be just below the anticipated lowest water level of the flood model across the solution front. This required range, referred to as the bottom elevation shift or 'slot depth' is set to be the maximum difference between the highest ground surface elevation and lowest water surface elevation across the solution front of the model.

For the model the following values have been used to describe the marsh elements:

- bottom elevation shift (slot depth) = 13.2 metres;
- depth range over which porosity reduces (transition range) = 0.25 metres;
- effective porosity in the sub-surface zone (kappa) = 0.005.

6.2.7 Initial Flow Conditions

Before it can accept inflow hydrographs, the RMA-2 model requires that steady state flow conditions be established throughout the model domain. By trial and error, it was found that inflows from the sub-catchments totalling approximately 50 m^3/s were required to establish a stable numerical solution for flow and water levels that could be used as a starting point for analysing the effect of storm event inflows. As such the initial losses for all elements within the RMA-2 model are assumed to have occurred prior to the start to the modelling period.

6.2.8 Element Inflows

To account for rainfall on the surface of the floodplain, the RMA-2 model incorporates a feature that allows 'inflow' to each element in addition to the horizontal flow through the side boundaries. As noted above, the RMA-2 model requires steady state flow starting conditions totalling approximately 50 m^3/s in this instance. These conditions represent a situation in which the channels are almost full and the floodplain saturated. Accordingly, it is assumed that any rainfall onto the surface of the hydrodynamic model will contribute directly to the flow. In the RMA-2 model these conditions are represented by assuming zero initial and continuing loss within the boundary of the RMA-2 network. The rainfall inputs to the surface of the model use the same rainfall hyetograph as used for the XP-Storm model.

7.0 Two Dimensional Hydrodynamic Model Sensitivity and Design Flood Analysis

7.1 Approach

In order to determine the baseline 100 year ARI flood levels and velocities for the Stage 2 mining area a series of flood models were run to determine the sensitivity of the flood model to different initial loss rates and hydraulic roughness characteristics. In addition to this an actual storm event was modelled and the results compared to observations from local residents.

7.2 Sensitivity Analysis

7.2.1 Rainfall Losses

A sensitivity analysis was carried out on initial rainfall loss rates (refer to **Section 5.4.1.1**). This analysis indicated that changing the initial loss rate from 10 mm to 35 mm had little or no effect on flood flows within the RMA-2 model.

This comparison is shown on **Figure 5.2**.

7.2.2 Hydraulic Roughness

The hydraulic roughness parameters used in the RMA-2 model have been sourced from AR&R (IEAust, 1997) and are representative of the roughness characteristics of the Quorrobolong Valley.

To assess the sensitivity of the flood model to changes in hydraulic roughness the model was tested for a 'low' and 'high' set of hydraulic roughness values. These values and the base hydraulic roughness are listed in **Table 7.1**. The 'low' and 'high' values in **Table 7.1** correspond to +/- 20% from the 'medium' value.

Table 7.1 - Mannings 'n' values used in Sensitivity Analysis

Type	Land Use	Low	Medium	High
1	Open Grassland/Pasture	0.040	0.050	0.060
2	Roads	0.024	0.030	0.036
3	Road Reserves	0.056	0.070	0.084
4	Culverts	0.014	0.017	0.020
5	Open Water	0.008	0.010	0.012
6	Shrubs/Woodlands	0.064	0.080	0.096
7	Forest	0.096	0.120	0.144
8	Creek - Defined	0.048	0.060	0.072
9	Creek - Undefined	0.048	0.060	0.072
10	Road at Outlet	0.024	0.030	0.036

The sensitivity analysis for hydraulic roughness shows no discernable changes in flood flows or extents in the mining area of at the outlet of the model at Ellalong Bridge. This comparison of flood hydrographs is shown on **Figure 7.1**.

7.2.3 Marsh Porosity Values

The flood model was run with different transitions zones and porosity values to determine the impact of the marsh elements on the dynamics of the flood modelling and to determine whether the flows in the subsurface zone are significant. The results indicated that changing the transition and porosity values has little effect on the outflows of the model and has an insignificant impact on the shape of the outflow hydrograph. These results demonstrate the fact that the flow conveyance in the marsh elements is an insignificant proportion of the total flow.

7.3 1990 Flood Assessment

As discussed in **Section 3.3** four major storm events have occurred in the valley since 1920. The most recent and significant of these storm events occurred during 1990 and was equivalent to the 200 year ARI design storm event.

Discussions with two local residents also indicate that limited flood level observation data is also available for this flooding event.

7.3.1 Rainfall Characteristics

Daily rainfalls totals are available for two local BOM stations for the 1990 storm event (refer to **Table 3.1**). The data from these stations is shown in **Table 7.2** below.

Table 7.2 - 1990 Storm Event Rainfall Data

Date	Rainfall (mm)	
	Mulbring (Station 061048)	Congewai (Greenock) (Station 061152)
3/02/1990	181.5	136
4/02/1990	129	160*
5/02/1990	18.8	20*
Maximum 48 hour rainfall depth(3/02/1990 – 4/02/1990)	311	296

* Estimated using combined two day rainfall total of 180 mm for 4/02/1990 and 5/02/1990

Analysis of the pluviograph data for Station 061238 Pokolbin indicated that this station had significantly less rainfall during the 1990 storm event compared to Mulbring and Congewai. As such it is considered that the temporal pattern available from the pluviograph data is not suitable to be applied to the available daily data.

For the modelling a temporal pattern sourced from AR&R (IEAust, 1997) for a 200 year 48 hour ARI storm event using the 48 hour rainfall total for Congewai of 296 mm was used.

7.3.2 Flood Model Results

The peak discharges at the mining area and the model outlet at Ellalong Bridge are shown on **Figure 7.1**. The maximum water depths and maximum flow velocities were determined for the 1990 storm event and are shown for the valley extent and the mining area on **Figures 7.2** to **7.4**. The flood duration at the mining area and the model outlet for the 1990 storm event is shown on **Figure 7.5**.

Discussions with two local residents indicated four flood observation levels for the valley for the 1990 storm event. The flood observation points are shown on **Figure 7.3** and discussed in **Table 7.3** below.

Table 7.3 - 1990 Observed Flood Data

Observation Point	Description	Comparison to 1990 Storm Event Model Results
A	Flood extent observed to come to within 15 metres to the south of the fourth row of vines.	Flood modelling confirms this flood extent.
B	Flooding experienced up to the wheel arches of a vehicle to the south of the bridge.	Flood model indicates flood depths of up to 170 mm across the road at this location.
C	When standing in the old orchard flooding experienced to waist height.	Flood modelling indicates a flood depth of approximately 600 mm in this location. This is consistent with the observation.
D	Flood extent observed to come to the base of the water tank tower.	Flood extent is modelled to come within 5 metres of the base of the water tank tower.

From analysis of the sensitivity assessment for roughness characteristics, it is considered that with an increase in roughness of 20% that flood depths would increase approximately 120 mm over Quorrobolong Road during the 100 year ARI storm event. An increase in roughness would be expected in the creek systems after periods of above average rainfall or debris associated with flooding. It is possible that the roughness in the valley was higher due to vegetation during 1990 as 1990 and 1989 were wet rainfall years. The difference in roughness characteristics of the valley between now and 1990 may explain the difference in observed versus modelled water levels at Point B in **Table 7.3**.

It is considered that the model results from the 1990 storm event are consistent with observed flood behaviour in the valley.

7.4 100 year and 1 year ARI Design Flood – Existing Conditions

The same XP-Storm and RMA-2 model parameters that were adopted for the 1990 storm event and described in **Sections 5.0** and **6.0** were also adopted for the analysis of the 100 year and 1 year ARI flood conditions.

The results from the RMA-2 model for the 100 year ARI storm event are shown on the following figures:

- **Figure 7.6** – 100 Year ARI Storm: Maximum Water Depths for Existing Conditions (full RMA-2 model results);
- **Figure 7.7** – 100 Year ARI Storm: Maximum Water Depths for Existing Conditions;
- **Figure 7.8** – 100 Year ARI Storm: Maximum Water Velocities for Existing Conditions (full RMA-2 model results);
- **Figure 7.9** - 100 Year ARI Storm: Maximum Water Velocities for Existing Conditions; and

- **Figure 7.10** - 100 Year ARI Storm: Duration.

The results from the RMA-2 model for the 1 year ARI storm event are shown on the following figures:

- **Figure 7.11** – 1 Year ARI Storm: Maximum Water Depths for Existing Conditions (full RMA-2 model results);
- **Figure 7.12** – 1 Year ARI Storm: Maximum Water Depths for Existing Conditions;
- **Figure 7.13** – 1 Year ARI Storm: Maximum Water Velocities for Existing Conditions (full RMA-2 model results);
- **Figure 7.14** - 1 Year ARI Storm: Maximum Water Velocities for Existing Conditions; and
- **Figure 7.15** - 1 Year ARI Storm: Duration.

The influence of natural constriction located near the chain pillar between Longwall A4 and A5 on flooding can readily be seen on the **Figures 7.7** and **7.12**. The figures indicate that ponding occurs during major storm events upstream of this natural constriction and that the constriction influences flood depths, velocities and hazard both within and upstream of the mining area.

The analysis also indicates that no dwellings within the mining area will be inundated during the 100 year AR flood event.

7.4.1 Review of Flood Information

Council has indicated the design of Forbes Bridge, located over Quorrobolong Creek at Sandy Creek Road, by Tricad Pty Ltd indicated a headwater level of 129.94 mAHD and tailwater level of 129.70 mAHD for the 100 year ARI storm event (refer to **Section 3.5**). The flood modelling results from the 100 year ARI storm event indicates that the headwater and tailwater levels are similar at 129.73 mAHD.

Modelling indicates peak 100 year ARI discharges at Ellalong Bridge of 316 m^3/s. This compares to 362 m^3/s indicated by the Probabilistic Rational Method and 468 m^3/s by Regional Flood Frequency Results (average value) (refer to **Section 4.0**).

Similarly peak flows for the 100 year ARI storm event on Quorrobolong Creek downstream of the confluence with Cony Creek were calculated by the RMA-2 model to be 271 m^3/s. This compares to 288 m^3/s indicated by the Probabilistic Rational Method and 189 m^3/s by Regional Flood Frequency Results (average value) (refer to **Section 4.0**).

In comparison the RMA-2 model peak discharge is of a similar order of magnitude to the peak discharge predicted by the Probabilistic Rational Method. Similarly if the RMA-2 model peak discharge is compared to the Regional Flood Frequency Results (refer to **Table 4.2**) the peak discharges are lower than the calculated average value at Ellalong Bridge and higher than the calculated average value at the mining area. It is considered that this is due to the extension floodplain and its interactions with the natural constrictions in the valley.

7.5 Model Suitability

Combined with the results of the sensitivity analysis (refer to **Sections 7.2**) and the 1990 flood assessment (refer to **Section 7.3**) it is considered that the developed flood model is suitable to assess potential impacts on flooding, including flood levels, velocities and associated flood hazards, for the proposed Stage 2 mining area.

8.0 Effects of Mine Subsidence – Longwalls A3, A4 and A5

8.1 Approach

The RMA-2 flood model that is described in **Sections 6** and **7** was used in the flooding assessment for Longwalls A3, A4 and A5. The RMA-2 model has been developed to be used as a comparative tool to facilitate the flood assessment for the Stage 2 mining area.

The elevations of nodes in the RMA-2 network located within the subsidence zone were modified to take into account the predicted maximum and upper bound subsidence (refer to **Section 8.2**). The same inflows, boundary conditions, roughness characteristics and mesh structure as were used for the 100 year ARI storm event and 1 year ARI storm event (refer to **Section 7.0**) were used in the modelling.

The RMA-2 model was run for twelve modelling scenarios:

- 100 year ARI storm event with the predicted maximum subsided landform after underground mining of Longwall A3;
- 100 year ARI storm event with the upper bound subsided landform after underground mining of Longwall A3;
- 1 year ARI storm event with the predicted maximum subsided landform after underground mining of Longwall A3;
- 1 year ARI storm event with the upper bound subsided landform after underground mining of Longwall A3;
- 100 year ARI storm event with the predicted maximum subsided landform after underground mining of Longwalls A3 and A4;
- 100 year ARI storm event with the upper bound subsided landform after underground mining of Longwalls A3 and A4;
- 1 year ARI storm event with the predicted maximum subsided landform after underground mining of Longwalls A3 and A4;
- 1 year ARI storm event with the upper bound subsided landform after underground mining of Longwalls A3 and A4;
- 100 year ARI storm event with the predicted maximum subsided landform after underground mining of Longwalls A3, A4 and A5;
- 100 year ARI storm event with the upper bound subsided landform after underground mining of Longwalls A3, A4 and A5;
- 1 year ARI storm event with the predicted maximum subsided landform after underground mining of Longwalls A3, A4 and A5; and
- 1 year ARI storm event with the upper bound subsided landform after underground mining of Longwalls A3, A4 and A5.

8.2 Subsidence Information

To assess the potential impacts of the proposed underground mining development on surface water characteristics, subsidence predictions, prepared by MSEC (2007) for the mining of proposed Longwalls A3, A4 and A5, were used to develop a post-mining landform for the area to be undermined. The modelling used the predicted maximum and upper bound subsidence predictions calculated by MSEC (2007).

8.3 Results

For each of the scenarios modelled the maximum water depths, maximum water velocities and maximum flood hazards were determined. The analysis also included an assessment of changes to flood durations due to underground mining.

The predicted changes to flooding as a result of the upper bound subsidence for Longwalls A3, A4 and A5 are discussed in **Sections 8.3.1**, **8.3.2** and **8.3.3** below.

8.3.1 Flooding Impacts due to Longwall A3

Figures 8.1 to **8.4** describe the modelled maximum flood depths, velocities and flow durations for the 100 year ARI storm event after upper bound subsidence occurs during mining of Longwall A3.

The analysis indicates that with the upper bound predicted subsidence there will be a maximum increase in flood depths during the 100 year ARI storm event by up to 280 mm (refer to **Figure 8.1**). This increase in depth is localised over Longwall A3 and is predicted to occur in an area that has modelled flood depths up to approximately 2.3 metres in the existing landform. The analysis also indicates that there will be a negligible increase in flood extents for the 100 year ARI design storm event.

The impact on velocities during the 100 year ARI design storm event are predicted to be negligible with minor decreases in velocities in the Stage 2 mining area and minor increases in velocities between the mining area and the bridge at Quorrobolong Road (refer to **Figure 8.2**).

Figures 8.3 and **8.4** also indicate that there will be no discernable change in flood duration due to the predicted subsidence of Longwall A3.

The analysis indicates that longwall mining of Longwall A3 will not increase flood levels or flood hazard at dwellings or their access routes during the 100 year ARI storm event.

Figures 8.5 to **8.8** describe the modelled maximum flood depths, velocities and flow durations for the 1 year ARI storm event after upper bound subsidence occurs during mining of Longwall A3.

The analysis indicates that with the upper bound predicted subsidence there will be a maximum increase in flood depths during the 1 year ARI storm event by up to 265 mm (refer to **Figure 8.5**). This increase will occur in an area that is predicted to be flooded to depths of over 2 metres in the existing landform. The analysis also indicates that there will only be minor increases in flood extents for the 1 year ARI design storm event.

Similarly the impact on velocities during the 1 year ARI design storm event are predicted to be negligible with minor decreases in velocities in the Stage 2 mining area and minor increases in velocities between the mining area and the bridge at Quorrobolong Road (refer to **Figure 8.6**).

Figures 8.7 and **8.8** also indicate that there will be no discernable change in flood duration due to the predicted subsidence of Longwall A3.

The analysis indicates that longwall mining of Longwall A3 will not increase flood levels or flood hazard at dwellings or their access routes during the 1 year ARI storm event.

8.3.2 Flooding Impacts due to Longwall A3 and A4

Figures 8.9 to **8.12** describe the modelled maximum flood depths, velocities and flow durations for the 100 year ARI storm event after upper bound subsidence occurs during mining of Longwalls A3 and A4.

The predicted subsidence associated with Longwalls A3 and A4 will result in an increase in the flow conveyance area for Quorrobolong Creek in the subsidence zone without a substantial increase in the flood extent. This is due to the nature of the existing topography with extensive floodplain areas bounded by steep spurs (refer to **Section 2.2**).

The analysis indicates that with the upper bound predicted subsidence there will be a maximum increase in flood depths during the 100 year ARI storm event of up to 1.44 metres near the chain pillar between Longwalls A3 and A4 (refer to **Figure 8.9**). Increases in flood depth are evident across the width of the flood in the subsidence zone. However, the flood extent to the south of the subsided area is not increased. There is one region where the extent of flooding is predicted to decrease. In this region, shallow flooding (i.e. less than 100 mm) is predicted to occur during the 100 year ARI storm event for the existing landform and is predicted not to flood after subsidence of Longwalls A3 and A4. The increase in flood extent to the north of the creek is negligible due to the steepness of the landform.

The predicted impacts of the subsidence over Longwalls A3 and A4 on velocities during the 100 year ARI design storm event include decreases in maximum velocities through Longwalls A3 and A4 and minor increases in velocities over the chain pillar between Longwalls A4 and A5 and upstream to the Quorrobolong Road bridge (refer to **Figure 8.10**). The increase in maximum velocities upstream of the mining area is due to increases in the hydraulic grade. The analysis indicates that typically maximum velocities within the creek will remain below 1.5 m/s.

Figures 8.11 and **8.12** also indicate that there will be no discernable change in flood duration due to the predicted subsidence of Longwalls A3 and A4.

The analysis indicates that longwall mining of Longwalls A3 and A4 will not increase flood levels or flood hazard at dwellings or their access routes during the 100 year ARI storm event.

Figures 8.13 to **8.16** describe the modelled maximum flood depths, velocities and flow durations for the 1 year ARI storm event after upper bound subsidence occurs during mining of Longwalls A3 and A4.

The analysis indicates that with the upper bound predicted subsidence there will be a maximum increase in flood depths during the 1 year ARI storm event of up to 1.26 metres near the chain pillar between Longwalls A3 and A4 (refer to **Figure 8.13**). Increases in flood depth are evident across the width of the flood in the subsidence zone with **Figure 8.13** showing an increase in the flood extent to the south of the creek. The increase in flood extent to the north of the creek is negligible due to the steepness of the landform.

Associated with the increase in flood extent in the mining area is a decrease in flood extent upstream. This is due to the changes in hydraulic grade with the predicted subsidence.

The predicted impacts of the subsidence over Longwalls A3 and A4 on velocities during the 1 year ARI design storm event include decreases in maximum velocities through Longwalls A3 and A4 and minor increases in velocities over the chain pillar between Longwalls A4 and A5 and upstream to the Quorrobolong Road bridge (refer to **Figure 8.14**). The increase in maximum velocities upstream of the mining area is due to increases in the hydraulic grade. The analysis indicates that typically maximum velocities within the creek will remain below 1.25 m/s.

Figures 8.15 and **8.16** also indicate that there will be no discernable change in flood duration due to the predicted subsidence of Longwalls A3, A4 and A5. **Figures 8.15** and **8.16** indicate that although there will not be a discernable change in flood duration the predicted peak discharges through the mining area will increase. The maximum increase is predicted to be in the middle of the mining area with an increase in peak flows from 50 m^3/s to 54 m^3/s.

The analysis indicates that longwall mining of Longwalls A3 and A4 will not increase flood levels or flood hazard at dwellings or their access routes during the 1 year ARI storm event.

8.3.3 Flooding Impacts due to Longwall A3, A4 and A5

Figures 8.17 to **8.20** describe the modelled maximum flood depths, velocities and flow durations for the 100 year ARI storm event after upper bound subsidence occurs during mining of Longwalls A3, A4 and A5.

The predicted subsidence associated with Longwalls A3, A4 and A5, similarly to subsidence associated with Longwalls A3 and A4, will result an increase in the flow conveyance area for Quorrobolong Creek in the subsidence zone without a substantial increase in the hydraulic radius. This is due to the nature of the existing topography with extensive floodplain areas bounded by steep spurs (refer to **Section 2.2**).

The analysis indicates that with the upper bound predicted subsidence there will be a maximum increase in flood depths during the 100 year ARI storm event by up to 1.91 metres near the chain pillar between Longwalls A3 and A4 (refer to **Figure 8.9**). Increases in flood depth are evident across the width of the flood in the subsidence zone. The flood extent to the south of the subsided area is increased in the area above the southern end of the chain pillar between Longwalls A4 and A5. The increase in flood extent to the north of the creek is negligible due to the steepness of the landform.

The analysis indicates that flood depths will be decreased upstream of the mining area. Decreases in flood depth are predicted to occur up to approximately 600 metres upstream of the Quorrobolong Road bridge over Cony Creek. Similarly decreases in flood depth are predicted to occur approximately 100 metres to the south of the mining area upstream along Quorrobolong Creek.

The predicted impacts of the subsidence over Longwalls A3, A4 and A5 on velocities during the 100 year ARI design storm event include decreases in maximum velocities through Longwalls A3, A4 and A5 and minor increases in velocities over the chain pillar between Longwalls A4 and A5 and upstream to the Quorrobolong Road bridge (refer to **Figure 8.10**). The increase in maximum velocities upstream of the mining area is due to increases in the hydraulic grade. The analysis indicates that typically maximum velocities within the creek will remain below 1.25 m/s.

Figures 8.19 and **8.20** also indicate that there will be no discernable change in flood duration due to the predicted subsidence of Longwalls A3, A4 and A5.

The analysis indicates that longwall mining of Longwalls A3, A4 and A5 will not increase flood levels or flood hazard at dwellings or their access routes during the 100 year ARI storm event.

Figures 8.21 to **8.24** describe the modelled maximum flood depths, velocities and flow durations for the 1 year ARI storm event after upper bound subsidence occurs during mining of Longwalls A3, A4 and A5.

The analysis indicates that with the upper bound predicted subsidence there will be a maximum increase in flood depths during the 1 year ARI storm event by up to 1.73 metres near the chain pillar between Longwalls A3 and A4 (refer to **Figure 8.21**). Increases in flood depth are evident across the width of the flood in the subsidence zone. The flood extent to the south of the subsided area is also increased. The increase in flood extent to the north of the creek is negligible due to the steepness of the landform.

The analysis also indicates that flood depths will be decreased upstream of the mining area. With decreases predicted as far upstream as the Quorrobolong Road bridge.

The predicted impacts of the subsidence over Longwalls A3, A4 and A5 on velocities during the 1 year ARI design storm event include decreases in maximum velocities and minor increases in velocities upstream of the mining area to the Quorrobolong Road bridge (refer to **Figure 8.22**). The increase in maximum velocities upstream of the mining area is due to increases in the hydraulic grade. The analysis indicates that typically maximum velocities within the creek will remain below 1.0 m/s.

Figures 8.23 and **8.24** also indicate that there will be no discernable change in flood duration due to the predicted subsidence of Longwalls A3, A4 and A5. **Figures 8.15** and **8.16** indicate that although there will not be a discernable change in flood duration the predicted peak discharges through the mining area will increase. The maximum increase is predicted to be in the middle of the mining area with an increase in peak flows from 50 m^3/s to 53 m^3/s.

The analysis indicates that longwall mining of Longwalls A3, A4 and A5 will not increase flood levels or flood hazard at dwellings or their access routes during the 1 year ARI storm event.

9.0 Summary and Conclusions

The flooding assessment of Longwalls A3, A4 and A5 indicates that flood depths will be typically increased in the mining area. However, there will be minimal impact on flow velocities.

The flooding assessment also indicates that there will be no changes to flood inundation of access roads to dwellings or their associated flood hazards.

In addition, the flooding assessment indicates that the subsidence associated with mining will not result in the inundation of any dwellings during the 100 year ARI storm event that were not previously inundated.

It is predicted that freeboard of dwellings located upstream of the Stage 2 mining area to as far as 600 metres upstream of the Quorrobolong Road bridge will be increased with the predicted subsidence for the 100 year ARI storm event.

10.0 References

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