REPORT:

RED HILL MINING LEASE EIS

Geomorphic Impact Assessment

December 2011

BHP Billiton Mitsubishi Alliance

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1 Introduction

Alluvium Consulting have undertaken a geomorphic assessment of the waterways over the proposed Red Hill underground mine footprint (RHM). This report provides an assessment of the existing physical condition, character and behaviour of the Isaac River and tributaries and the potential impacts of the proposed RHM on those attributes of the waterways.

1.1 Overview of RHM underground mine plan

An overview of the RHM underground mine plan is shown in Figure 1. The timeframe for mining 20 to 25 years with anticipated progress illustrated in Figure 2. The current mine plan will involve the mining of 21 longwall panels to the north of the existing BMA Broadmeadow Mine (BRM). Major watercourses to be directly impacted by RHM are the Isaac River and its tributaries, Goonyella Creek and 12 Mile Gully.

The longwall panels planned for RHM range from approximately 1.1km to 4.2km long are mostly 320m wide and separated by chain pillars ranging from approximately 40m to 160m wide. When mining of the coal has occurred and the longwall miner advances, the land surface of the panel subsides following underground collapse. This subsidence creates a trough or void superimposed on existing surface topography. The amount of subsidence experienced at surface is largely dependent on strata, depth below surface of mining, location relative to pillar and panel and extraction thickness of seam mined.

Subsidence predictions for RHM have been determined by IMC Mining Solutions Pty Ltd based on an extraction thickness for longwall panels of 9.6m overall. The maximum vertical subsidence as expressed on the surface for RHM is conservatively predicted to be 6m. The magnitude and spatial variation of subsidence is discussed further in Section 3 Mine plan and predicted subsidence (1st order impacts).

1.2 Background and previous studies

Over the last decade, Alluvium's staff have undertaken various projects for ACARP, BMA and Anglo American Metallurgical Coal Pty Ltd (AAMC) in close consultation with Department of Environment and Heritage Protection (EHP), formerly known as Department of Environment and Resource Management (DERM) that have generated an improved understanding of processes, condition and longwall mining related impacts on the Isaac River and its tributaries. A brief description of some of this previous work follows.

Isaac River Cumulative Impact Assessment of Mine Developments

The potential impacts of longwall mining on the Isaac River have been subject to investigation for some time. AAMC Moranbah North Mine began subsidence impact investigations in 2001 for the Isaac River. This was followed by the development of a management strategy in 2002-3. BRM undertook subsidence impact investigations and development of a management strategy in 2005-6. Both investigations were largely based around the single mine. However, river systems are a continuum and impacts (including management actions to mitigate impacts) at different locations are likely to influence each other and may compound. BMA and AAMC recognised the need to undertake an assessment of the Isaac River and potential impacts on a broader scale than individual mine leases, hence the Isaac River Cumulative Impact Assessment of Mine Developments (IRCIA).

DERM were sought as the key stakeholder in the assessment and involved in each stage of the project, providing input to the scope and method and signing off on the process and technical studies along the way. The impacts of longwall mining on alluvial stream systems were categorised by industry stakeholders at a workshop convened by DERM in Rockhampton in April 2007. Impacts on waterways from subsidence were categorised into the following hierarchy:

- 1st order – direct physical effects of subsidence
- 2nd order – geomorphic response to subsidence
- 3rd order – changes to water quantity and quality
- 4th order – biological response
- 5th order – impacts of human response to other impacts

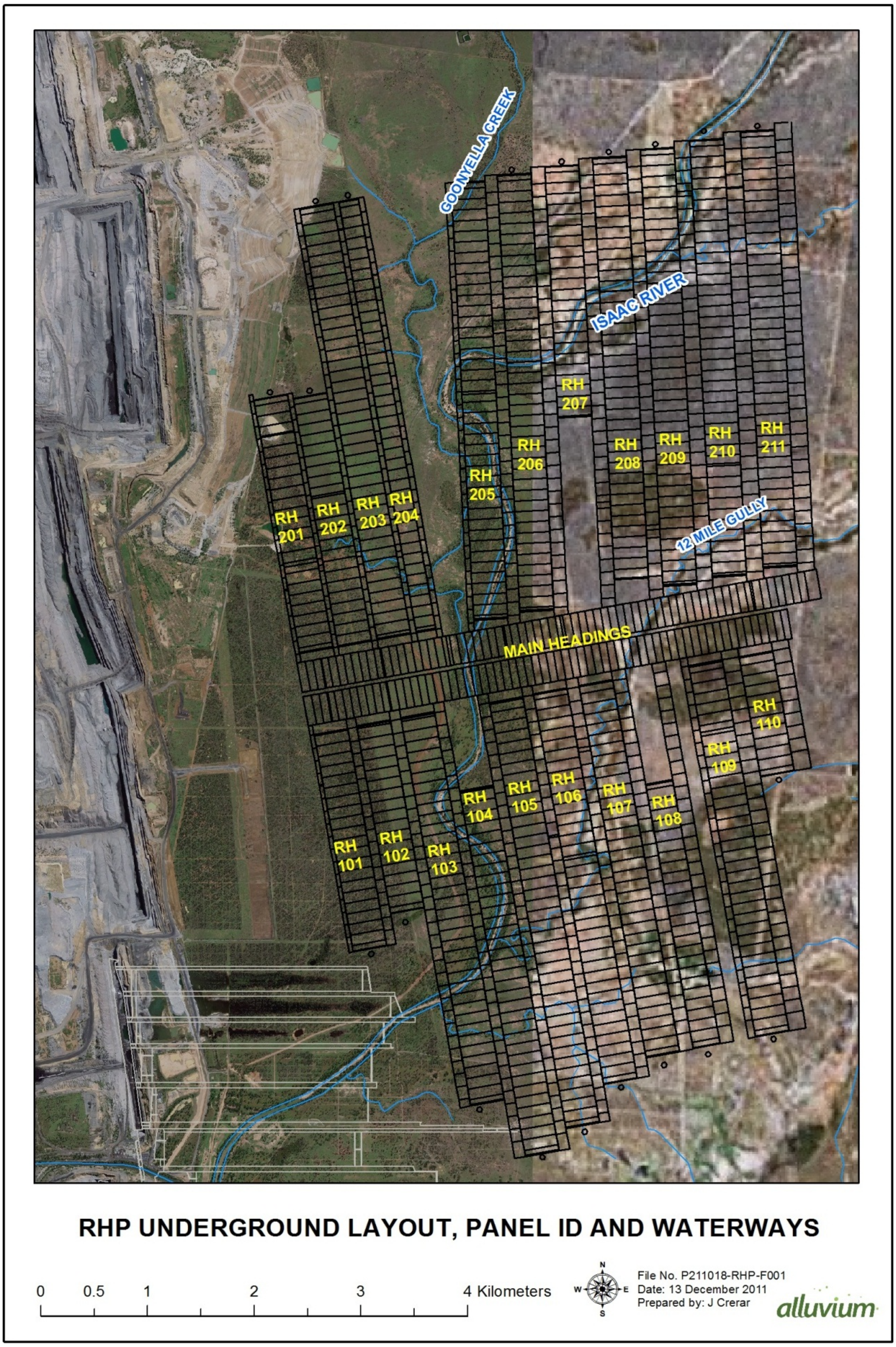


Figure 1. Overview of RHM Mine Area

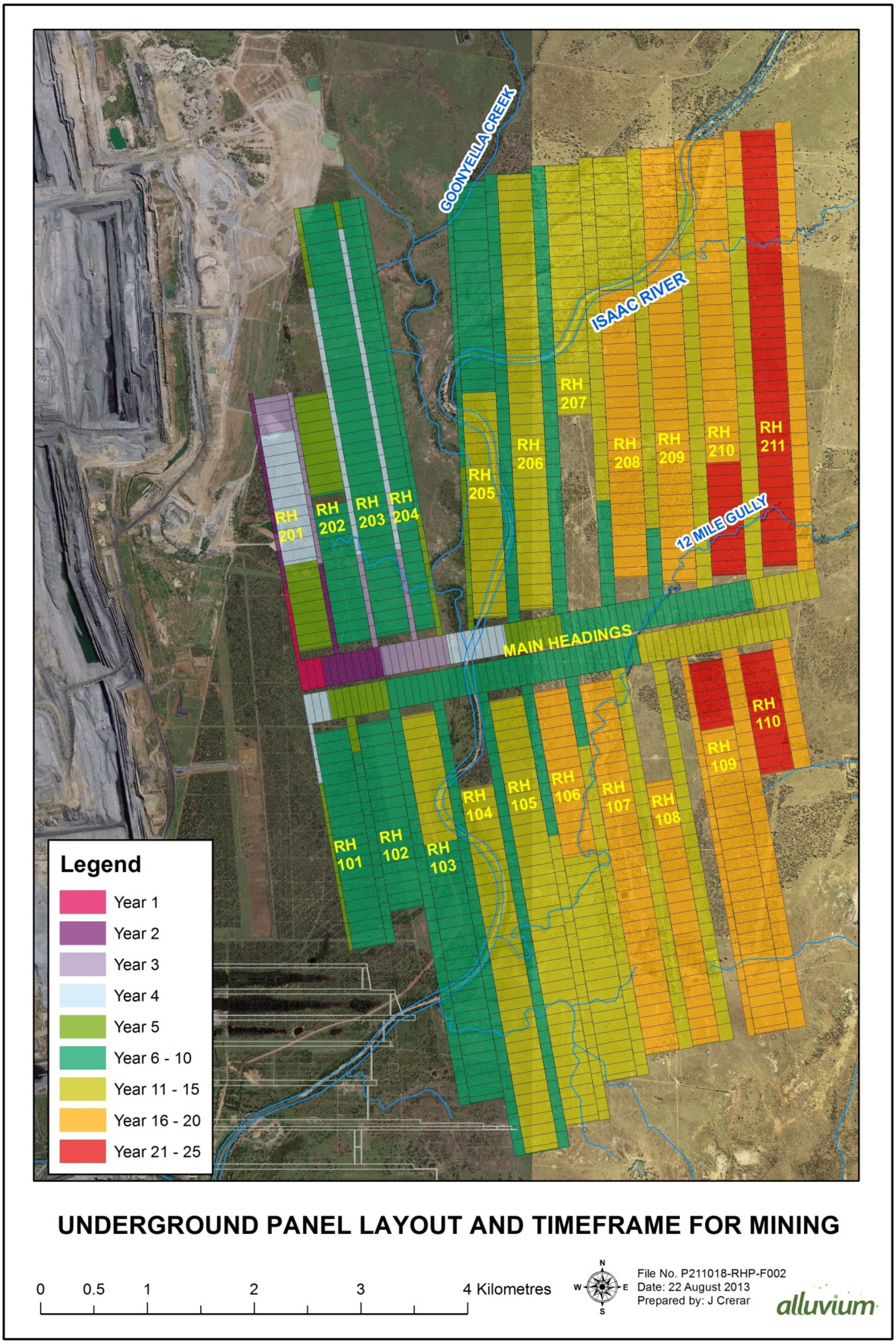


Figure 2. RHM underground mine longwall panel layout and anticipated timeframe for mining

Within an alluvial system such as the Isaac River, the immediate physical and subsequent geomorphic changes to the system were identified as 1st and 2nd order impacts of subsidence. These are the immediate impacts with other impacts such as water quality and quantity and ecological changes being dependant on the scale and location of the 1st and 2nd Order impacts. A key to understanding the 3rd and 4th order impacts is the development of an understanding of the 1st and 2nd order impacts. The IRCIA developed and quantified 1st and 2nd order impacts across all the existing and proposed underground mine plans that were planned to extend beneath the Isaac River as of 2007. Overall, plans to subside approximately 28km of the Isaac River channel were included with approximately 60 longwalls extending beneath the river with maximum subsidence of approximately 3m.

The IRCIA identified that while there is potential for impacts of the Isaac River as a result of mine related subsidence, none were determined to be significant in terms of instigating long term large scale geomorphological change. Subsidence voids based on the then current mine plans when considered on a reach scale were predicted to have close to 50% or greater probability of infilling during the period of mining. Overall, subsidence voids were predicted to be infilled within 20 years after the cessation of mining on the Isaac River unless there is a substantial reduction of sediment inputs from the Isaac River catchment. Within the mining period however, risks were identified to bed and bank stability, such as potential for river bed deepening of up to 1.8m and subsequent widening through bank erosion within the BRM plan reach. Such impacts are presently being managed at the local scale with soft engineering solutions such as timber pile fields and vegetation as implemented at BRM and Moranbah North mine.

The final version of the IRCIA report was provided to DERM in August 2009. Further to this, a workshop was held in Moranbah attended by approximately 30 people, including 12 people from DERM. An update of the IRCIA is currently underway, which includes the assessment of the RHM as considered herein.

Subsidence Management Strategy and Monitoring

A Subsidence Management Strategy for surface water processes was developed to address the areas of risk associated with the mining operations under the Isaac River at BRM for longwalls 101-106 (Lucas et al., 2006). The Subsidence Management Strategy components are:

1. Monitoring, evaluation and review
2. Managing bed and bank stability
3. Vegetation management
4. Panel catchment and overbank flood flow management
5. Infrastructure relocation

The strategy was based on the concepts of adaptive management and is reliant upon an effective program of monitoring, evaluation, review and implementation of appropriate management actions. Following the approval of the Subsidence Management Strategy, the Isaac River Monitoring Program for BRM was established in 2007 and has been repeated annually thereafter. The monitoring program was designed to report on the impact of longwall mining related subsidence on the Isaac River and also, the condition of the Isaac River Diversion.

The monitoring program is designed to track changes in condition over time; reduce risks to the environment and mining operations by raising potential maintenance and management issues; and facilitate any licencing requirements.

The baseline monitoring in 2007 and subsequent annual monitoring has been undertaken in accordance with the DERM recommended ACARP monitoring for Bowen Basin diversions. The Index of Diversion Condition (IDC) method was used to record the condition of reaches upstream from the diversions, the diversions and downstream from the diversions. The monitoring program includes geomorphic and ecologic aspects along the channel and riparian zones and some terrestrial sites on the terrace or adjacent slopes. The monitoring program quantifies and qualifies existing conditions and any changes that occur during and post subsidence for both the Isaac River channel and floodplain/terrestrial areas.

Monitoring photopoints for the Isaac River monitoring program implemented at BRM are shown in Figure 3.

In 2011, BMA submitted an updated subsidence management plan (SMP) that incorporated recommendations detailed in Draft Central West Water Management and Use Regional Guideline ‘Watercourse Subsidence – Central Queensland Mining Industry’ V1 (DERM, 2011). The SMP was approved by the department of EHP in March 2012.

Figure 3. Reach descriptions and subsidence monitoring locations implemented at Broadmeadow Mine

2 Geomorphic assessment of watercourses

This assessment describes the geomorphic character, behaviour and condition of the Isaac River and tributaries within the RHM area proposed for longwall mining. One of the purposes of the assessment is to present EHP with sufficient information to determine the nature of watercourses on the site (as defined in the *Water Act 2000*) so that licence conditions, if any, may be determined for mining activities that may impact upon those watercourses.

2.1 *Water Act 2000* watercourse definition

The following definition of a watercourse is copied directly from the Water Act 2000 Glossary (note an Amendment Bill on the definition has been through Queensland Parliament in 2010 that supersedes this definition).

> ***watercourse***—
>
> 1 *Watercourse* means a river, creek or stream in which water flows permanently or intermittently—
>
> (a) in a natural channel, whether artificially improved or not; or
>
> (b) in an artificial channel that has changed the course of the watercourse;
>
> but, in any case, only—
>
> (c) unless a regulation under paragraph (d), (e) or (f) declares otherwise—at every place upstream of the point (***point** A*) to which the high spring tide ordinarily flows and reflows, whether due to a natural cause or to an artificial barrier; or
>
> (d) if a regulation has declared an upstream limit for the watercourse—the part of the river, creek or stream between the upstream limit and point A; or
>
> (e) if a regulation has declared a downstream limit for the watercourse—the part of the river, creek or stream upstream of the limit; or
>
> (f) if a regulation has declared an upstream and a downstream limit for the watercourse—the part of the river, creek or stream between the upstream and the downstream limits.
>
> 2 *Watercourse* includes the bed and banks and any other element of a river, creek or stream confining or containing water.

The definition of a watercourse as provided in the *Water Act 2000* does not provide clarity in defining what reaches of the watercourse network should not be included as watercourses other than for the inclusion of the word channel. Therefore, it is assumed that only continuous channels would be considered a ‘watercourse’ under the Act. Watercourses identified on Geoscience Australia digital mapping at the scale of 1:100,000 are shown in Figure 4.

The Isaac River is the major watercourse traversing the RHM area of longwall mining, with major tributaries Goonyella Creek and 12 Mile Gully also identified. Numerous unnamed tributaries are also mapped however, there are gaps where watercourses appear to become discontinuous or are unchannelised. For the purposes of determining the impact of longwall mining, the geomorphic characterisation of watercourses has been expanded to include these sections of watercourses and also additional flow paths identified from aerial photography and interrogation of digital terrain data. Herein, all watercourses, channelised or unchannelised, will be referred to as waterways or flow paths to avoid confusion with their definition under the Act.

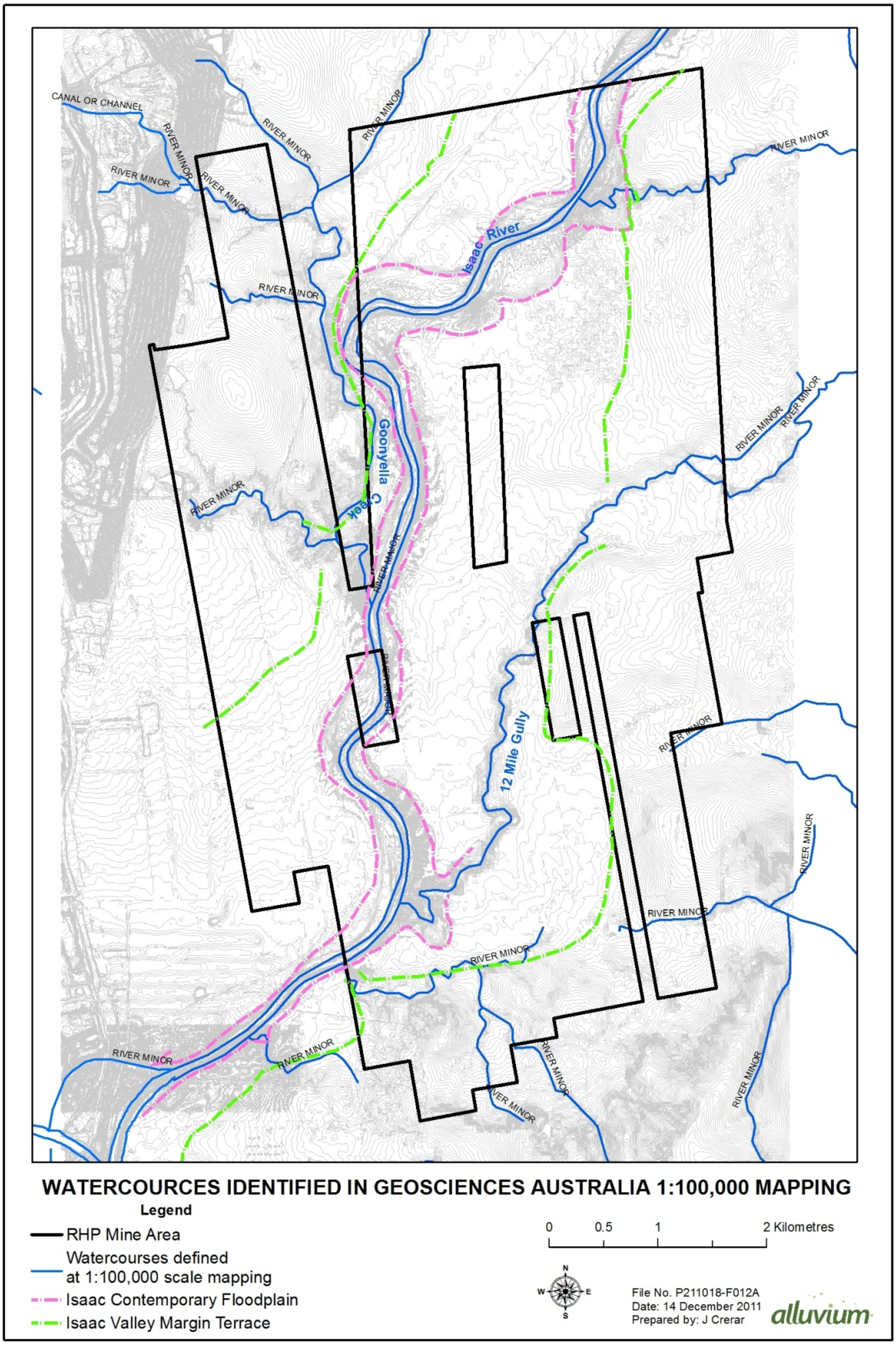


Figure 4. Watercourses identified at 1:100,000 scale mapping across the RHM area of longwall mining

2.2 Characterisation, behaviour and condition of waterways

A basic geomorphic categorisation around channel attributes (presence/absence, continuity and number of channels) has been undertaken for waterways and flow paths identified across the RHM area of longwall mining. This is presented in Figure 9. The characterisation, behaviour and condition of the Isaac River and its tributaries are discussed below.

Isaac River

The Isaac River is an ephemeral sand bed stream that is largely alluvial downstream of the Burton Gorge. Burton Gorge is located approximately 15km upstream of planned underground mining at RHM and while there are some bedrock controls on the river over this distance, the bedrock controls are not dominant and the reach of Isaac River through RHM can be categorised as a low to moderate sinuosity alluvial stream. That is, the alluvial channel boundaries (the bed and banks) can adjust in response to changes in variables such as flow, gradient, sediment supply and sediment transport.

Within that categorisation (refer Table 1), the Isaac River can further be defined as terrace confined. The contemporary channel is constrained by the terrace, which is essentially a paleo floodplain. The contemporary floodplain is a narrow (150-500m wide) band on one or both sides of the channel that is 2-4m lower in elevation than the terrace (2,000 to 5,000m wide) (as shown on Figure 4). Flow events up to approximately a 100 year ARI are contained within the narrow floodplain belt before inundating the much broader terrace in more extreme flood events. Where the contemporary channel impinges on the terrace (such as over the main headings in the mine plan) it produces vertical scarps, which appear to be more actively eroding than the banks elsewhere which are at slopes of 1h:1v to 4h:1v. However, the terrace material is older, more consolidated and weathered and generally more resistant to erosion processes than the Quaternary alluvium.

The terrace is likely to have been formed by the river during climatic conditions that produced larger discharges than the contemporary regime. There are examples of infill of the Tertiary channel in the banks of the current channel where it crosses the northern end of longwall RH205. There are also geologic influences on the extents of the terrace such as constraints provided by Tertiary basalt in the northwest area of the mine plan and further north.

Permian bedrock is noted to outcrop sporadically in the channel bed through the mine plan area. Its presence/absence and continuity along the bed of the river is not known and would depend on the depth of the erosion surface and channel in the Tertiary. This bedrock will provide some control that would limit potential deepening but may also increase the risk of bank erosion at the control.

The condition of the Isaac River is compromised by the excess sediment inputs that have been generated through the catchment with changes in land use. This has smothered nearly all bedforms, infilling pools and creating a smooth sand bed profile with limited potential for aquatic habitat outside of the wet season. The riparian vegetation along the RHM reaches remains reasonably continuous at the overstorey level but minimal at the understorey level. Groundcover is variable but often dense with exotic grasses dominant. These provide conditions for deposition of a mud drape which enhances bank stability. See Figure 5 for example photos across the RHM reach.

Table 1. Geomorphic categorisation of Isaac River over RHM

<table>
<tr><td>Geomorphic Characterisation</td><td colspan="2">Alluvial Continuous – terrace confined</td></tr>
<tr><td>Channel Geometry</td><td colspan="2">Compound with low and high level benches. Floodplain inset below broad terrace.</td></tr>
<tr><td>Channel Pattern</td><td colspan="2">Single, low to moderate sinuosity.</td></tr>
<tr><td>Geomorphic Units</td><td>Channel zone: Plain sand bed, low and high level benches, point bar/bench complexes</td><td>Floodplain/terrace zone: Occasional Gilgai in the terrace, scroll bars with ridge and swale topography in floodplain</td></tr>
<tr><td>Geomorphic Behaviour</td><td colspan="2">Oblique accretion trend with present sediment supply regime. Limited lateral activity.</td></tr>
<tr><td>Sediment Transfer Behaviour</td><td colspan="2">Transport limited, oblique accretion storing some sediment on banks.</td></tr>
</table>

Isaac River at the upstream limit of subsidence for RHM
View upstream

Isaac River at the upstream limit of subsidence for RHM
View downstream

Typical straight reach of Isaac River through RHM
View upstream

Typical straight reach of Isaac River through RHM
View downstream

Isaac River at main headings, erosion at terrace impingement
View upstream

Isaac River at main headings, erosion at terrace impingement
View downstream

Figure 5. Isaac River photos across RHM reach

Goonyella Creek

Goonyella Creek is an ephemeral partly confined single low to moderate sinuosity channel (refer Table 2) that sits largely at the Isaac River terrace-valley margin. It has frequent bed and lower bank bedrock controls upstream of Red Hill Road. Its lower end (last 2.5km) runs parallel with the Isaac River channel in the terrace and may have some interaction during extreme flood events. The channel is relatively narrow and deep in the Isaac River terrace with thick mud drape covered banks (see Figure 6) and a reasonably diverse pool-riffle-run bedform due to a gradient that is steep enough to transport sediment supplied to it. Sediment supply characteristics appear to be influenced by the presence of basalt in the catchment which means it is not oversupplied with sand as many of the other waterways in the Isaac River catchment are.

Table 2. Geomorphic categorisation of Goonyella Creek over RHM

Geomorphic Characterisation	Partly confined low to moderate sinuosity	
Channel Geometry	Compound with low level benches	
Channel Pattern	Single, low to moderate sinuosity with frequent bedrock or terrace controls on planform	
Geomorphic Units	Channel zone: Pool-riffle-run bed, benches, bank	Floodplain/terrace zone: As per Isaac terrace
Geomorphic Behaviour	Limited channel adjustment where bedrock controlled. Mud drape covered banks limit change in bank profile in Isaac terrace	
Sediment Transfer Behaviour	Hydraulic conditions able to transfer most sediment through reach	

Goonyella Creek at confluence with Isaac River
View upstream

Goonyella Creek at confluence with Isaac River
View downstream

Figure 6. Goonyella Creek photos in RHM

12 Mile Gully

12 Mile Gully is an ephemeral tributary of the Isaac River in RHM. The majority of 12 Mile Gully over the RHM mine plan is in the Isaac River terrace. Where the channel flows out from the hillslopes to the east 12 Mile Gully is directed south, parallel to the Isaac River as the Isaac River has deferred its confluence. It is a moderate to high sinuosity single alluvial channel waterway in a broad floodplain with numerous flood channels. 12 Mile Gully is presently grazed heavily with numerous cattle pads and associated bank erosion.

Table 3. Geomorphic categorisation of 12 Mile Gully over RHM

Geomorphic Characterisation	Alluvial Continuous – meandering single channel	
Channel Geometry	Symmetrical straights, asymmetrical bends	
Channel Pattern	Moderate to high sinuosity with meander cutoffs	
Geomorphic Units	Channel zone: sand smothered bed, point bar/bench complexes on high angle meanders, banks	Floodplain zone: flood channel(s), meander cutoffs, gilgai
Geomorphic Behaviour	Laterally active channel with outside of bend bank erosion prevalent. Meander cutoffs prevalent. Incises down to Isaac River invert level in lower reaches where there are near vertical banks.	
Sediment Transfer Behaviour	Excess sediment supply from upstream smothering bedforms in some reaches. Where steeper and more incised most sand transported through.	

12 Mile Gully near to Mains Heading
View upstream

12 Mile Gully near to Mains Heading
View downstream

12 Mile Gully near upstream limit of subsidence for RHM
View upstream

12 Mile Gully near upstream limit of subsidence for RHM
View downstream to cut bank erosion

12 Mile Gully upstream view from Isaac River confluence

12 Mile Gully upstream view, 200m upstream of confluence

Figure 7. 12 Mile Gully example photos in RHM

Minor Tributaries and flow paths
There are numerous un-named and/or unmapped tributaries of the watercourses described above across the RHM plan. Many of them are within the Isaac River terrace and have low gradients and are unconfined. These conditions have produced many waterways that are unchannelised such as a number of chain of ponds (some

of which are the same in appearance as Gilgai) or discontinuous cut and fill flow paths (see Figure 8). In the hillslopes around the eastern and southern perimeter of the RHM mine plan there are continuous headwater gullies of the minor tributaries. These often floodout on the terrace (a floodout is where a continuous channel no longer has sufficient energy and confinement to maintain a channel and the flow path becomes the broader plain). Where these tributaries approach the Isaac they are continuous as the channel cuts down through the terrace to meet its downstream control which is the Isaac River bed.

Discontinuous and unchannelised waterways are important stores of sediment and water in the landscape. Due to land use change and various disturbances much of this component of the waterway network which has low resilience to change has been subject to gully erosion throughout the catchment. The impact of gully erosion or channelization is that runoff is concentrated and hence flow peaks are higher and shorter and delivered to trunk streams in a more efficient manner. Water no longer moves slowly through the landscape. It also means that much greater quantities of sediment are liberated and transported to the main watercourses.

Unchannelised flow paths east of Isaac River

Discontinuous waterways east of Isaac River (Chain of Ponds)

Figure 8. Discontinuous unchannelised flow paths on Isaac River terrace east of the river

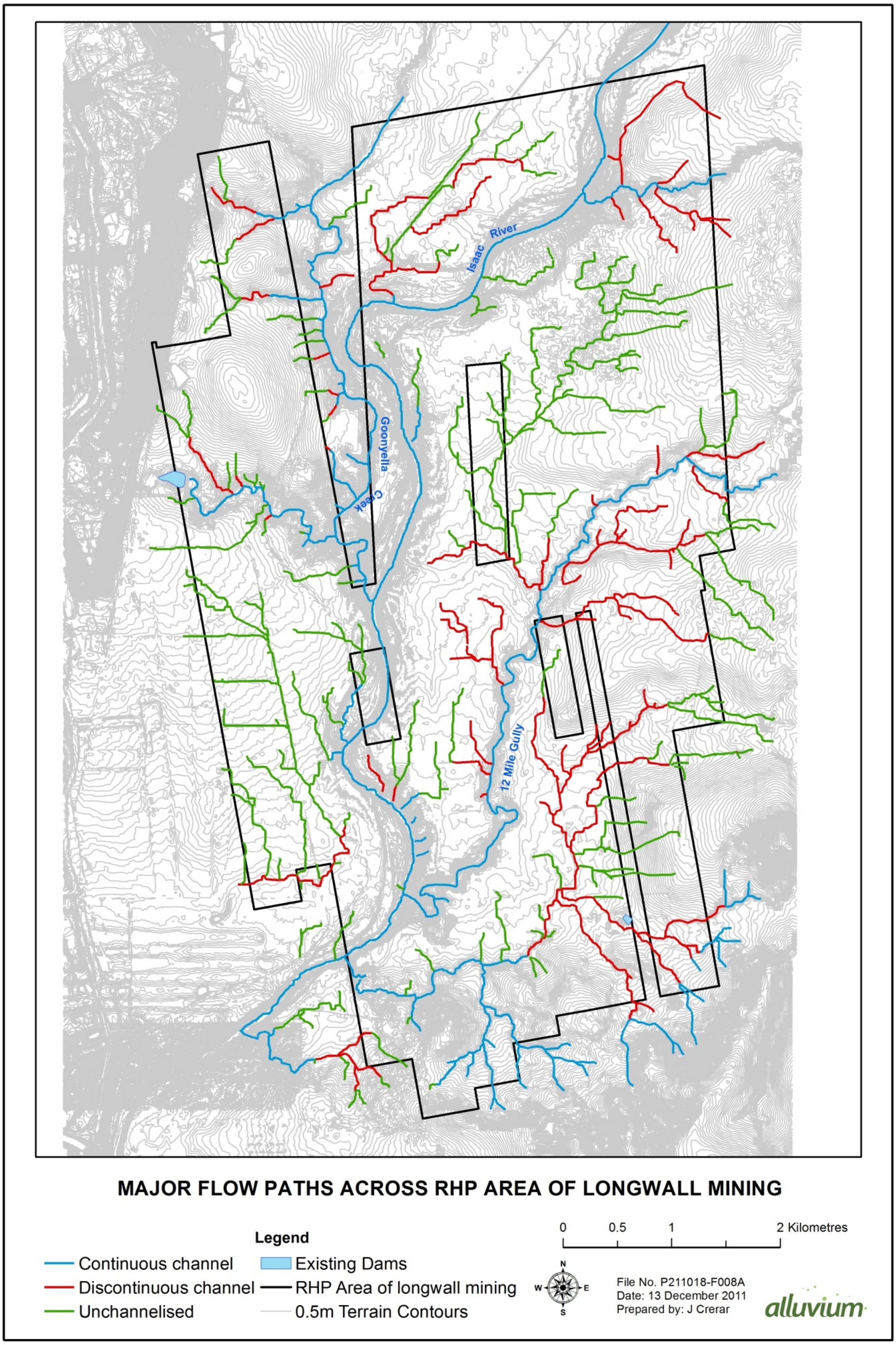


Figure 9. Characterisation of major flow paths across RHM area of longwall mining

3 Mine plan and predicted subsidence (1st order impacts)

3.1 Surface subsidence predictions

The 1st order impacts of subsidence for the RHM have been assessed by IMC Mining Solutions Pty Ltd (IMC, 2010). IMC have used Surface Deformation Prediction Software (SDPS) to predict the maximum depth of subsidence and create subsidence contours for RHM 100 series and 200 series panels. These subsidence contours are shown in Figure 10.

The maximum depth of subsidence for each longwall panel varies from -5 to -6m based on a worst case scenario modelled by IMC. However, depending on where the river crosses the longwall panel, the depth of subsidence trough in-channel may be less. The maximum subsidence depth and volume estimate for each subsidence trough (otherwise referred to as a void) that intersects the Isaac River is shown in Table 4. Where a panel crosses the river more than once, each pass is denoted with a, b or c. The total void volume in channel created by all subsidence is estimated at 1,309,033 m^3. This has been obtained by subtracting the subsided surface from existing terrain.

Table 4. Maximum depth of Isaac River subsidence troughs and void volumes

Red Hill 100 Series Longwall panels (South of main headings)			
Panel ID	Max Depth (m)	Subsidence void (m^3)	Timeframe for Mining
RH103a	- 6	135,121	Year 11 - 15
RH103b	-6	79,975	Year 6 - 10
RH104	-6	338,697	2026-2030Year 11 - 15
	Sub-total	*553,792*	
Red Hill 200 Series Longwall panels (North of main headings)			
Panel ID	Max. Depth (m)	Subsidence void (m^3)	Timeframe for Mining
RH205a	-6	58,466	Year 6 - 10
RH205b	-6	283,360	Year 11 - 15
RH205c	-6	131,978	Year 11 - 15
RH206	-6	53,482	Year 11 - 15
RH207	-6	110,868	Year 11 - 15
RH208	-5	34,655	Year 11 - 15
RH209	-6	71,784	Year 16 - 20
RH210	-4	10,649	Year 16 - 20
Sub-total		*755,241*	

Digital terrain data was provided to the project team for use in the EIS, both Airborne Laser Scanning (LiDAR) and photogrammetry data, the extents of which are shown below in Figure 11. LiDAR data was acquired for the Isaac River Corridor (500m wide) on 25 November 2008. This has been utilised in the hydraulic modelling, sediment transport assessment and estimating void volumes in channel post subsidence (see Table 4). The vertical accuracy of the LiDAR data was reported as 0.15m and the horizontal accuracy <0.5m.

An amalgam of the 2010 and 2006 aerial photogrammetry datasets has been used to create a pre subsidence surface for RHM. The post subsidence surface is based on this pre subsidence DTM and incorporated predictions of subsidence developed by IMC Mining Pty Ltd. The vertical accuracy of the 2010 aerial photogrammetry was reported as 0.20m and the horizontal accuracy 0.5m.

The 2005 dataset is expected to be of similar accuracy. A longitudinal section of the Isaac River comparing the various data and predicted post subsidence surface is presented in Appendix A.

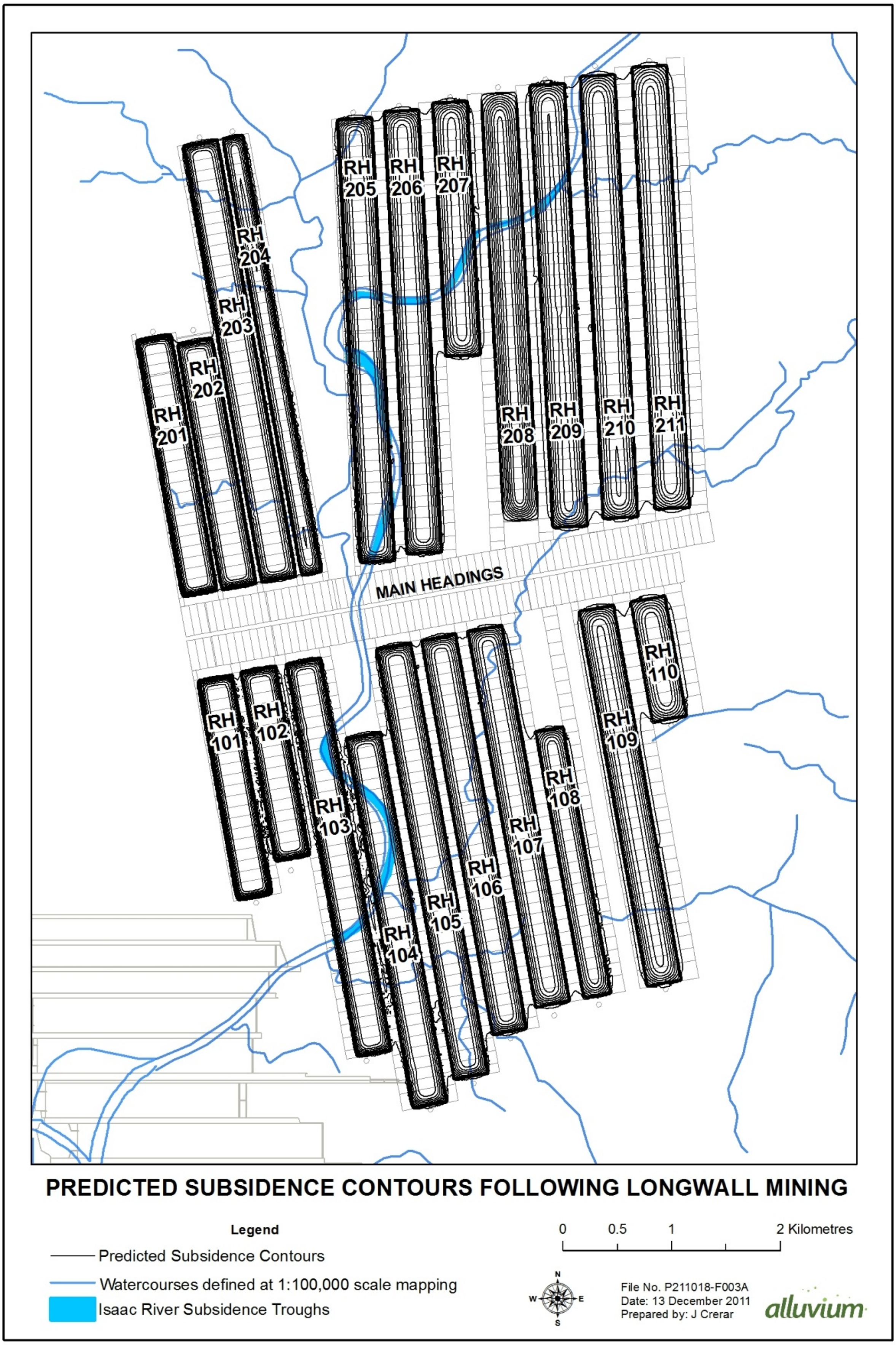


Figure 10. Red Hill underground expansion option longwall mine panels and predicted subsidence contours

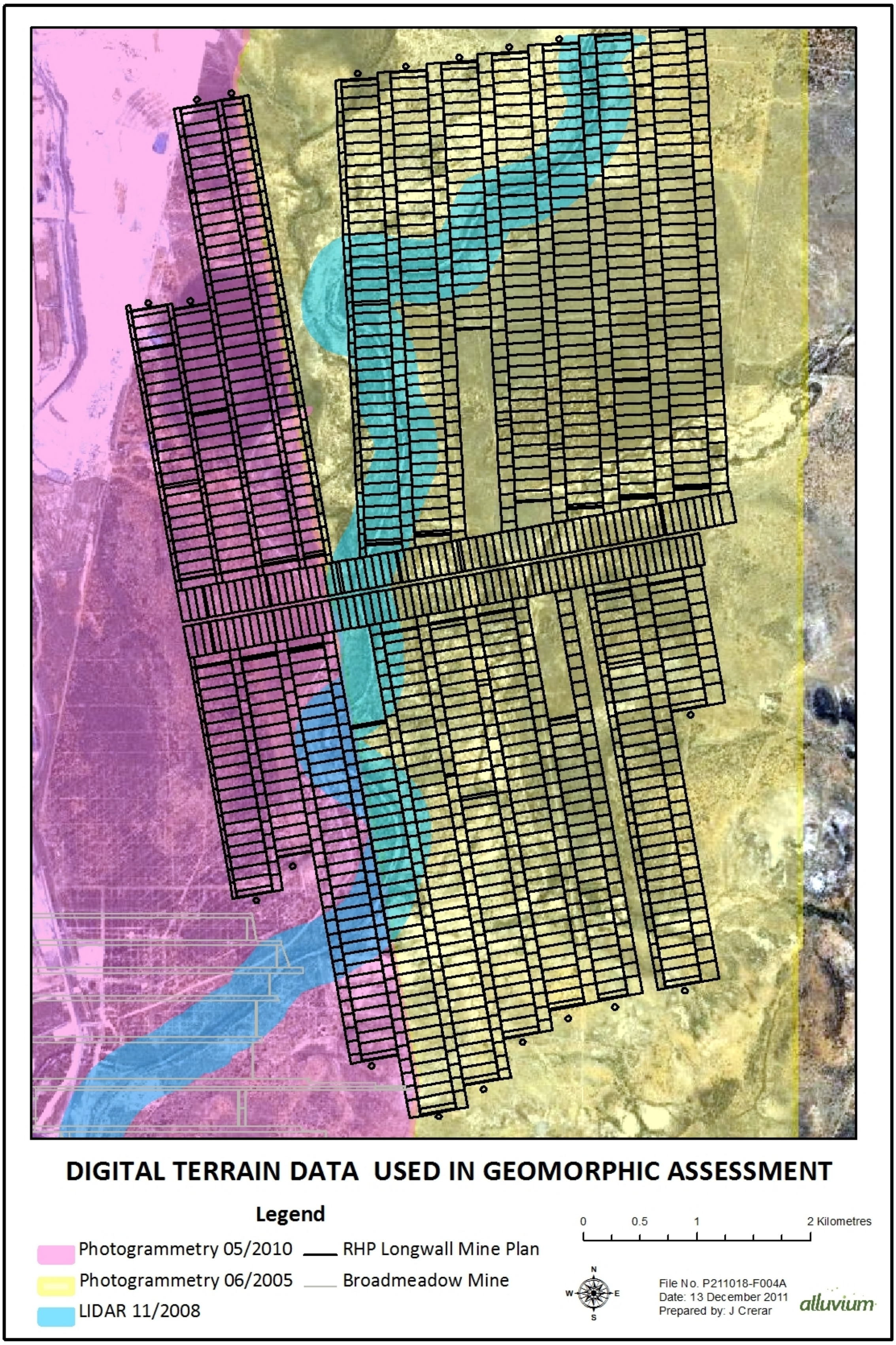


Figure 11. Digital terrain data covering the RHM underground mine area

3.2 Changes to waterways and flow paths post subsidence

The photogrammetric datasets created for pre and post subsidence have been used to determine changes to runoff patterns as a result of the RHM plans for underground mining. A 3m grid digital terrain model (DTM) of the pre and post subsidence triangulated surfaces was used to delineate runoff patterns using the computer program CatchmentSIM. Flow paths were defined at a scale that could be used as a practical tool for the assessment of pre and post subsidence runoff.

The post subsidence DTM is shown in Figure 12. The post subsidence runoff patterns and subsidence troughs in the Isaac River are also highlighted.

The subsidence associated with longwall mining creates panel catchments on the floodplain with flow paths generally forming down the centre of the panel. Despite these realignments most major flow paths will continue along their original course. Some panel catchments will pond water until they fill and spill. Despite the creation of subsidence troughs, the spill point in most cases is similar to the pre subsidence flow path due to the nature of the topography.

Accelerated erosion behaviour in the form of avulsion paths, meander cut offs and head cuts may occur in areas where the energy gradients are increased by subsidence, particularly flow paths which drop into subsided panel zones. This is discussed further in Sections 4 and 5.

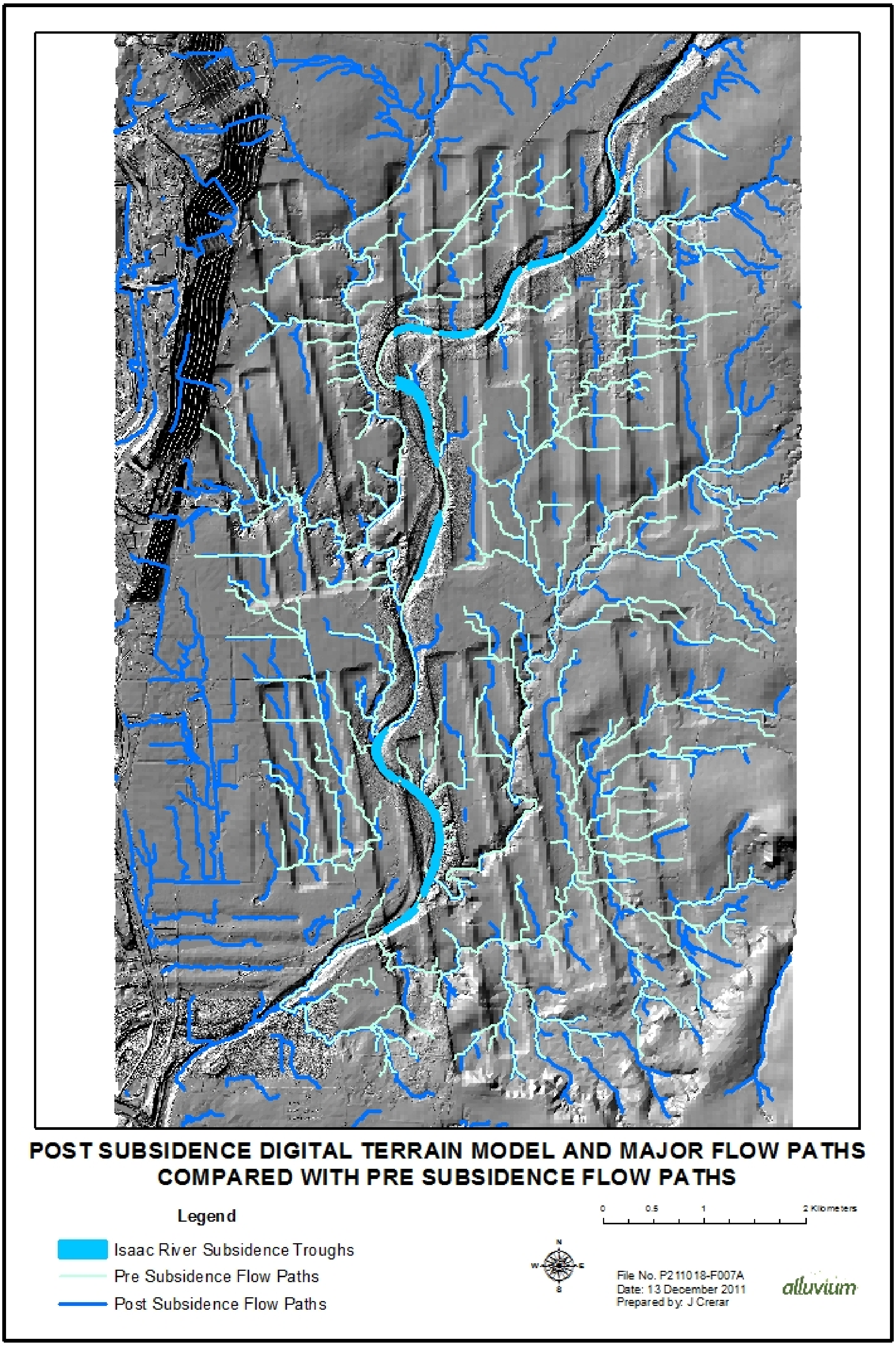


Figure 12. RHM post subsidence digital terrain model showing runoff flow paths and panel catchments

4 Isaac River Predicted geomorphic response (2nd order impacts)

4.1 Hydraulic modelling

Hydraulic and sediment transport modelling has been undertaken to assist with predicting the response of the Isaac River to subsidence. The Hydrologic Engineering Centre's River Analysis System (HEC- RAS) for one-dimensional steady flow has been applied to the Isaac River to model existing conditions and post subsidence of RHM. The River is represented by cross sections spaced 50m apart as shown in Figure 13.

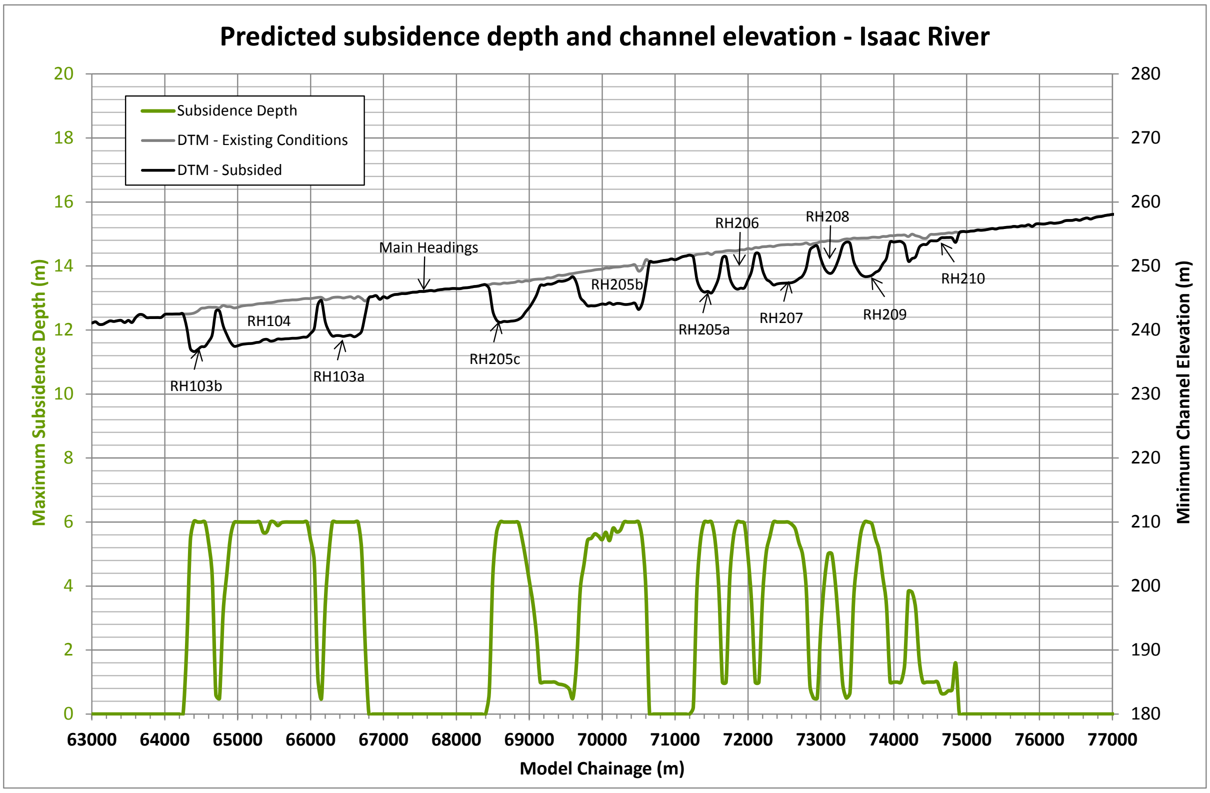


Figure 13. RHM Reach of Isaac River for existing conditions and post subsidence

Modelling results for velocity, shear stress and stream power are provided in Appendix B. Stream flows of $250m^3/s$ and $1000m^3/s$ have been selected for presentation purposes.

The predicted change post subsidence when compared to existing for the key hydraulic parameters is shown graphically in Figure 14 and Figure 15. A decrease in value is predicted through the Panel (subsidence void) and an increase in value at the upstream limit of subsidence, over the pillars and downstream of the main headings. The maximum increases are predicted to occur over the longer remnant raised sections of the Isaac River. In particular,

- Upstream limit of subsidence void RH205b
- Downstream limit of the main headings (subsidence void RH104)
- Over the pillar zone between subsidence troughs RH103a and RH104

These findings are consistent with previous studies and field observations where a deposition environment is created through the longwall panels and deepening occurs over pillars, remnant raised sections and upstream. The hydraulic modelling does not represent the deepening that can occur downstream of a panel due to interrupted bedload sediment transport continuity. The geomorphic response of the river to subsidence is discussed further in Section 4.2.

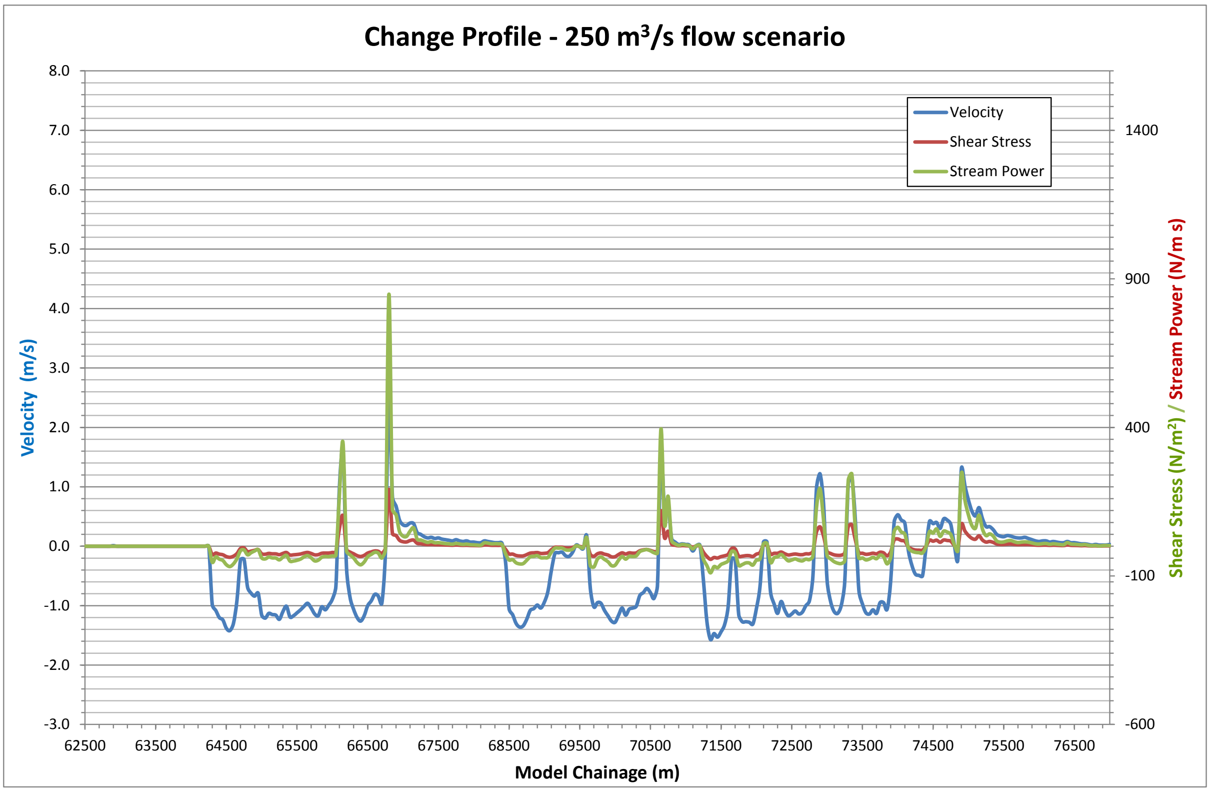


Figure 14. Predicted change in hydraulic parameters post subsidence for 250 m^3/s stream flow

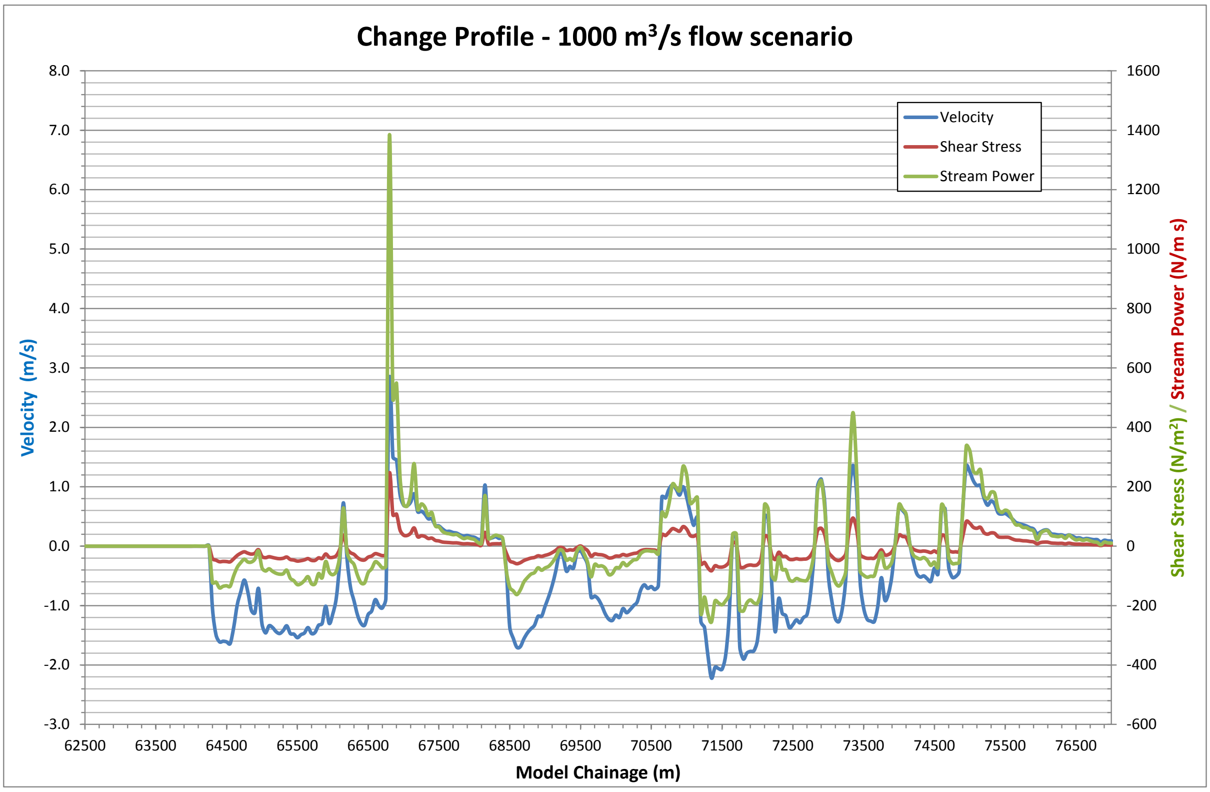


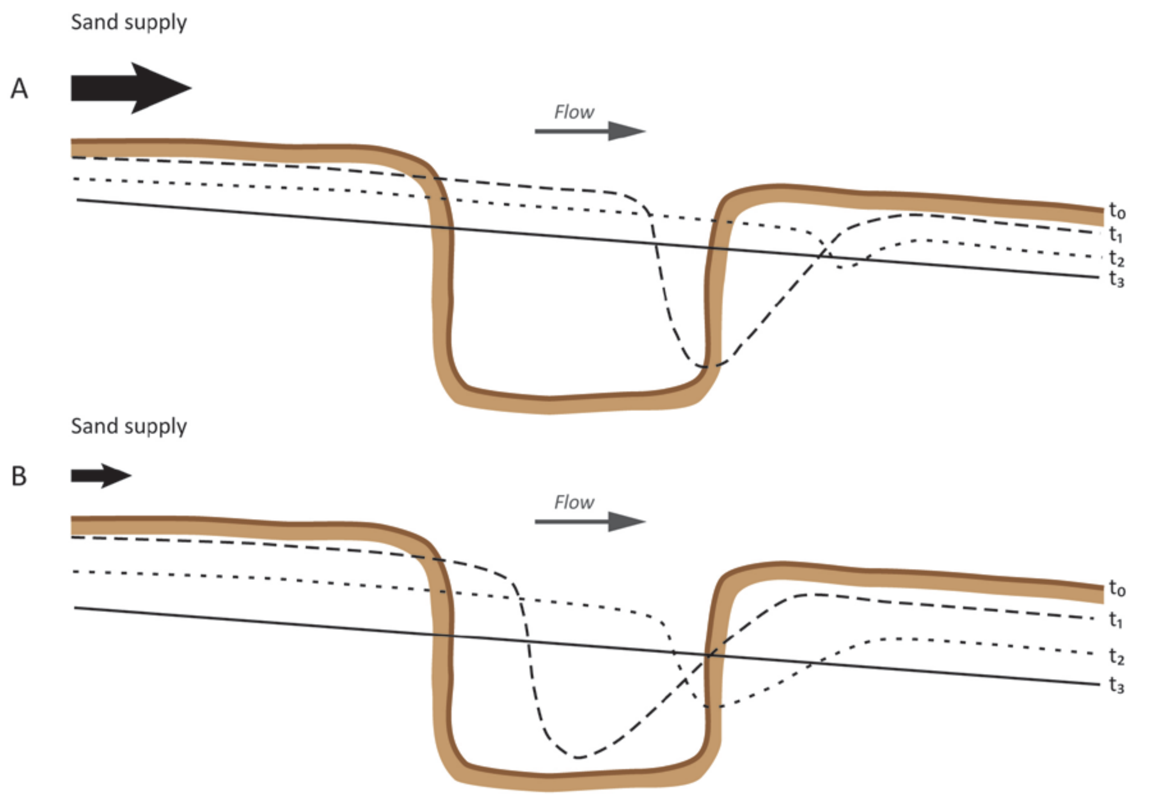
Figure 15. Predicted change in hydraulic parameters post subsidence for 1000 m^3/s stream flow

4.2 Sediment transport assessment

The geomorphic processes in an alluvial mobile sand bed stream like the Isaac River, following longwall mining related subsidence, are similar to the geomorphic response to sediment extraction programs. This process is illustrated in Figure 16.

If the volume of the voids created by the subsidence is found to be insignificant when compared to the volume of sediment transported by the river, then we would expect ongoing sediment transport in the river to overwhelm the voids and have limited impact on geomorphic processes in the Isaac River at a reach scale, impacts would be limited to short terms and a local level.

Alternatively if the volume of void created by subsidence is of a similar scale or larger than event sediment transport then we could expect some geomorphic impacts at a reach scale and over a longer term. Fundamental to this assessment is to identify whether the volume of the voids created by subsidence is of a similar scale to or larger than the sediment volumes transported by the river.



Schematic effects of extracting sediment from a stream bed.
In A, where there is a large sediment load, the pit migrates downstream, but overall bed lowering is small. In B, where sediment load is small, the pit fills slowly and the bed lowers considerably.

Adopted from Rutherford, I.D., Jerie, K. and Marsh, N. 2000. Stream Rehabilitation Manual, Vol.2, Land and Water Australia

Figure 16. Typical geomorphic response to sediment extraction

The assessment of the sediment transport draws upon the work previously completed for the IRCIA, which included sediment rating curve and sediment budget analyses. A brief summary of the findings and comparisons to the current plan for the RHM EIS follows.

Isaac River cumulative impact assessment of mine developments (IRCIA)

The length of river broadly assessed in the IRCIA was 110km. 70km of this, mostly within BMA and Anglo American Metallurgical Coal (AAMC) leases, was assessed in detail. Within that 70km there were existing or proposed mine plans to subside approximately 28km of the river channel with approximately 60 longwalls extending beneath the river. For the purpose of IRCIA, the Isaac River was divided into 10 reaches based on the existing and potential mine developments. At the time of undertaking the IRCIA, the Red Hill underground component was planned for Reach 2, with longwall mining also occurring or planned for downstream in Reaches 3, 5, 7 and 9. The proposed mine plans, extent of the DTM and reach breakdown adopted for the IRCIA are shown in Figure 17.

The IRCIA was primarily focused in Reaches 1 – 9, from Burton Gorge to the southern extents of the future Moranbah South project. The volume of the mobile sand bed within these reaches was estimated as a result of multiplying the plan area of the bed (defined by the toe of bank) by an average depth of sand. An average depth of 3m was adopted for the IRCIA (based on test pits and Ground Penetrating Radar surveys) giving an estimate of 13,000,000 cubic metres of sand available in-stream over the subject reaches.

The IRCIA estimated that over a period of 35 years from 2008, approximately 2.15 million cubic metres of void space will be created in the bed of the Isaac River as a result of longwall mining operations. The void space created represented approximately 10 times the annual average sediment transport and approximately 10% of the total discharge transported over the past 97 years (simulated flow data provided by DERM from IQQM modelling) through most reaches.

Based on the annual totals of sediment discharge for each year of the 97 year period, the total amount of sediment that could potentially be transported through each reach was calculated for increments of 1, 5, 10, 15, 20, 25, 30, 35 and 40 years. A frequency analysis of sediment transport capacity for each reach was then undertaken, from which the probability of subsidence voids infilling could then be determined. The IRCIA probability assessment indicated that the subsidence voids created in the Red Hill underground Reach and BRM would be infilled by 2048, with all subsidence voids downstream infilled by 2068.

In the IRCIA, the estimate for the RHM was for 13 longwalls to subside the Isaac River over the period from 2024 to 2043. The current proposed mine plan includes 8 longwalls to be mined under the river over the period of time from 2021 to 2035. The revised mine plan for the RHM in the context of the IRCIA is shown in Figure 18. A comparison of the subsidence void totals in 5 year increments is provided in Table 5.

Table 5. Comparison of the longwall mine program adopted for the IRCIA and for the RHM EIS

No. of years after mining commences beneath the Isaac River	Adopted in the IRCIA		RHM EIS	
	Subsidence void over 5-year block (m^3)	Cumulative Void Volume (m^3)	Subsidence void over 5-year block (m^3)	Cumulative Void Volume (m^3)
5	66,333	66,333	138,440	138,440
10	59,359	125,692	1,088,160	1,226,600
15	123,321	249,013	82,433	1,309,033
20	78,629	327,642		

Despite a reduction in the number of longwalls subsiding the Isaac River and the timeframe for mining, the estimated increase in subsidence void created within the river is 981,391m^3. This is due to the change in alignment of the longwall panels affecting a greater length of river and also the greater extraction thickness resulting in more subsidence expressed at the surface. The potential impacts due to this subsidence and mitigation options are discussed in Section 4.4, 4.5 and 6.

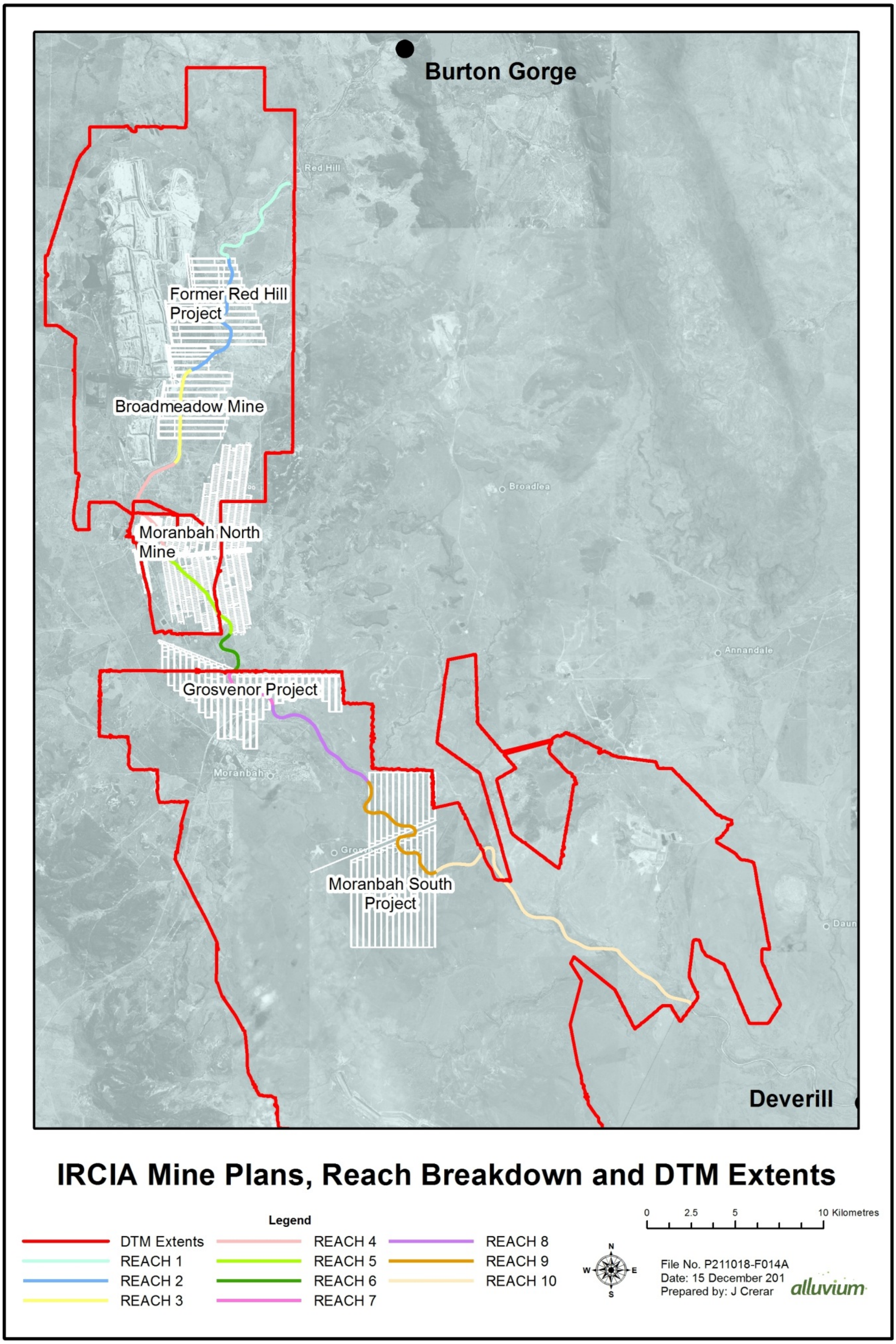


Figure 17. Overview and extents of the IRCIA of Mine Developments

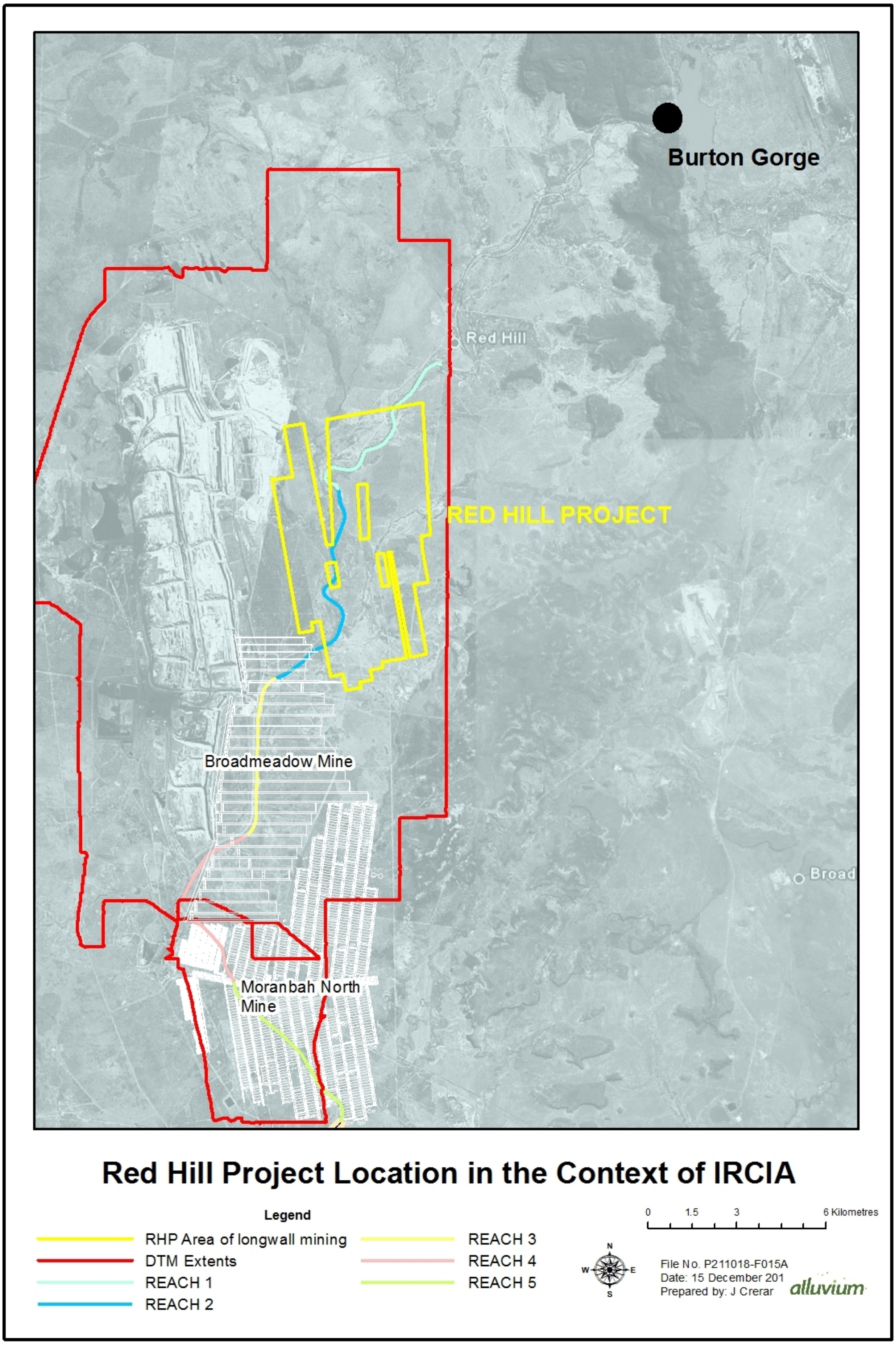


Figure 18. The revised RHM location in the context of the IRCIA undertaken in 2007

Sediment rating curve analysis

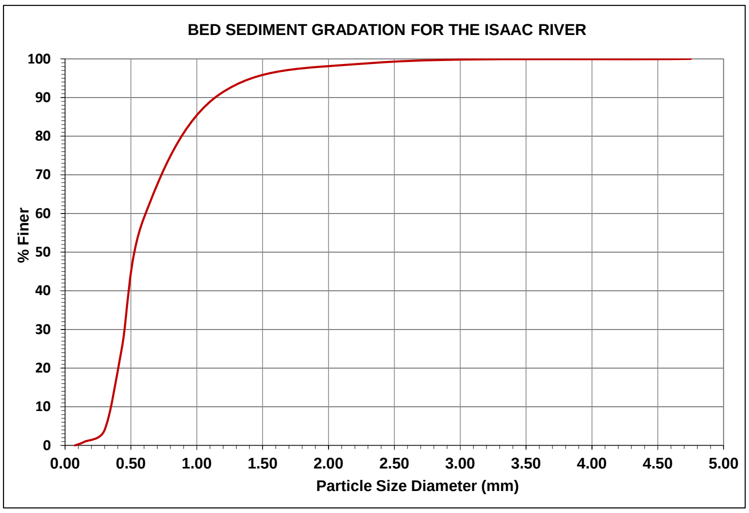
Updated hydraulic modelling and projections of sediment transport capacity for the proposed RHM have been undertaken as part of this EIS, utilising the same methodology as the IRCIA with an updated DTM captured with LiDAR in November 2008.

Sediment transport capacity is calculated within HEC-RAS using the hydraulic parameters for a range of flows at each cross section and applying the Ackers-White function. The Ackers-White function is applicable to large sand bed rivers and was determined during the IRCIA to be the most representative of sediment transport rates when compared to observations of infilling of longwall subsidence voids at Moranbah North Mine during the 2008 wet season.

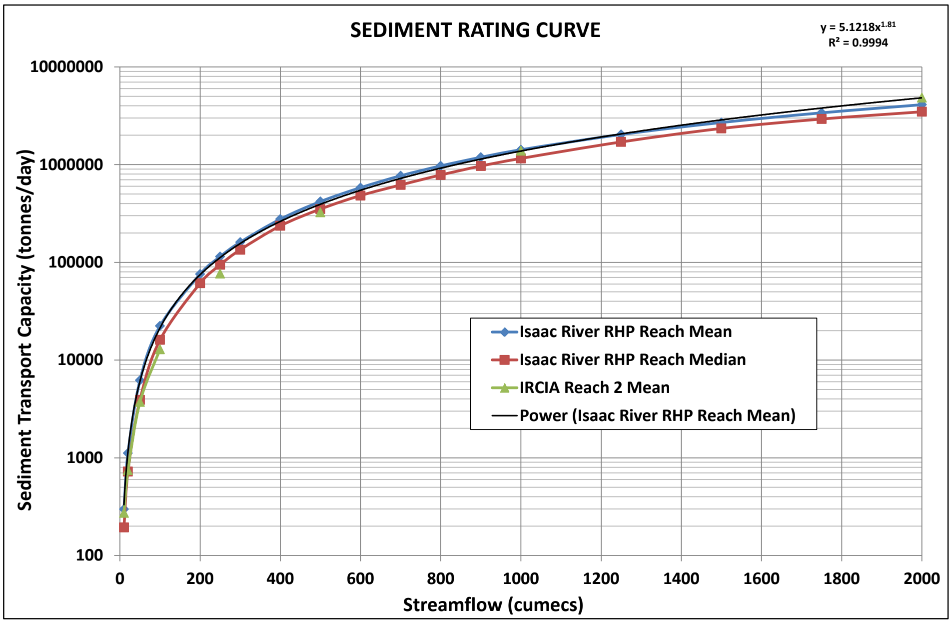
The model input also requires sediment gradation. The bed sediment gradation sampled at Goonyella Rail Bridge has been adopted for use in this assessment (refer Table 6), consistent with the IRCIA.

Table 6. Sediment Gradation

Goonyella Rail Bridge	
Bed Sediment Gradation	
Size mm	% Finer
4.75	100
2.36	99
1.18	91
0.6	59
0.43	25
0.3	4
0.15	1
0.075	0



The sediment rating curve derived for the Isaac River is shown in Figure 19, (STC is Sediment Transport Capacity). In this instance, the relationship between sediment transport and streamflow is described by a power relationship. The relationship shows a good fit and good agreement with that developed in IRCIA.



Flow m3/s	Derived STC tonnes/day
10	331
20	1160
50	6089
100	21351
200	74866
250	112123
300	155960
400	262513
500	393150
600	546860
700	722853
800	920482
900	1139204
1000	1378550
1250	2064571
1500	2871758
1750	3795959
2000	4833780

Figure 19. Sediment Rating Curve for the Isaac River RHM Reach

The sediment rating curve analysis is only suitable for application to streams that are transport limited. That is, they are not limited by sediment supply. Assuming that sediment discharge is equivalent to the river's sediment transport capacity, comparisons of rating curves between reaches enables a qualitative analysis of the likely response in the downstream reach e.g. deposition or erosion.

Within subsidence troughs, hydraulic parameters reduce such that sediment transport capacity of bed sediments is negligible and the environment depositional. However, this assessment does not account for changes in sediment transport capacity that occur as sediment is deposited and geometry changes. It is therefore conservative. This is discussed further in Section 4.3.

4.3 Sediment budget analysis

The sediment budget for the RHM has been estimated by calculating the sediment yield and comparing this to the subsidence void created in the river from longwall mining. Sediment yield is calculated by applying the sediment rating curve to the mean daily flow duration curve to obtain an estimate of sediment yield over time.

For the Isaac River, streamflow information is available for Station 130414A at Goonyella, located 10km downstream, which has been in operation for 28 years (1983 – 2011). Also available is the IQQM 97-year dataset of simulated flows obtained from DERM for the Isaac River at Burton Gorge and Deverill. These flow datasets were used in the IRCIA, with flows at reach locations apportioned by catchment area. A comparison of the flow duration curves for the IQQM estimates compared with the gauged data is provided in Figure 20.

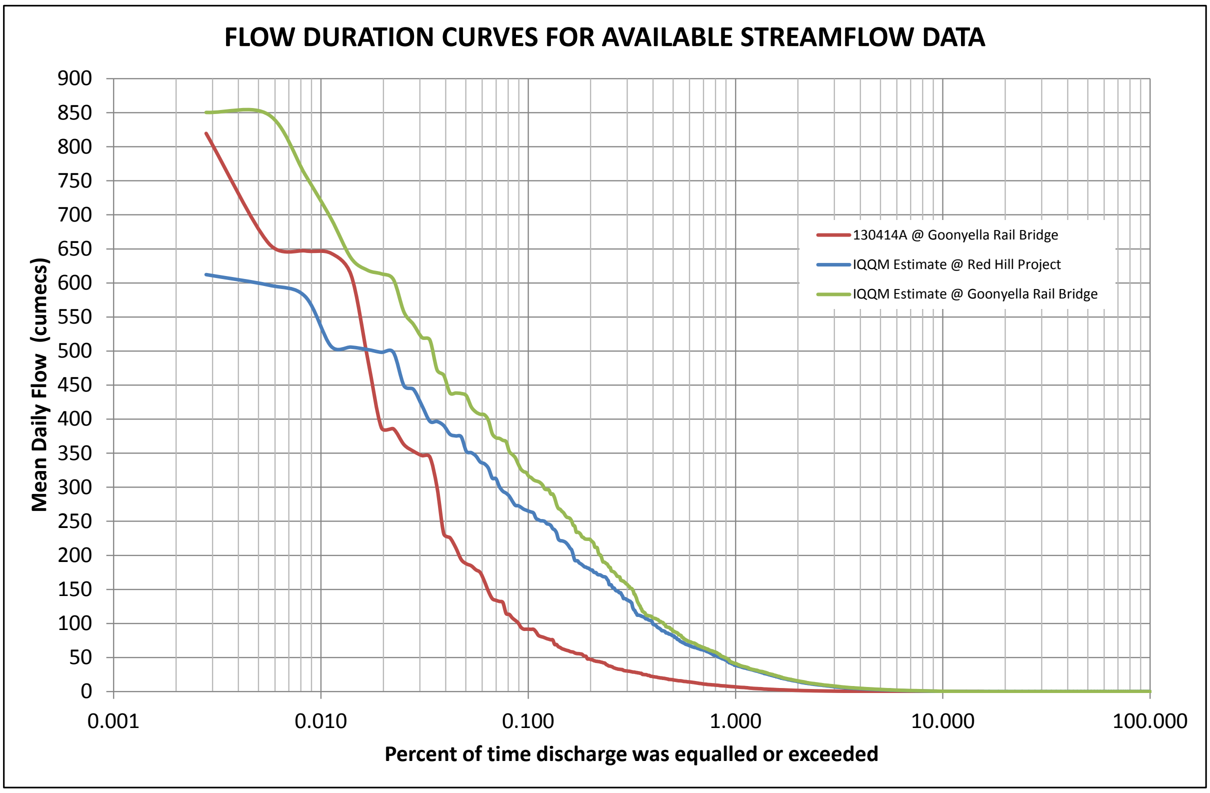


Figure 20. Flow duration curve (mean daily) for Isaac River flow data

The IQQM estimate for RHM is for the downstream end of the mine plan and should account for the flows from Goonyella Creek and 12 Mile Gully. The Goonyella Rail Bridge is located downstream of the Isaac River confluence with Eureka and (formerly) Fischer Creek and therefore, is expected to have slightly higher flows. This is reflected in the difference between the IQQM estimates. Overall, the flow duration curves are similar, with the gauged data showing minor flows account for less time than the IQQM datasets. Given that low flows are not significant with regard to sediment transport in the Isaac River, the IQQM flows for RHM have been adopted for the calculation of sediment yield. The resultant sediment yield curve is shown in Figure 21.

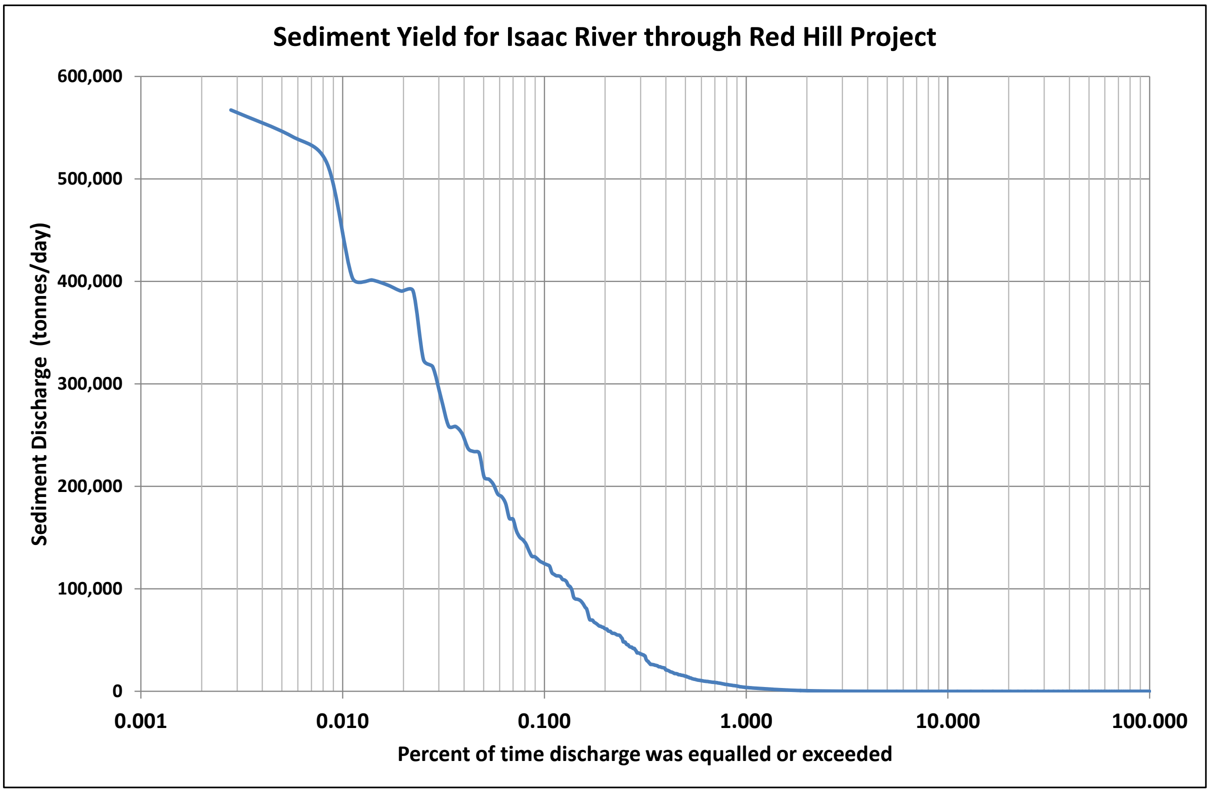


Figure 21. Sediment Yield Curve for Isaac River at RHM

Sediment yield through this Reach occurs for approximately 1% of the time, based on the IQQM mean daily flow estimates from July 1898 to June 1995. A summary of the mean, maximum and minimum annual sediment yield and totals in 5-year increments is provided in Table 8. Tonnes have been converted to cubic metres by the division of 1.9 to convert the weight of wet sand to a volume. This has also been converted to an equivalent depth across the reach for visualisation purposes and to assess the potential for stream bed deepening associated with any deficit in the sediment budget.

There is great inter-annual variability in Isaac River flows which is evidenced by the large difference between mean annual sediment yield of 151,943 tonnes and maximum annual yield of 3,671,611 tonnes. A frequency analysis on this data has been undertaken to provide an indication of the timeframe for infilling of subsidence voids assuming that future flow rates are similar to the past ~100 years and that subsidence voids trap all bed sediments. The results should be used with some obvious cautions as we cannot predict future flows and it does not account for land use (affecting sediment supply) or climate change. Nonetheless, the results provide some indication of the order of magnitude and scale.

The void space created in channel for each 5-year block of mining for RHM is shown in Table 7**,** along with the cumulative void total. All sediment transport quantities have also been expressed as a depth of sand over the RHM reach of the Isaac River. Assuming no infilling, the subsidence voids created in channel would be equivalent to a strip depth 3.1m over the RHM Reach.

Based on the past flow record, there is 36% chance of the subsidence voids created in the RHM Reach infilling over the period of mining. Following the cessation of mining, there is the possibility that infilling will not occur for a further 25 years. It should also be noted that this methodology does not account for progressive infilling and changes to cross sections over time. It therefore, may overestimate the persistence of subsidence voids within the Isaac River channel (representing a potential worst case).

Table 7. Subsidence void volumes created in-channel through RHM timeframe for mining

Time period for mining	5-year block		No. of years after mining commences	Cumulative	
	Subsidence void (m^3)	Equivalent Strip Depth (m)		Cumulative Void Volume (m^3)	Cumulative Strip Depth (m)
Year 6 - 10	138,440	0.33	5	138,440	0.33
Year 11 - 15	1,088,160	2.57	10	1,226,600	2.9
Year 16 - 20	82,433	0.2	15	1,309,033	3.1

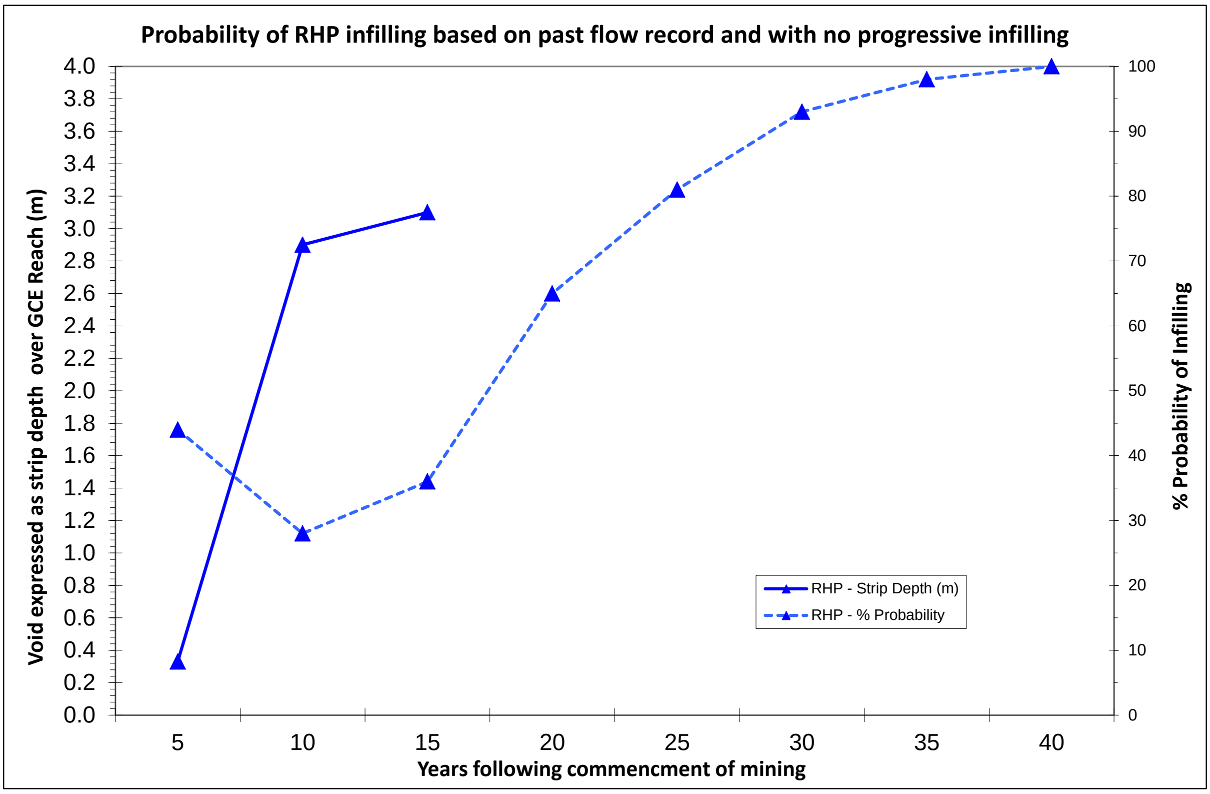


Figure 22. Estimate of infilling for RHM based on past flow record and assuming no progressive infilling

Table 8. Annual Sediment Yield for Isaac River and Totals in 5-year Increments over IQQM simulated flow record (1898 – 1995)

	Sediment Yield Totals (tonnes)									
	Annual	*5-year*	*10-year*	*15-year*	*20-year*	*25-year*	*30-year*	*35-year*	*40-year*	*45-year*
Mean	151,943	759,670	1,519,280	2,272,296	3,020,641	3,738,847	4,457,020	5,175,062	5,892,993	6,610,594
Maximum	3,671,611	4,184,468	5,578,837	5,881,787	5,966,895	6,732,021	7,442,048	7,578,459	8,304,260	9,037,509
Minimum	-	-	53,018	94,768	181,309	337,517	423,701	1,544,624	4,256,948	4,480,622
	Sediment Yield Totals (cubic metres)									
	Annual	*5-year*	*10-year*	*15-year*	*20-year*	*25-year*	*30-year*	*35-year*	*40-year*	*45-year*
Mean	79,970	399,826	799,621	1,195,945	1,589,811	1,967,814	2,345,800	2,723,717	3,101,575	3,479,260
Maximum	1,932,427	2,202,351	2,936,230	3,095,677	3,140,471	3,543,169	3,916,868	3,988,663	4,370,663	4,756,584
Minimum	-	-	27,904	49,878	95,426	177,640	223,001	812,960	2,240,499	2,358,222
	Equivalent Depth of Sand over RHM Reach (metres)									
	Annual	*5-year*	*10-year*	*15-year*	*20-year*	*25-year*	*30-year*	*35-year*	*40-year*	*45-year*
Mean	0.19	0.95	1.89	2.83	3.76	4.66	5.55	6.45	7.34	8.24
Maximum	4.58	5.21	6.95	7.33	7.44	8.39	9.27	9.44	10.35	11.26
Minimum	0.00	0.00	0.07	0.12	0.23	0.42	0.53	1.92	5.30	5.58

Sediment availability

Fundamental to the sediment rating curve and budget analyses as it applies here is the assumption of sediment availability. For the IRCIA, the volume of sand within the river channel was estimated to be 3m deep on average over the length of the study reach. This was based on test pits conducted at BRM and Moranbah North Mine over 2003 to 2007 and also, Ground Penetrating Radar Survey undertaken for the 13km of the Isaac River through the Moranbah North mine lease in 2003.

Recent field observations suggest that an average 3m depth of sand is possibly excessive in some parts of the channel, in particular the Isaac River diversion. For this assessment and to be conservative, the average depth of sand in the Isaac River has been reduced to 2m through the RHM Reach and upstream. The depth of sand in the diversion is estimated to be less than 1m deep on average at present. In total, the sand volume available in channel upstream of RHM is estimated at 2.2 million cubic metres. The estimated in channel mobile bedload sediment for reaches upstream and immediately downstream of RHM is summarised in Table 9.

Table 9. Estimates of sand volume in channel

Description	River length (km)	River Bed Area (m^2)	Estimated Current Condition (m^3)
Upstream of RHM	17.8	1,107,526	2,215,052 (2m deep)
RHM Reach	10.6	422,375	854,749 (2m deep)
RHM to Isaac River Diversion*	2.32	85,141	170,286 (2m deep)
Isaac River Diversion	6.45	377,789	<377,389 (<1m deep)

* Excludes any sand removed from the system through infilling of BRM subsidence troughs

The total subsidence void created in channel by mining RHM is estimated to be 1,309,033m^3. The volume of sand available in channel upstream is estimated to be approximately 170% of the amount of subsidence void created by longwall mining through the RHM Reach. On this basis, it is likely that subsidence voids created by RHM will be overwhelmed by sediment already in the river system in the longer term. However, there will also be sediment inputs to the system from bank, gully and hillslope erosion. Minor tributaries from the sandstone escarpment which forms the Burton Gorge to the east of RHM provide for natural inputs of sand to the river. The rate of input has been accelerated by clearing and development up to the base of the escarpment. Within the RHM Reach neither Goonyella Creek nor 12 Mile Gully provide substantive bedload sediment inputs.

SedNET modelling has been undertaken for the Fitzroy River Basin by DERM. The SedNET modelling considered bank, gully and hill-slope erosion, the latter of which was identified as the dominant sediment source of the Fitzroy River Basin. Despite being primarily concerned with suspended sediment load, the contributions to bed load were assumed to be 50% for bank and gully erosion and no contribution to bed load was assumed for hill-slope erosion. The total predicted sediment inputs for the Isaac River catchment upstream of Deverill range from 0.31 to 1.25 tonnes per hectare per year (Dougall, C. et. al, 2006).

A summary of estimates for sediment input to stream and bed contributions based on the results of the SedNET modelling are provided in Table 10.

Table 10. Estimates for sediment input to stream and bed contributions based on SedNET modelling

Catchment Location	Catchment Area (ha)	Annual Sediment Input Total (tonnes)		Annual Bed Load Contribution (tonnes)	
		lower limit	upper Limit	50% of lower limit	50% of upper limit
Isaac River at Burton Gorge	55,100	17,081	68,875	8,541	34,438
Isaac River at Goonyella	121,400	37,634	151,750	18,817	75,875
Isaac River at Goonyella (excluding upstream of Burton Gorge)	66,300	20,553	82,875	10,277	41,438

The sediment transport assessment demonstrates that infilling may occur within a relatively short timeframe if there are a series of high stream flows. However, there could also be a window where there will be minimal sediment yield, possibly over decades, while the subsidence void volume from longwall mining is accumulating. This will require management of the geomorphic response and risks from subsequent flows.

Despite the availability of sediment upstream and substantial inputs to the channel from bank, gully and hill-slope erosion, there is also the potential to create a sediment supply limited scenario for the BRM Reach immediately downstream. This is discussed further in Section 4.5.

4.4 **Predicted geomorphic impacts and increased erosion risks**

River channels will naturally trend towards a state of dynamic equilibrium whereby inputs of water and sediment are in balance with the ability of the river to transport and store water and sediment. Subsidence voids act similar to sediment extraction in that they have the potential to change the balance between sediment storage and transport. The change created will disrupt an equilibrium that may have established in the river (though equilibrium in a river is highly dynamic depending on the flow history). Impacts from the sediment deficit will continue until a new equilibrium is reached, at which time the impacts of the subsidence will gradually abate.

Deepening – upstream, downstream and over pillar zones and mains heading

Erosion and deposition during flow events means that the subsidence void is spatially and temporally dynamic (refer to Figure 16). The void will create an initial draw down effect and locally higher values of velocity, shear stress and stream power at the upstream limit of subsidence. The draw down effect will tend to be greater at lower flows and this is most likely due to the reduced backwater and the strip depth relative to the depth of flow. As the bed longitudinally 'lays back' or deepens, hydraulic and hence sediment transport conditions begin to approach their pre-subsidence state.

The Isaac River through RHM area is currently transport limited. That is, there is more bedload sand supplied to the river than it has the capacity to transport. These factors suggest that deepening may consist of localised adjustment to bed slope and may not progress a long way upstream. The presence of occasional bedrock controls in the river bed is also expected to limit the progression of deepening upstream (depending on whether and how much the bedrock is subsided).

Downstream deepening is also expected to occur as a consequence of subsidence voids capturing a large proportion (if not all) of the bed sediment load of the river until they are infilled. This causes the reach of river immediately downstream of the void to be effectively starved of bed load and to a much lesser extent suspended sediment. To balance the reduction in sediment discharge from the area of subsidence, there is a reduction in stream gradient downstream of the void. This is often referred to as "clear water" erosion.

As flow over the subsidence void will be sub-critical, subsidence will not influence downstream flow depths and velocities. However, the reduction in cross-sectional area at the downstream limit of subsidence may induce some turbulence. This may combine with the threat posed by clear water erosion to locally exacerbate bed and bank instabilities.

A combination of this turbulence, clear water impact and draw down effect may result in deepening of the mobile bed over pillar zones between subsidence voids and also the remnant raised sections of river bed where there is no mining.

The negative impact associated with deepening of the mobile bed will be potential bank erosion instigation. Initial deepening is likely to expose the un-vegetated toe of the riverbank and reduce support for the bank. Also, where riverbanks are less resistant to erosion than the riverbed, lateral migration may occur. Lateral migration is another mechanism by which the river can decrease the slope of the bed. However, it is unlikely that lateral migration will occur in the natural reaches of the Isaac River as it is not evident as having occurred in the recent past and high-suspended load sediment concentrations have created thick mud drapes colonised by vegetation, which limit bank instabilities. For the reach of the Isaac River through RHM, bank erosion is likely to be localised (see Figure 23 for an example).

Figure 23. Existing bank instability that will be exacerbated over the main headings

Impacts on overall channel stability
Areas of potential bank instability and accelerated erosion processes such as avulsion or meander cut-offs (the term avulsion is used throughout as meander cut-offs are a type of avulsion) are highlighted in Figure 27 and discussed in Table 11.

An assessment of the potential geomorphic response to the proposed mine plan has been undertaken qualitatively and where possible quantitatively. The quantitative aspect utilises URS flood modelling outputs for existing conditions (Base case) and a fully subsided mine plan (Proposed case). No model outputs at various points in time through the life of mining have been available to utilise in this assessment, this has been done qualitatively where a risk has been identified at a certain time step (eg. one panel subsided and the next is not). The 100 year ARI event is discussed most commonly in the assessment, as it is the smallest and most likely to occur of the model outputs provided (though still infrequent and large) (see Figure 24).

A proposed levee roughly along the alignment of existing Red Hill Road to protect the proposed Mine Industrial Area (MIA) has been included in the proposed case flood modelling. This reduces the floodplain/terrace flow area in the more extreme events.

The potential geomorphic response may change into the future as a result of earlier geomorphic response such as upstream and downstream progressing deepening. The modelling undertaken is based on a static scenario of modelled subsided existing terrain (eg. no progressive infilling). To undertake dynamic predictions of the evolution of response in the future would require modelling many scenarios based on the many flow spell possibilities.

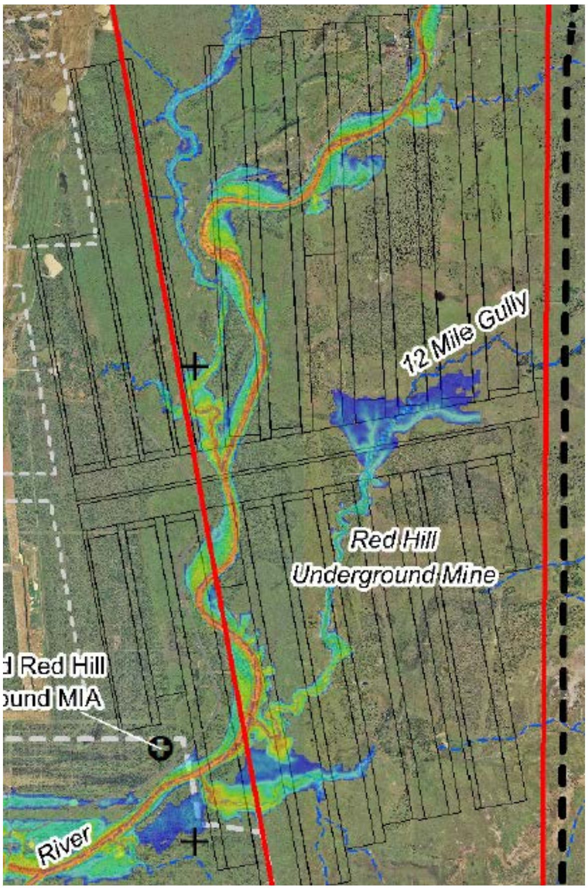
The timing and direction of mining is also important for geomorphic response. Mining commences in the western part of the mine plan and moves east and generally from downstream to upstream along the Isaac River. This has implications for the flood modelling; as much of the full mine plan subsidence floodplain storage created in the upstream panels (RH 206-10) will not exist for a period of ~10 years when RH103-4 and RH205 (those which intercept most of the Isaac River length over the mine plan) have subsided. This means there will be less attenuation and peak flows will be greater for the large events should they occur.

Predicted potential geomorphic impacts specific to the mine plan are summarised in Table 11.

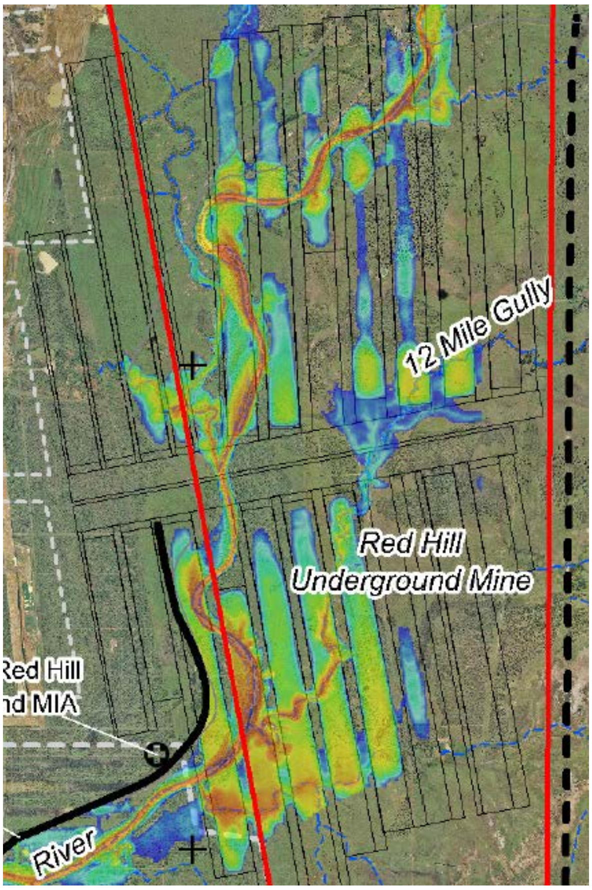
Table 11. Predicted potential geomorphic impacts

Waterway	Location on mine plan	Predicted potential geomorphic impact
Isaac River	All pillar zones and main headings (unsubsided or relatively little subsidence sections)	There is a short to medium term risk window when the supply of bedload sediment is going to be diminished to the extent where bank erosion may be instigated at these relatively un-subsided sites and in the sections of river shortly upstream and downstream of the mine plan. This process is well known and has been observed at BRM and Moranbah North downstream of RHM. Over the longer term it is predicted that bed sediment supply will return to the quantum at these locations where the risk of instigation of bank erosion is back to existing levels. This has also been observed at the downstream mine sites.
Isaac River	RH 103	Increased potential for avulsion while RH103 is subsided and RH104 is not (~1-2 years). The 100 year ARI event does not inundate RH103 at present. The same event when subsided has at least several metres depth of flow down centre of panel. The existing terrace surface in RH103 will become lower than the active floodplain in RH104 until it is subsided. The potential for an avulsion remains above existing after RH104 is subsided due to the increased likelihood of flood flows down RH103 across the inside of meander but not as elevated as described above. The RH103-4 pillar continues to provide some constriction of flood flows in this event. The proposed levee down the centre of RH103 panel (as opposed to on the RH102-3 pillar) most likely elevates hydraulic parameters by confinement of flow area at this location and may increase risk of floodplain scour and avulsion channel development.
	RH104	Should the left bank of the Isaac River, which is presently subject to terrace scarp erosion (Figure 23 provides an example), erode toward the northern extent of subsidence in RH104, avulsion of this section of river is likely. If the erosion does not occur avulsion risk is negligible as the proposed case flood modelling shows the terrace is not overtopped up to a 2000 year ARI event.
	RH103-104 pillars and main headings	This section has an elevated risk of bank instability as a result of upstream and downstream progressing deepening and elevated hydraulic parameters. This risk will be further elevated while RH205 and upstream are capturing bedload sediment input from upstream. This is a known risk at BRM and has been effectively managed by BMA to date with pile field protection of pillar zones.
	RH205 – upstream, shorter wavelength meander	A section of the meander sits outside the subsided area and will remain elevated when panels are subsided (refer Figure 25 and Figure 26). The frequency, extent and volume of flow across the inside of the meander will be increased and this occurs in events substantially less than a 100 year ARI (it may occur in all events). Subsidence here creates a channel of similar scale to the existing channel with a similar bed elevation. Hence this will initially be a very short small scale anabranch (or bifurcated) section of river with the western RH205 pillar forming an island or inset floodplain approximately 120m wide and 5-6m above channel invert. Depending on flow events it is likely the existing channel will be abandoned in favour of the 'new' channel through the inside of the bend and the existing channel will become a form of billabong. A further contributing factor here will be bedrock controls in the channel at the

		second crossing of the western RH205 pillar which will limit potential for deepening to migrate upstream in the channel (thus increasing channel capacity again in response to subsidence).
	RH205 – downstream, longer wavelength meander	This section comes off the meander discussed above and extends through to the Goonyella Creek confluence over the Mains Heading. The eastern apex of the meander is over the RH205-6 pillar. Much of the terrace which is not subject to flows in the existing 100 year ARI event are subject to several metres depth of flow when subsided. However, hydraulic parameters are not likely to be elevated if the river channel remains near current dimensions over the main headings as this will provide some backwatering by both elevation and constriction. Depending on what occurs with Goonyella Creek at the northern end of RH205, this section may have increased flood connectivity with lower Goonyella Creek.
Isaac River and 12 Mile Gully	RH208-210, RH 104-107	Increased frequencies of flood flows from the Isaac River via RH208-210 have the potential to alter channel and floodplain form. Hydraulic parameter values, hence erosion potential over the main headings greatly increased. Overall risk of channel enlargement and anabranch development is low due to frequency of event required.
12 Mile Gully	All pillar zones, main headings and upstream of mine plan	Longitudinal cut and fill mobilising increased sediment loads (bed and suspended load) from increased rates of bed and bank erosion at these locations.
Goonyella Creek	RH205	The proposed case 100 year ARI event is captured in RH205 and would potentially abandon the lower 5km of Goonyella Creek. There are several other locations where the confluence of Goonyella Creek with the Isaac may also alter along RH205 should it not be completely captured at the northern end of the panel.
Tributary of Goonyella Creek	RH201-4	Pooling, local cut and fill likely depending on depth to bedrock below channel invert.



Base case



Proposed

Figure 24. 100 year ARI water surface extents and depths for Base case and Proposed RHM (URS, 2012)

Left bank of channel subject to meander migration and flood flow re-entry erosion

Bedrock controlling channel invert

Figure 25. Bed and bank conditions at RH205, where channel re-enters panel from section not to be subsided

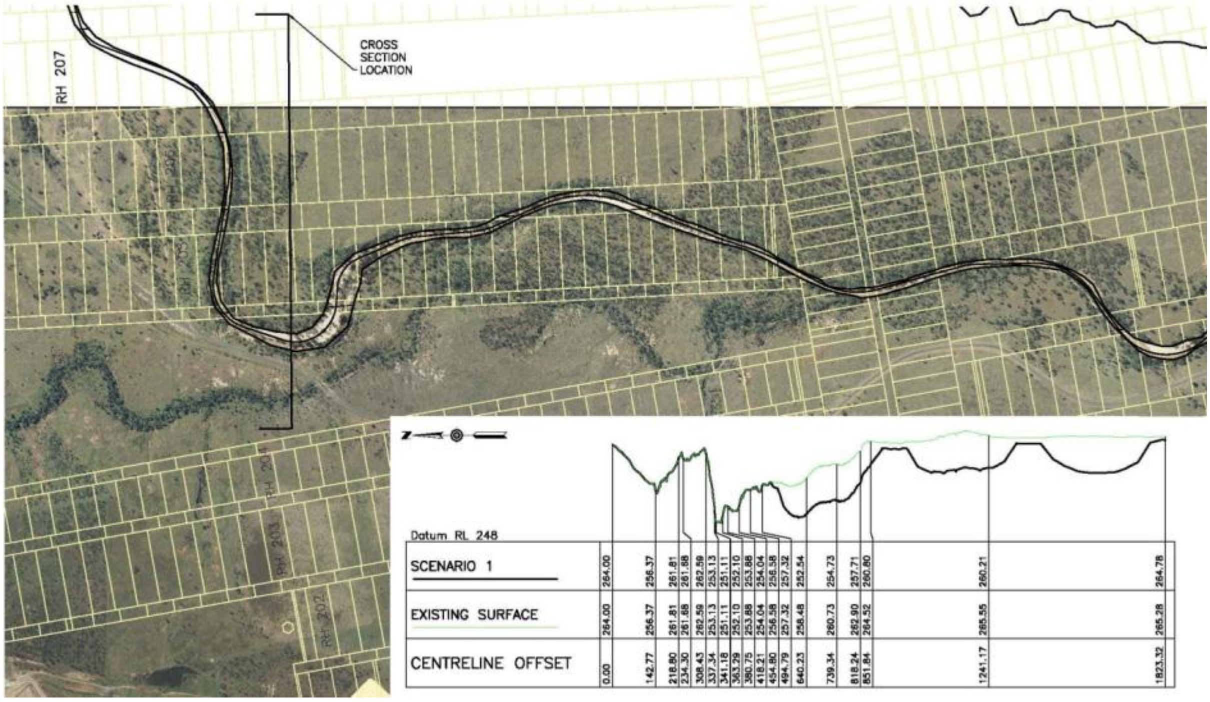


Figure 26. Subsided cross section through upstream meander on RH205

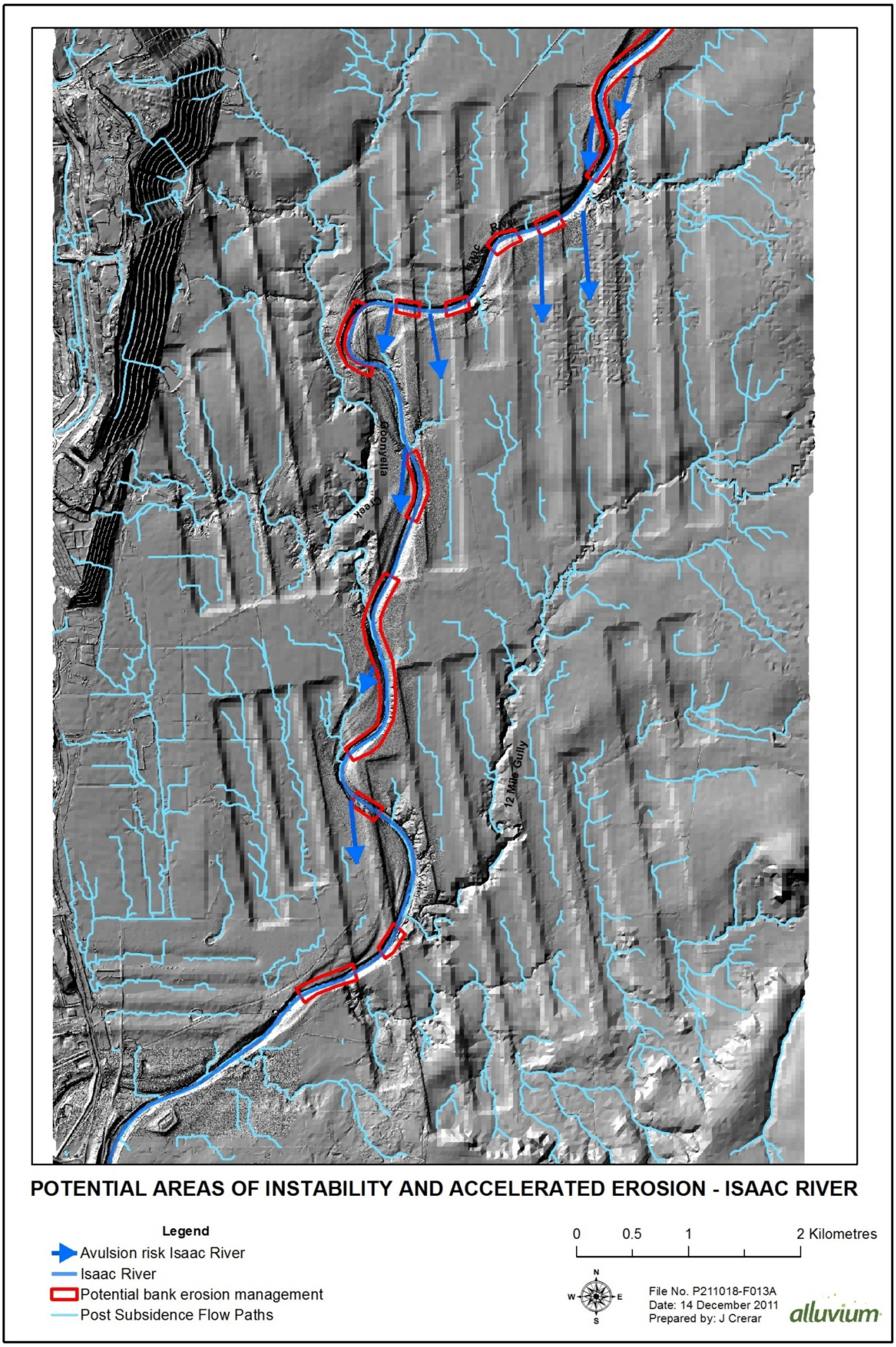


Figure 27. Potential areas of instability and accelerated erosion post subsidence of RHM – Isaac River

Observed Geomorphic Response

As shown in Figure 3 a monitoring program for subsidence impacts at BRM has been in place since 2007. This has allowed observation of geomorphic response to subsidence and the performance of measure implemented to manage subsidence impacts. Figure 28 illustrates the geomorphic response downstream of LW105 at BRM. The longwall was subsided in late 2009. LW104 subsided the river immediately upstream of this in 2008. During the 2009-10 wet season only small magnitude (<2yr ARI) flow peaks and relatively small total discharge was experienced in this reach of the Isaac River. During the 2009-10 wet season LW104, upstream of LW105 absorbed all the bedload being transported by the Isaac River into the BRM reach. This meant no infilling of LW105 and deepening downstream of LW105 due to the clear water (sediment starvation) effect. This is clear in the 2010 photos.

The 2010-11 wet season had several larger (10-20 year ARI) flow magnitude peaks and a much larger total discharge over an extended wet season. Those flows transported sufficient bed load sediment into the BRM reach to infill LW104 and LW105 and the section that had deepened immediately downstream of LW105 as shown in the 2011 photos.

However, despite the substantial discharge and sediment transport over the 2010-11 wet season, the interruption to bedload sediment has been observed as a phase of deepening that is progressing further downstream. The result is that there is no mobile bed sediment in the next section further downstream in the Isaac River diversion. The diversion bed has been stripped to harder substrate (Tertiary or weathered Permian). A subsequent outcome is that the benches are eroding, threatening to increase rates of bank erosion. The ongoing response of these benches is subject to flow event occurrence and will be closely observed in the monitoring program and management intervention implemented should the high flow channel banks be threatened with further erosion.

Upstream view – 2009

Downstream view – 2009

Upstream view – 2010

Downstream view – 2010

Upstream view – 2011

Downstream view – 2011

Figure 28. Observation of bed form changes at LW105-6 pillar zone at BRM downstream of subsidence

4.5 Potential cumulative impacts

BRM is located immediately downstream of the proposed RHM Underground Mine. Based on the current mine plan, BRM will have 18 longwall panels subsiding the Isaac River in total extending from LW103 to LW120. To date, LW103, 4 & 5 have been mined and their subsidence voids infilled following substantial wet season flows (2008-2011). LW106 to LW120 are planned to subside the river at a rate of approximately one panel each year from 2011 until 2027, creating a subsidence void space of 667,259 m^3.

When considering the RHM and BRM Reaches as a continuum, the cumulative void is approximately 2 million cubic metres or an equivalent strip depth of approximately 2.23m over approximately 19.4km of river channel. Due to the large cumulative void volume created from mining in the RHM, downstream reaches may become supply limited, in particular the Isaac River Diversion. The magnitude and extent of which will depend on the sequence of stream flows in relation to the progress of mining. The biggest risk window appears to be from Years 11 - 15. During this time, BRM would have 15 subsidence voids in the Isaac River Diversion; with RHM contributing an additional 11 subsidence voids from the mining of 6 longwall panels (RH103, RH104, RH205, RH206, RH207 & RH208) under the river by Year 15. Should flows capable of infilling the subsidence voids not occur during this time a worst case scenario may occur that may have implications for lateral stability of the Isaac River due to bedload sediment supply loss/interruption, upstream and downstream progressing deepening and subsequent bank erosion. Given existing instabilities in the Isaac River diversion the risk of increased rates of bank erosion would be elevated there. Management response and methods may need to change if a supply limited scenario looks likely to develop.

Table 12. Estimates of timeframe for infilling for RHM and BRM Reaches combined

Year	Subsidence void over 5-year block (m^3)	Cumulative Void Volume (m^3)	Equivalent Cumulative Strip Depth (m)
Year 1	170,393	170,393	0.19
Year 5	170,254	340,647	0.38
Year 10	323,642	664,289	0.75
Year 15	1,229,570	1,893,859	2.14
Year 20	82,433	1,976,292	2.23

Downstream of BRM there are other existing and planned longwall operations beneath the Isaac River as assessed in the IRCIA. Mine plans at these operations are subject to change and at present the overall cumulative impact for currently proposed mine plans is not assessed. Sand and gravel extraction also occurs in the Isaac River, with the nearest known licenced operator (Moranbah Sand & Gravel) located approximately 30km downstream of the RHM site. Cumulative impacts from the Red Hill Mining Lease are not anticipated so far downstream. Teviot Brook is a substantial sediment contributor to the Isaac River and its confluence is within the extraction reach.

5 Impacts on tributaries and runoff flow paths (2nd order impacts)

The likely impact of subsidence on tributaries and minor flow paths across the RHM area has been assessed qualitatively based on the geomorphic characterisation of waterways (Section 2.2) and the 1st order impacts of subsidence (Section 3.2), as presented in Figure 29. Outcomes of flood modeling for large and extreme flood (100 year ARI and greater) have also been utilized.

The predicted geomorphic response of tributaries and flow paths on the floodplain is dependent on their existing characteristics and the extent to which the creation of panel catchments interferes with channel gradient and/or changes to runoff volume or concentration. Broadly, the following impacts are anticipated:

Upstream/outer limit of subsidence

- Existing unchannelised flow paths and discontinuous waterways may incise (headcuts) into the landscape due to an increase in local gradient and concentration of runoff.

- Bed and bank instability may also occur in channelised waterways due to the changes in local bed gradient and upstream progressing deepening (headcuts/incision).

Subsidence Zone

- For unchannelised and discontinuous waterways, flow paths will generally realign down the centre of the panel catchment, creating a low energy, fill and spill environment. Due to the relatively small catchment area upstream of the area of subsidence, this is not likely to create instability issues. However, some incision or bed and bank instability may occur at the confluence of existing waterways (e.g. 12 Mile Gully) should that waterway be subject to deepening

- Similar to the Isaac River, subsidence troughs created by panels and pillars are likely to create temporary ponds in channelised waterways, until such time as they are infilled with sediment (or if limited supply they will persist as pools). A lowering of the mobile sand bed over the pillar zones is anticipated in the short term, which will in turn increase the risk of local bank erosion.

- Post subsidence of longwall panel RH205, there is an increased risk of Goonyella Creek avulsing into the Isaac River.

The areas of potential erosion in tributaries and panel catchments across the RHM area of longwall mining are highlighted in Figure 30. Also identified are two dams requiring decommissioning prior to subsidence.

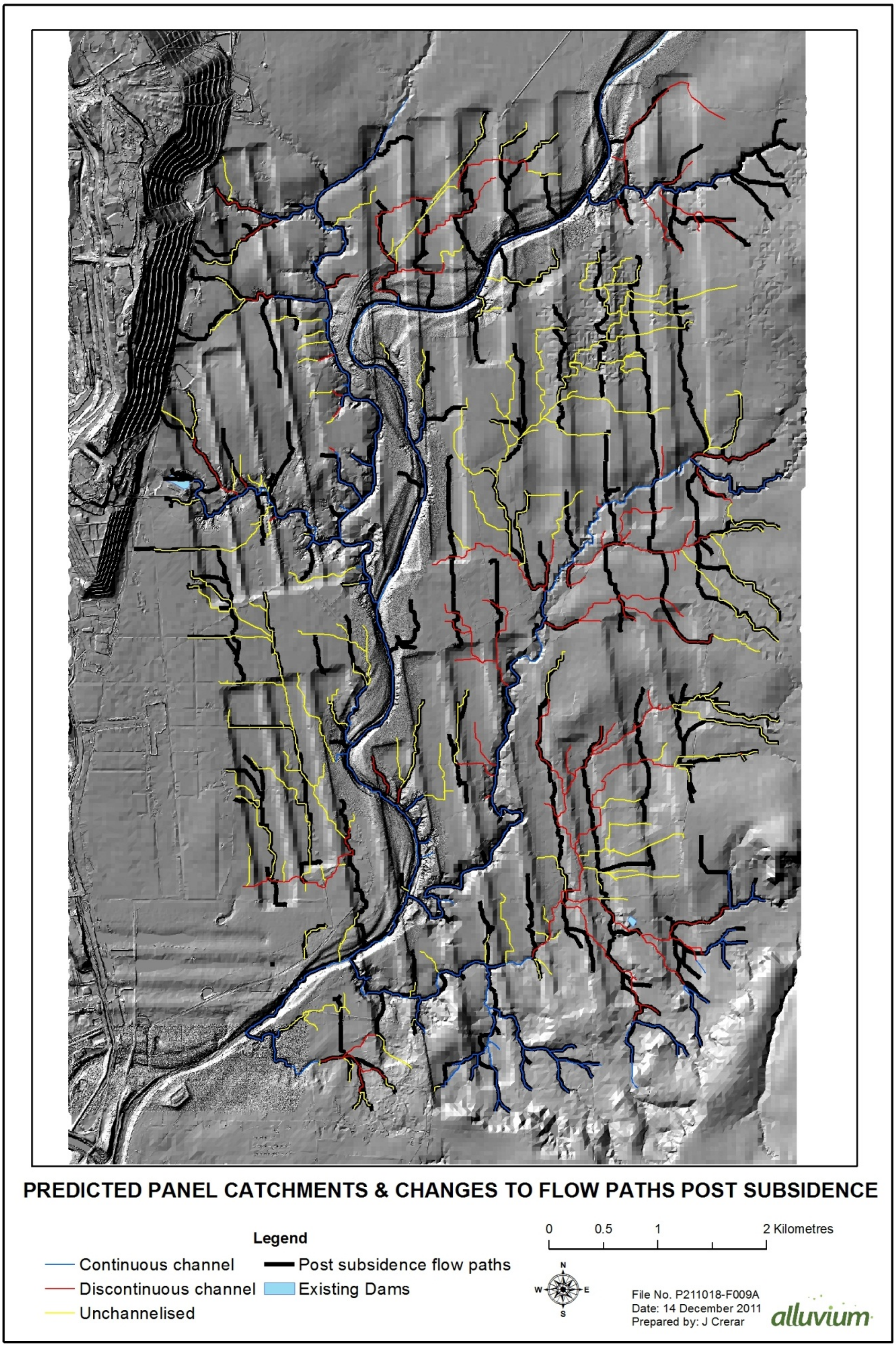


Figure 29. RHM post subsidence digital terrain model, existing and changes to flow paths

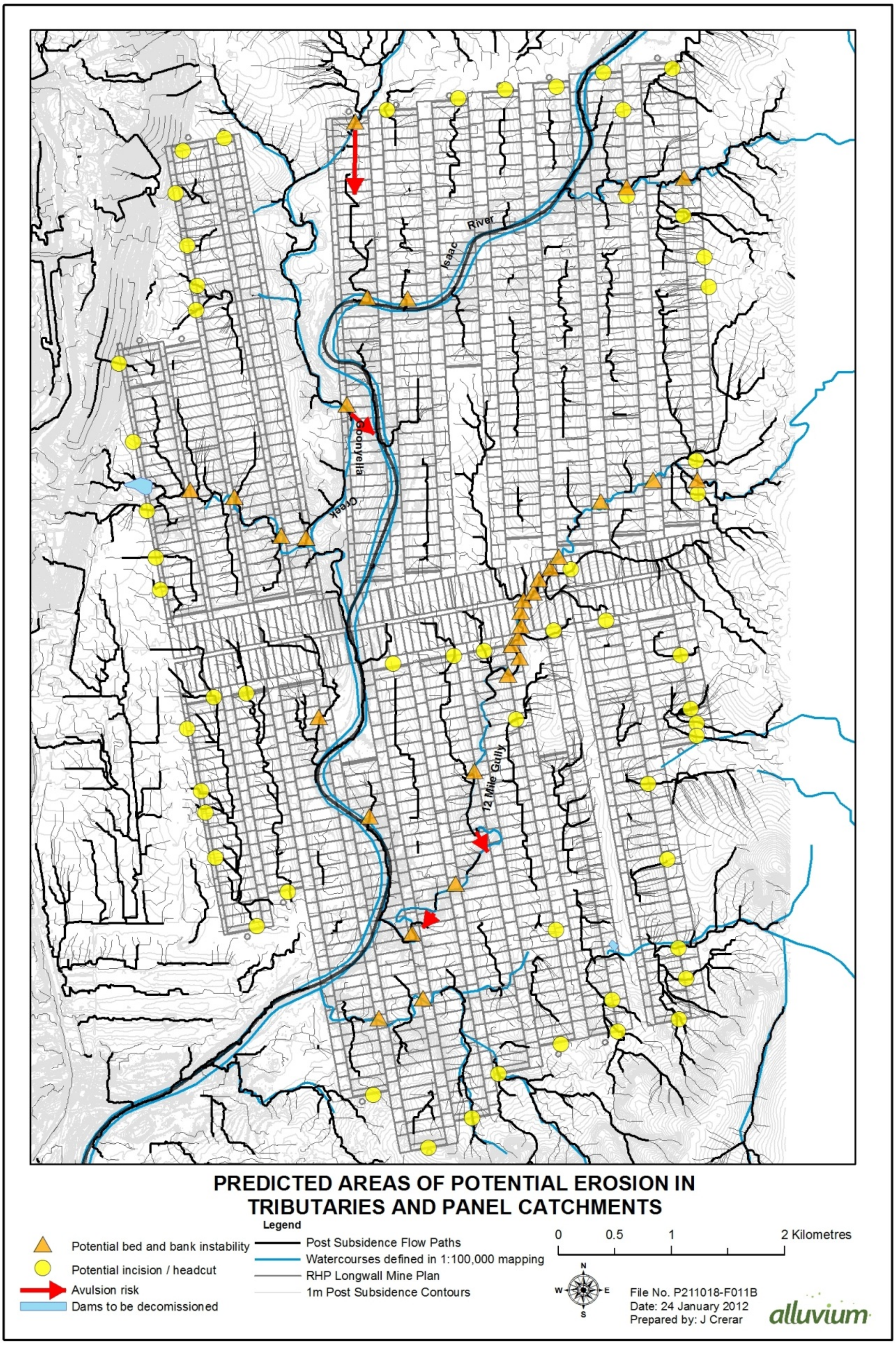


Figure 30. Areas identified for potential erosion in tributaries and panel catchments across RHM

6 Summary of impacts and mitigation options

Positive and negative impacts of longwall mining on the Isaac River were identified as part of the IRCIA and in consultation with DERM. A brief summary is provided in Table 13.

Table 13. Summary of positive and negative impacts of longwall mining on Isaac River as identified in the IRCIA

Geomorphic Response	Positive impacts	Negative Impacts
Establishment of pools in the river bed	• Replace habitat lost from the system as a result of contemporary sediment input into the river. Note that location of pools may not be on bends and may not match that of the intact system.	• None determined. • The question of whether or not having pools actually impacts on water quality and quantity was not addressed in the IRCIA.
Upstream migrating streambed degradation *(Also referred to as upstream deepening)*	• Increase in morphologic diversity of bed form if presently smothered with excess sand inputs. • Works to manage the upstream migrating deepening impacts on bank stability over pillar zones will also increase habitat values within the waterway and could be included as a positive fifth order impact.	• This has potential to expose and undermine infrastructure such as pipelines, road crossings and bridge piers. • Potential instigator of bank erosion by removal of bed sediment that the stream bank and/or thick mud drape over the bank currently relies on for support at the toe, particularly during extended duration flows when the mud drape is saturated and becomes prone to slumping.
Sediment starvation and downstream bed degradation *(Also referred to as downstream deepening)*	• Increase in morphologic diversity of bed form if presently smothered with excess sand inputs.	• Similar negative impacts to that for upstream progressing deepening due to change from transport limited to supply limited for a period of time.
Incision in the tributaries	• Increase in morphologic diversity of bed form if presently smothered with excess sand inputs.	• Increased sediment export from tributaries (suspended and bed load). Loss of stream health values by bed incision and subsequent bank erosion.
Potential avulsion paths and interruption to overland flow paths on floodplain	• Potential for creation of ephemeral wetland habitat that has largely been lost from the landscape due to gully erosion.	• Increased rates of change and sediment inputs if avulsion paths develop. • Change from existing flora to ephemeral wetland species in subsidence troughs. • Incision through pillar zones creating short local gullies that will add to already high suspended sediment loads.

These impacts have also been identified in the assessment of 1st and 2nd order impacts as described in Sections 3, 4 & 5 for the proposed longwall mining component of RHM. Impacts are mostly expected to be local. However, there is the potential for incision in tributaries and deepening in the Isaac River to progress off mine lease. Of particular concern, is the potential cumulative impact with BRM leading to further destabilisation of the Isaac River diversion.

A summary of the main features or environmental values of the waterways across RHM, the predicted geomorphic response to subsidence, potential impacts and recommendations for mitigation are provided in Table 14. Examples of recommended mitigation measures for bank protection and incision control are provided in Attachment A (Drawing Nos. P211018-004 and P211018-005) and illustrated in Figure 31. Indicative locations of in stream mitigation for the Isaac River are shown in Figure 32.

Table 14. Summary of geomorphic responses, negative impacts, mitigation options and risks for RHM

Feature / Environmental Value	Geomorphic Response	Potential impact	Mitigation Options
Isaac River	Upstream deepening	• Bed and bank instability	Implement toe of bank protection measures at upstream limit of subsidence. Occasional bedrock control will naturally limit the progression of deepening upstream.
	Downstream deepening through BRM due to medium term loss/reduction of bed sediment supply due to RHM subsidence voids	• Bed and bank instability through the natural reach of Isaac River • Further destabilisation of the Isaac River diversion	Bank protection measures already implemented over pillar zones through the natural reach of Isaac River at BRM will reduce the impact of downstream deepening. These measures will continue as part of BRM and RHM impact management. Develop and implement a management strategy for the diversion that takes into account risks posed by RHM and BRM. The strategy will need to account for the sediment supply conditions that RHM is predicted to generate.
	Deepening/erosion over the pillar zones	• Bed and bank instability	Implement toe of bank protection measures over pillar zones.
	Accelerated erosion processes	• Avulsion / meander cut-off	High density vegetation cover should be maintained where potential for avulsion or cutoff identified. Monitor these areas following flood events. Actions need to be consistent with the panel catchment management component of the subsidence management plan for ponding and overland flow. Earthworks such as broad fill areas within the panel which mitigate avulsion risk pathways to be considered as part of subsidence management plan. A meander cut-off in Isaac River RH205 is highly likely. Given the location, this should be allowed to occur and managed to minimise any potential negative impacts (none foreseen).
Tributaries	Deepening/erosion at upstream limit of subsidence and over pillar zones	• Bed and bank instability	No mitigation recommended prior to subsidence. Monitoring of risk areas proposed. Grade control (eg. rock chutes) and bank protection techniques may need to be implemented immediately after full subsidence has occurred and prior to wet season where practical.
	Accelerated erosion processes	• Avulsion of Goonyella Creek into the Isaac River in RH205	High density vegetation cover should be maintained. Options to maintain the lower end of Goonyella Creek in current channel include filling part of north end of panel RH205 to prevent capture of the creek by this longwall or diverting around the panel with associated levee.
Un-channelised waterways & flow	Incision and erosion headcut instigation	• Substantial sediment generation • Loss of inherent environmental values	Treated with appropriate grade control and flow management immediately after any headcuts are instigated following subsidence. Standard gully

Feature / Environmental Value	Geomorphic Response	Potential impact	Mitigation Options
paths			management grade control rock chute techniques are appropriate.
Ephemeral wetland areas	Panel catchments (low energy, fill and spill environment) created in areas of overland flow or unchannelised flow paths	• Vegetation changes (more wetland species) • Increased water storage on the floodplain.	None proposed for geomorphic impacts, may be required due to overall impacts on low flow regime of Isaac or due to impacts on flora/fauna by extended ponding. Constructed drainage may cause more environmental harm than benefit(5th order impact) and should be considered on a case by case basis for best environmental and operational safety outcome.
	Creation of pools in channel from subsidence voids	• Aquatic habitat • Temporary due to excess sediment inputs into Isaac River system	Maintaining the positive impact in the long term would require reduction in sediment inputs on a catchment scale, beyond the RHM lease and is beyond the control of the proponent.

Downstream view at LW104-5 pillar zone November 2007

Downstream view at LW104-5 pillar zone mid 2008, note the pile fields maintaining and enhancing a bench against toe of bank

Bench maintained against toe of bank while river channel bed has deepened in response to subsidence

Deepening and bench erosion at LW106-7 monitoring site approximately 300m downstream of subsidence in LW105 in 2010 prior to infilling

Downstream view at LW103-4 pillar at subsidence pool in LW104 in 2009

Downstream view at LW103-4 pillar at subsidence pool in LW104 in 2010 after infilling

Figure 31. Examples of toe of bank erosion risk management at BRM

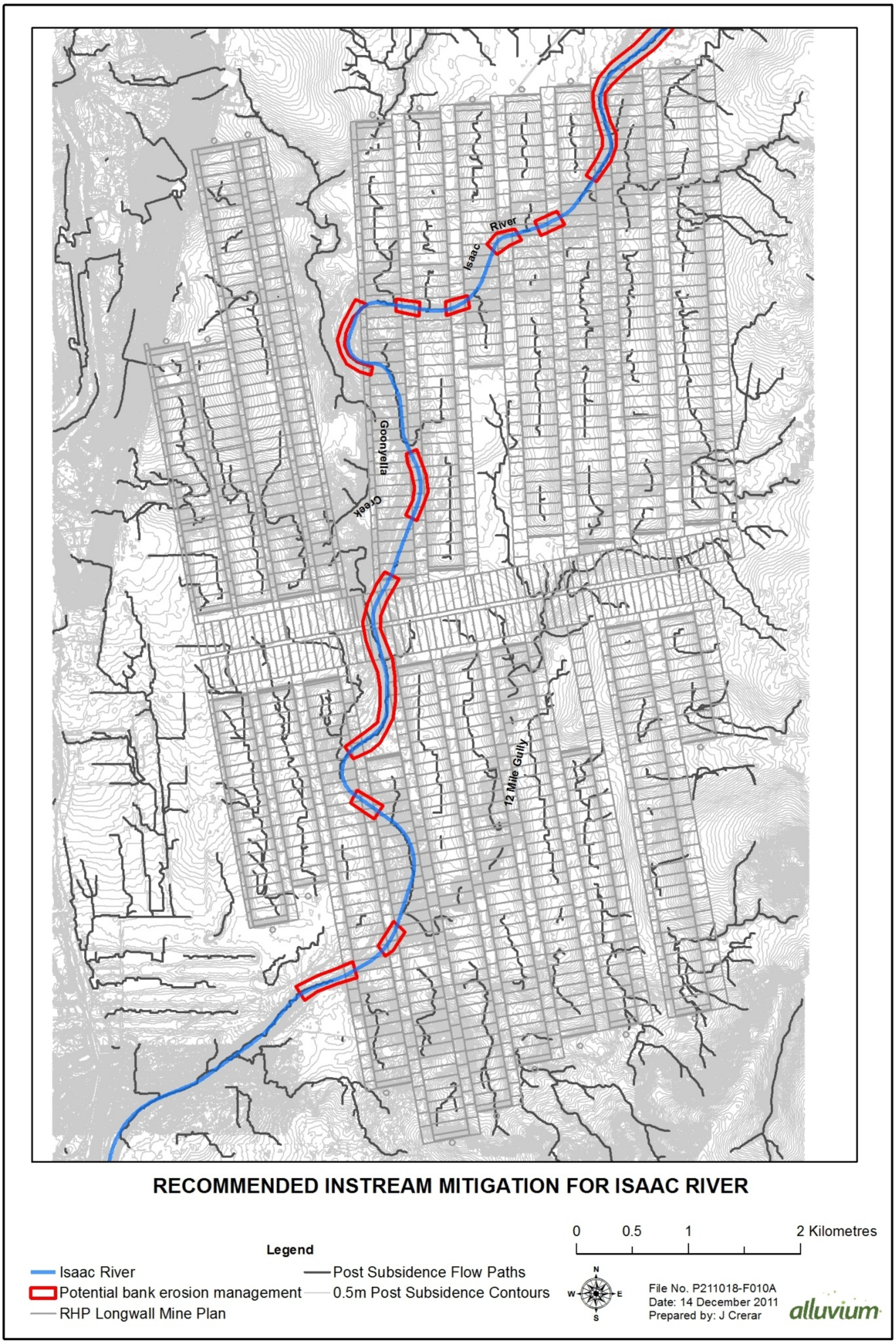


Figure 32. Recommended in-stream mitigation to be constructed prior to subsidence

7 Monitoring and management approach

7.1 Mine Plan Review

As mine planning for the proposed RHM is in early stages, it will be necessary to review the geomorphic assessment once the mine plan has been finalised. While changes in the mine plan are not likely to affect the overall long term outcomes in terms of geomorphic response, the mine plan will influence selection of monitoring locations and the locations and type of proactive management that might be required pre-subsidence.

7.2 Adaptive management

Mitigation and management strategies for subsidence that have already been implemented for BRM downstream of RHM revolve around the principles of adaptive management. The outcomes of the successes and learning's from those management strategies can be applied to the management approach for RHM. The principles of adaptive management are:

1. Assess the risk
2. Design operational treatments (mitigation measures)
3. Implement treatments
4. Monitor key response indicators
5. Re-evaluate effectiveness of implemented mitigation measures
6. Adjust policies and/or practices

The adaptive management approach accommodates the complexity involved with river processes, including the high variability of flow events and river response to management intervention. Mine plans are also known to change with time as will the nature and amount of subsidence, as it's highly dependent on strata and depth of extraction. The plan will be a combination of short and long term measures aimed at creating a self-sustaining, healthy functioning waterway through RHM suitable for relinquishment of management responsibility at or before life of mine.

Identified issues and management actions captured by the monitoring program will be evaluated on an annual basis following annual monitoring data collection and management recommendations.

In the longer term it is likely that management of subsidence impacts and existing condition issues for the waterway will involve creating a self-sustaining waterway that has the resilience to cope with 1st and 2nd order impacts, promotes potential to maintain the positive impacts of subsidence on river health and removes the reliance on drops structures for stability.

The components of a subsidence management strategy are typically:

- Ongoing subsidence monitoring, evaluation, review and improvement program
- Managing bed and bank stability
- Vegetation management
- Panel catchment management, including rehabilitation of subsidence cracking
- Infrastructure protection or relocation where necessary.

Each of these is discussed further under their respective headings.

7.3 Monitoring, evaluation, review and improvement program

A subsidence monitoring program has been implemented at BRM and Moranbah North mine. These monitoring programs have been in operation in excess of 4 years and have been submitted to DEHP/DNRM on an annual basis. The same monitoring program features are proposed for the Isaac River, its tributaries and minor waterways across the RHM impacted by longwall mining. The monitoring program involves quantitative and qualitative components.

The quantitative component of the program has been adapted from the river condition assessment method outlined in the 'Monitoring and Evaluation Program for Bowen Basin River Diversions (ID&A 2001), which was undertaken for the Australian Coal Association Research Program (ACARP). Despite subsidence not being a classed as a diversion, the methodology is readily applicable and has the advantage of being consistent with monitoring occurring for the Isaac River Diversion and other diverted waterways at mine sites in the region. The current monitoring program is based on "Isaac River Operations Monitoring 2010 (Alluvium 2010b). The outcome of this monitoring informs recommendations to manage any identified issues to minimised environmental impacts and potential threats to infrastructure and tracks condition (performance) over time. The monitoring program is consistent with the requirements of the Draft Central West Water Management and Use Regional Guideline 'Watercourse Subsidence' – Central Queensland Mining Industry V7 (DERM, 2011). Adopting a consistent monitoring methodology at the different mines along reaches of the Isaac River, means the results are comparable and able to provide an overall perspective on the river's response to mining related subsidence.

Baseline monitoring prior to subsidence at RHM will be necessary to:

- establish a baseline data set of waterway condition that can be used for comparison in the future; and
- compare the performance of the impacted reach with other reaches upstream and downstream pre and post-subsidence.

The baseline monitoring should consist of:

- Index of Diversion Condition (IDC) along waterways (including establishment of reaches and photo monitoring points)
- aerial photography analysis
- cross-sections and long-section survey comparison
- riparian vegetation assessment
- flow event information

The qualitative component of the monitoring program is the use of expertise in geomorphology, river health and river management to provide bigger picture process and condition interpretation and management recommendations.

Monitoring transects are generally established on the pillar zones over the proposed mine plans due this being the location of impacts to bed and bank stability.

Technical aspects of the monitoring program pertaining to potential impacts of subsidence in terms of groundwater and terrestrial land surfaces are addressed in respective EIS sections.

7.4 **Bed and bank stability**

Proactive management of the potential 2nd order impacts in the Isaac River is proposed. As discussed, upstream and downstream progressing deepening has potential to impact on bank stability, most likely at pillar zones and particularly if there is existing instability.

Measures to prevent this impact and provide protection to the toe of bank through BRM and Moranbah North mine have primarily involved the use of timber pile fields. Timber pile fields aim to reduce flow velocity against the toe of the bank, protecting the bank but also resulting in sediment deposition and vegetation regeneration. Their intent is to perform the required function of bank stabilisation but also provide conditions whereby vegetation can be established and perform the same role as the structural works once their design life is exceeded.

These works are proposed for implementation in the Isaac River in stages prior to subsidence at RHM.

7.5 **Vegetation management**

Structural works to manage any instabilities instigated by subsidence is only a component of the management strategy, ultimately vegetation is the preferred management tool. Grazing across and around the subsided area should be managed to maximise vegetation coverage, particularly in the areas of higher erosion risk and around any structural works.

7.6 Panel catchment management

There is the potential for erosion head cut instigation, channelisation and deepening of minor tributaries and overland flow paths. Vegetation management for maximum coverage to reduce the risk of erosion is recommended. If structural interventions are necessary, the monitoring program will provide recommendations on the timing of implementation of works.

7.7 Infrastructure relocation/protection

Direct 1st order impacts of subsidence on infrastructure are not discussed in this report. 2nd order impacts on infrastructure in waterways such as bed deepening are addressed in the mitigation options for that order of impact.

Homesteads, power lines, a transformer and dams are in the current mine footprint. As the mine plan progresses a risk assessment and monitoring program will inform the management required for these structures prior to subsiding. The Isaac River diversion and its drop structures are located downstream of the RHM and may be impacted by subsidence and geomorphic response at RHM.

A bridge is proposed as part of the RHM development across the Isaac River located on the main headings. It is proposed that the bridge has a deck level close to existing floodplain surface immediately adjacent the channel. So long as any footings are designed and constructed at appropriate levels in substrate of low erosion risk to mitigate against the risk of bed deepening and abutments have appropriate erosion protection, the bridges should not be impacted by geomorphic processes. An exception to this would be if an avulsion occurred. Avulsion risk is low at the proposed bridge locations.

8 References

ID&A, 2001, *Monitoring and Evaluation Program for Bowen Basin Diversions*, undertaken for the Australian Coal Association Research Program (ACARP), Program No. C9068.

IMC, (2010). *Surface Subsidence Prediction for the Goonyella Coal Extension (RHM) Mine Plan.* Report by IMC Mining Group Pty Ltd for BMA.

Department of Environment and Resource Management, (2011). *Central West Water Management and Use Regional Guideline: Watercourse subsidence – Central Queensland Mining Industry*, draft version 7.0.

Dougall C., Packett R., Carroll C., Sherman B.S., Read A., Chen Y. and Brodie J. (2006) Sediment and nutrient modelling in the Fitzroy NRM region. Volume 5. In: *The Use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting* Ed A.L. Cogle, C. Carroll and B.S. Sherman. Department of Natural Resources, Mines and Water. QNRM06138.

Lucas, R., Dickinson, A., Bellgard, S., Carter, J., Crerar, J. (2006) *Management Strategy for Mining Related Impacts of Subsidence on the Isaac River at Broadmeadow Mine*. Report by Earth Tech Engineering for BMA, Broadmeadow Mine.

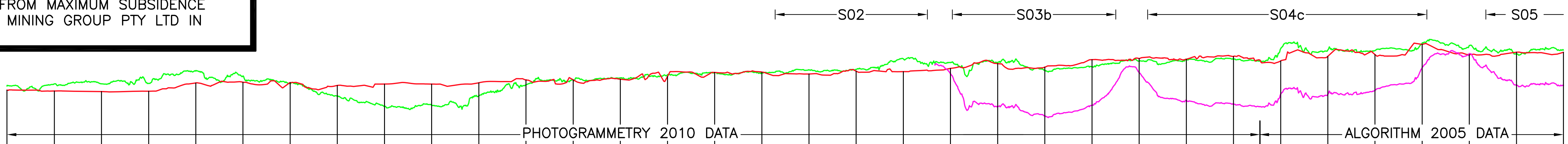
Lucas, R., Crerar, J., Hardie, R., Lovejoy, S., 2008. *Technical Report: Isaac River Cumulative Impact Assessment of Mine Developments*. Report by Alluvium Consulting for BMA and Anglo Coal.

URS, March 2012, *RHM EIS Hydraulics Technical Report*, Report by URS for BMA

Attachment A
Drawings

NOTES

1. SCALE A IS THE HORIZONTAL SCALE.
2. SCALE B IS THE VERTICAL SCALE.
3. LIDAR 2008 WAS SURVEYED IN NOVEMBER 2008.
4. PHOTOGRAMMETRY 2010 AND 2005 AMALGRAM IS PHOTOGRAMMETRY DATA RECEIVED IN 2010 AND 2005.
5. SUBSIDED SURFACE CREATED FROM MAXIMUM SUBSIDENCE DEPTHS PREDICTED FROM IMC MINING GROUP PTY LTD IN DECEMBER 2010.



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LIDAR 2008	241.56	241.83	242.15	242.39	242.31	242.66	242.72	243.83	243.44	243.43	242.63	243.00
CHAINAGE	63400.00	63500.00	63600.00	63700.00	63800.00	63900.00	64000.00	64100.00	64200.00	64300.00	64400.00	64500.00

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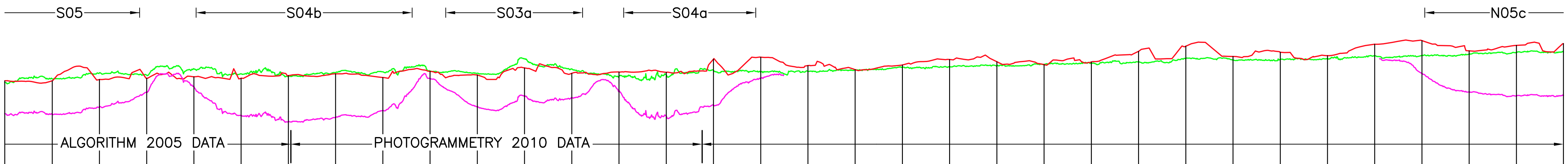

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LIDAR 2008	244.36	244.73	245.36	245.12	245.80	245.26	245.05	245.39	245.48	245.56	245.32	246.84
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SUBSIDED SURFACE	246.52	246.89	246.73	246.79	246.83	247.16	245.31	243.35	242.95	242.97
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REV	DESCRIPTION	DATE	INTL
A	ORIGINAL ISSUE	22/07/11	TB

REVISIONS

	NAME	DATE
DESIGNED:	T.BEADLE	22/07/11
DRAWN:	T.BEADLE	22/07/11
CHECKED:	J.CRERAR	22/07/11
APPROVED:	R.LUCAS	22/07/11

SCALE
A 0 100 200 400 m
B 0 5 10 20 m
C m

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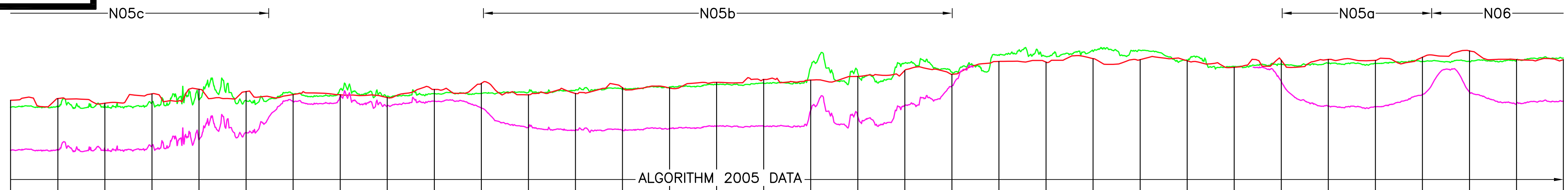
RED HILL PROJECT EIS
GEOMORPHIC ASSESSMENT
ISAAC RIVER
LONGITUDINAL SECTION SHEET 1

Drawing No. P211018-001 Revision No. A
Sheet No. 1 File Name: P211018 -001-003.dwg

A3

NOTES

SEE DRAWING P211018–001 FOR GENERAL NOTES



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69300.00	248.63	248.86	249.43
69400.00	247.67	248.56	248.68
69500.00	248.17	249.42	248.97
69600.00	247.45	250.06	249.00
69700.00	245.39	248.86	249.11
69800.00	245.12	249.00	249.36
69900.00	245.07	249.60	249.45
70000.00	245.27	249.59	249.68
70100.00	245.52	250.18	249.95
70200.00	245.51	250.49	250.07
70300.00	247.19	250.42	251.79
70400.00	246.56	250.80	251.16
70500.00	247.71	251.45	252.23
70600.00	249.80	251.03	251.26
70700.00	253.07	252.40	253.07
70800.00	252.93	252.34	252.93
70900.00	253.48	252.70	253.48
71000.00	253.58	252.59	253.58
71100.00	252.53	252.47	252.53
71200.00	251.86	251.78	251.86
71300.00	250.29	252.52	252.13
71400.00	247.63	252.62	252.19
71500.00	247.60	252.51	252.20
71600.00	248.89	252.85	252.41
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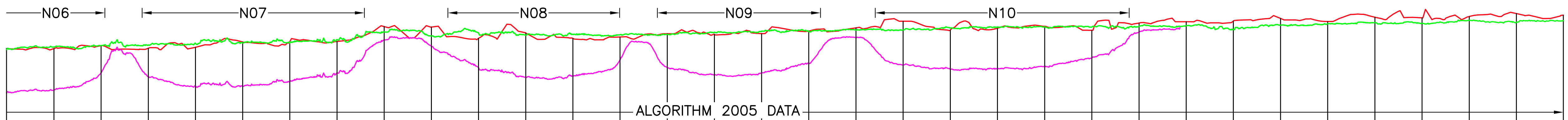

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72000.00	250.03	252.91	252.91
72100.00	249.62	252.63	252.96
72200.00	248.62	252.74	253.14
72300.00	248.59	253.29	253.19
72400.00	249.10	253.35	253.24
72500.00	250.00	253.35	253.54
72600.00	253.51	254.93	254.37
72700.00	252.85	254.88	253.93
72800.00	250.59	253.69	254.25
72900.00	249.52	254.26	254.02
73000.00	249.69	253.68	254.11
73100.00	251.41	253.83	254.06
73200.00	250.60	254.17	254.10
73300.00	249.86	254.10	254.34
73400.00	250.01	254.19	254.43
73500.00	251.03	254.45	254.43
73600.00	253.75	254.80	254.55
73700.00	250.87	255.50	254.57
73800.00	250.42	254.57	254.78
73900.00	250.48	254.76	254.88
74000.00	250.73	254.96	254.91
74100.00	251.60	254.54	254.89
74200.00	254.35	255.30	254.96
74300.00	255.02	255.44	255.02
74400.00	254.63	255.52	254.63
74500.00	255.07	255.80	255.07
74600.00	255.21	255.47	255.21
74700.00	255.34	255.92	255.34
74800.00	255.27	255.86	255.27
74900.00	255.59	256.00	255.59
75000.00	255.40	256.31	255.40
75099.49	255.56	256.14	255.56

REV	DESCRIPTION	DATE	INTL
A	ORIGINAL ISSUE	22/07/11	TB

REVISIONS

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DESIGNED:	T.BEADLE	22/07/11
DRAWN:	T.BEADLE	22/07/11
CHECKED:	J.CRERAR	22/07/11
APPROVED:	R.LUCAS	22/07/11

SCALE

A 0 100 200 400 m
B 0 5 10 20 m
C

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GEOMORPHIC ASSESSMENT

ISAAC RIVER

LONGITUDINAL SECTION SHEET 2

Drawing No. P211018-003 Revision No. A

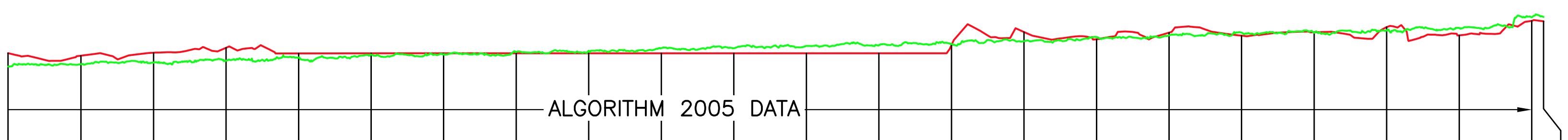
Sheet No. 3 File Name: P211018 -001-003.dwg

A3

NOTES

SEE DRAWING P211018–001 FOR GENERAL NOTES

Datum RL 250



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75500.00		256.31	256.22
75600.00		256.31	256.23
75700.00		256.31	256.40
75800.00		256.31	256.50
75900.00		256.31	256.67
76000.00		256.31	256.66
76100.00		256.31	256.81
76200.00		256.31	256.87
76300.00		256.87	256.94
76400.00		257.77	257.15
76500.00		257.27	257.42
76600.00		257.73	257.54
76700.00		257.52	257.73
76800.00		257.76	257.72
76900.00		258.11	257.89
77000.00		257.54	258.05
77100.00		258.54	258.79
77116.18		258.51	258.81

REV	DESCRIPTION	DATE	INTL
A	ORIGINAL ISSUE	22/07/11	TB

REVISIONS

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SCALE
A 0 100 200 400 m
B 0 5 10 20 m
C

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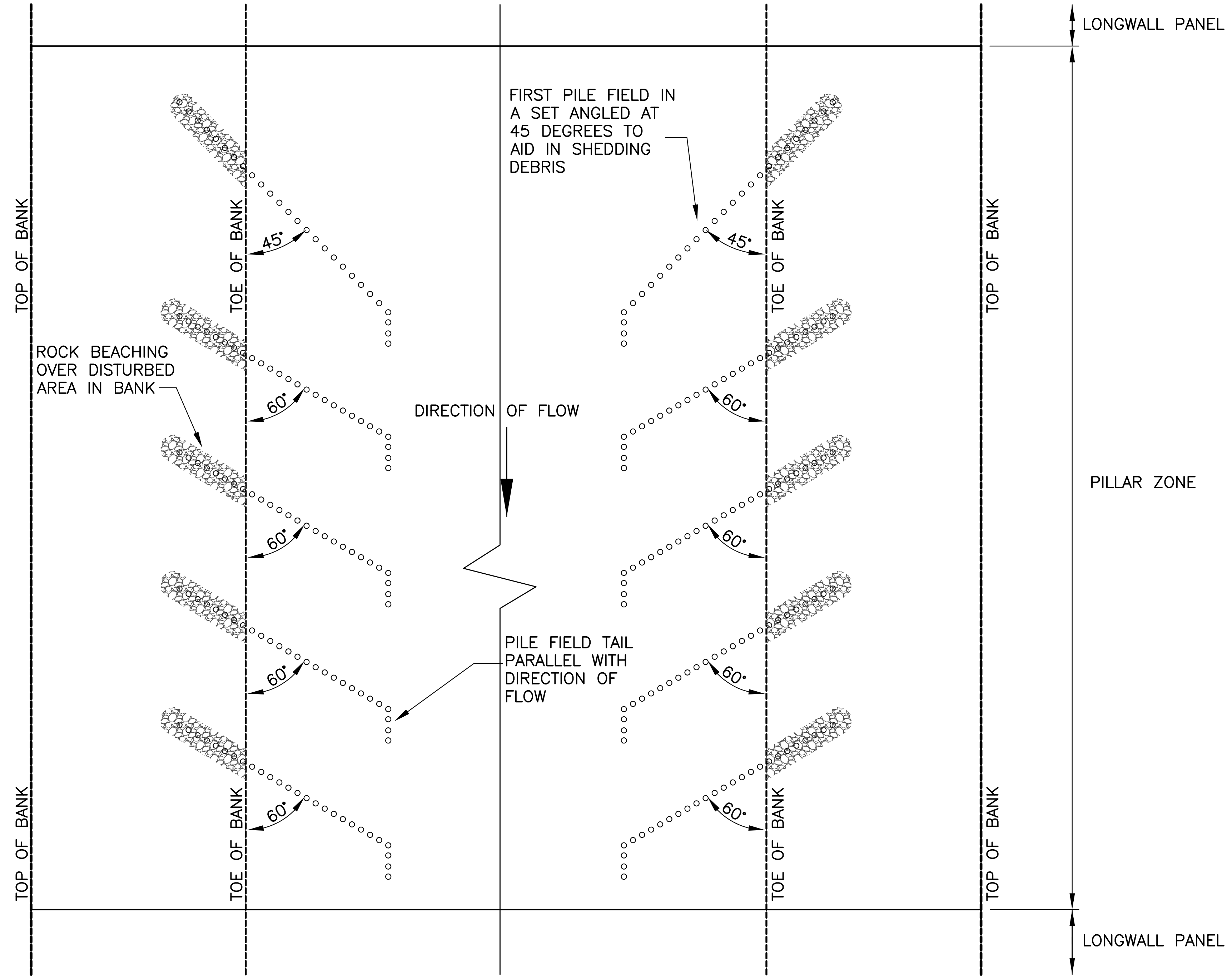
GEOMORPHIC ASSESSMENT
ISAAC RIVER
LONGITUDINAL SECTION SHEET 3

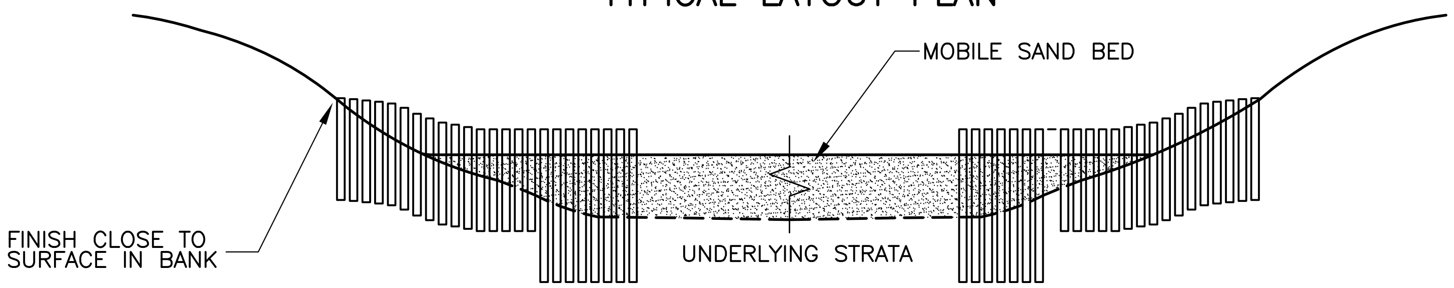
Drawing No. P211018-003 Revision No. A
Sheet No. 3 File Name: P211018 -001-003.dwg

A3

EXAMPLE – ISAAC RIVER PILE FIELDS AT BROADMEADOW MINE



TYPICAL LAYOUT PLAN



TYPICAL CROSS SECTION

REV	DESCRIPTION	DATE	INTL
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NOTES

LAYOUT PLAN AND CROSS SECTION ARE TYPICAL AND MAY VARY SUBJECT TO DETAIL DESIGN.

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CHECKED:	J.CRERAR	22/07/11
APPROVED:	R.LUCAS	22/07/11

SCALE
A B C NOT TO SCALE mm

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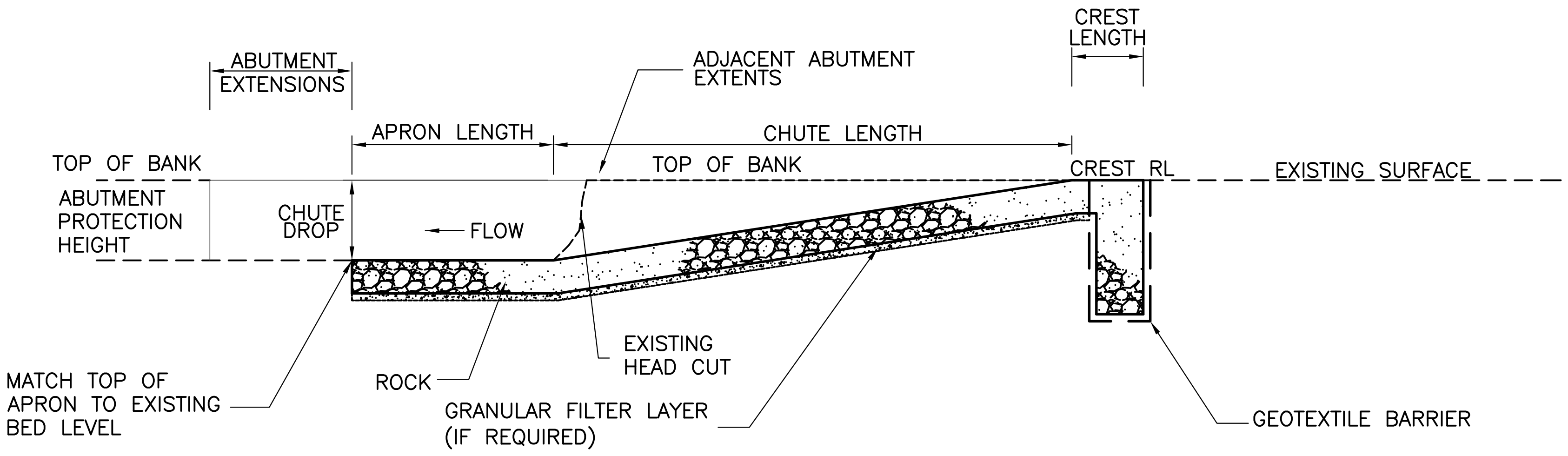
PILLAR ZONE BANK PROTECTION TYPICAL LAYOUT AND CROSS SECTION

Drawing No. P211018-004
Revision No. A
Sheet No. 4
File Name: P211018 -004-006.dwg

A3



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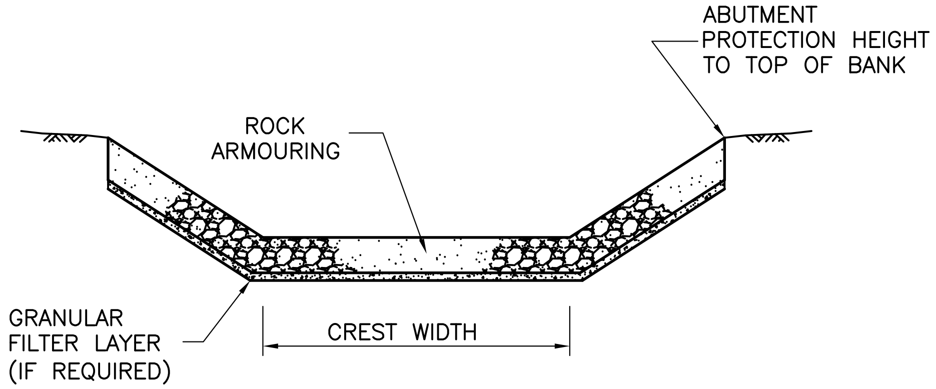

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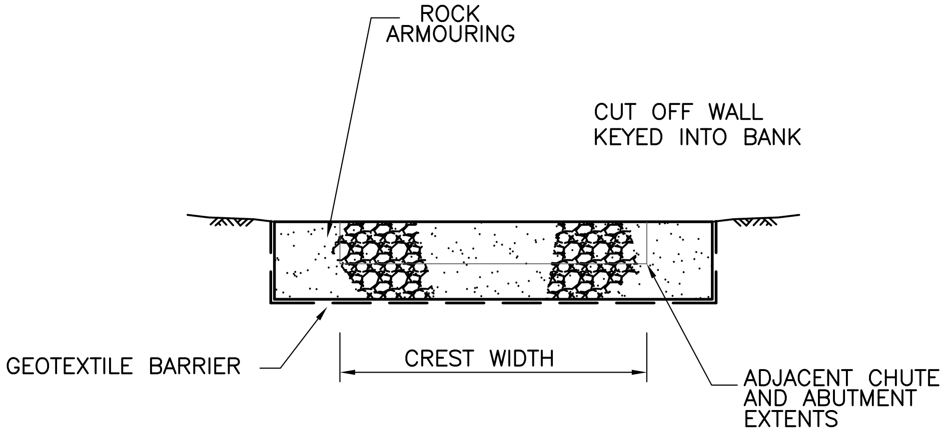
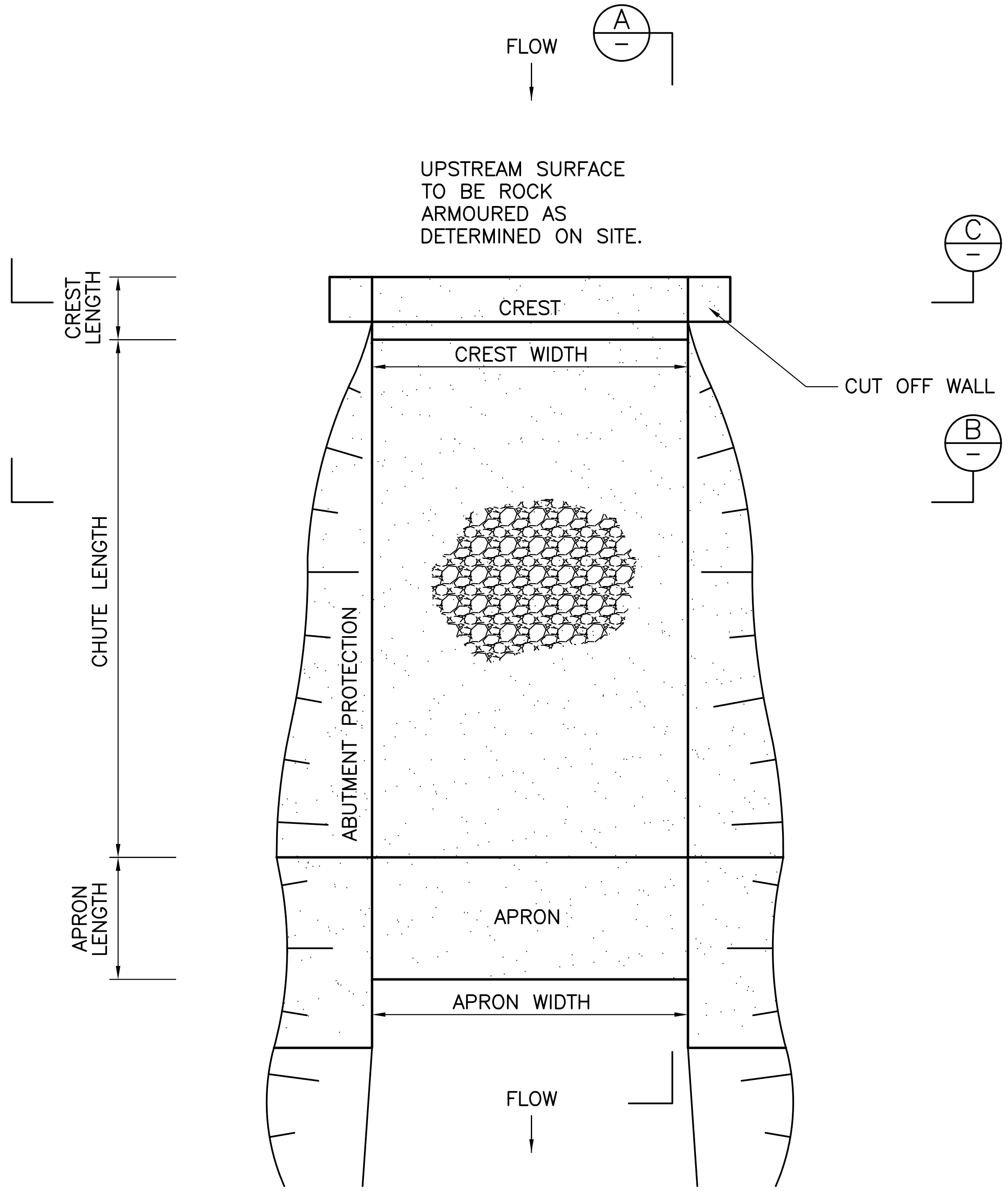


TYPICAL SECTION C
CUT OFF WALL



TYPICAL PLAN OF ROCK CHUTE

REV	DESCRIPTION	DATE	INTL
A	ORIGINAL ISSUE	22/07/11	TB

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NOTES
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	NAME	DATE
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DRAWN:	T.BEADLE	22/07/11
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APPROVED:	R.LUCAS	22/07/11

SCALE
A
B
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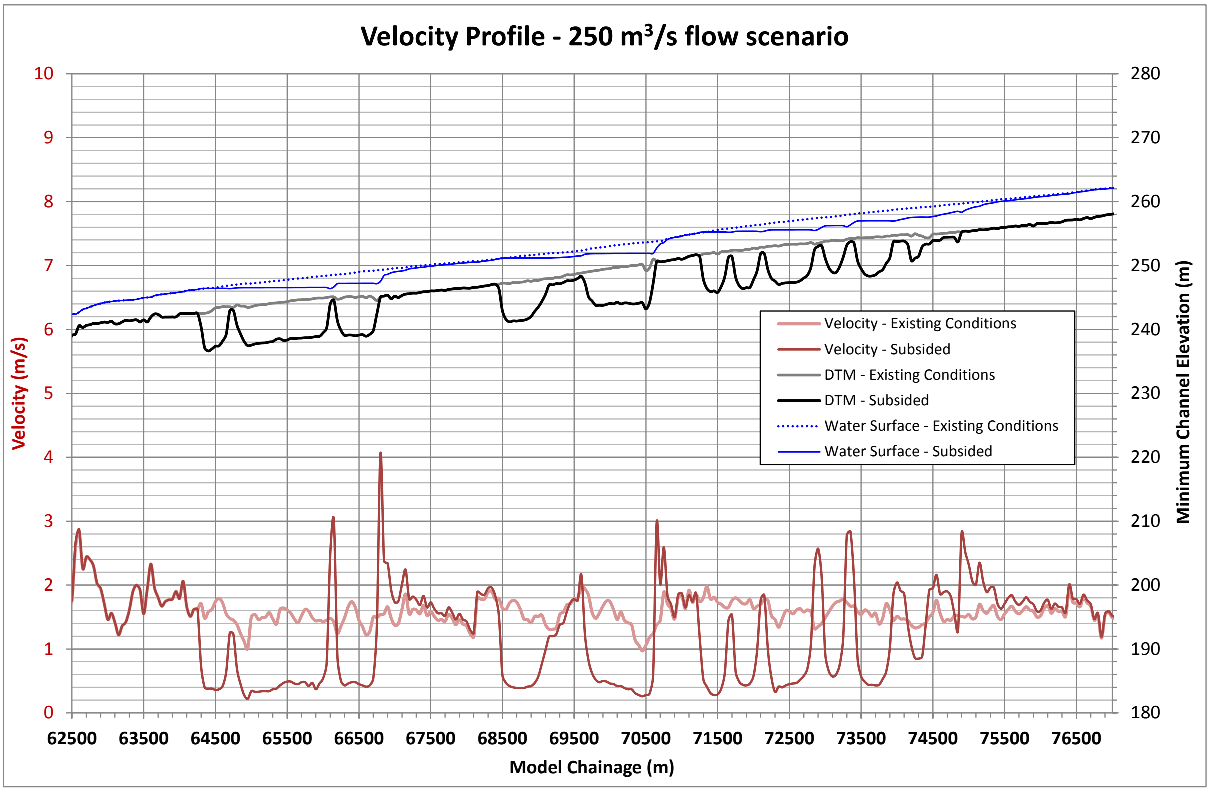
FLOOD PLAIN INCISION CONTROL
TYPICAL LAYOUT AND CROSS SECTION

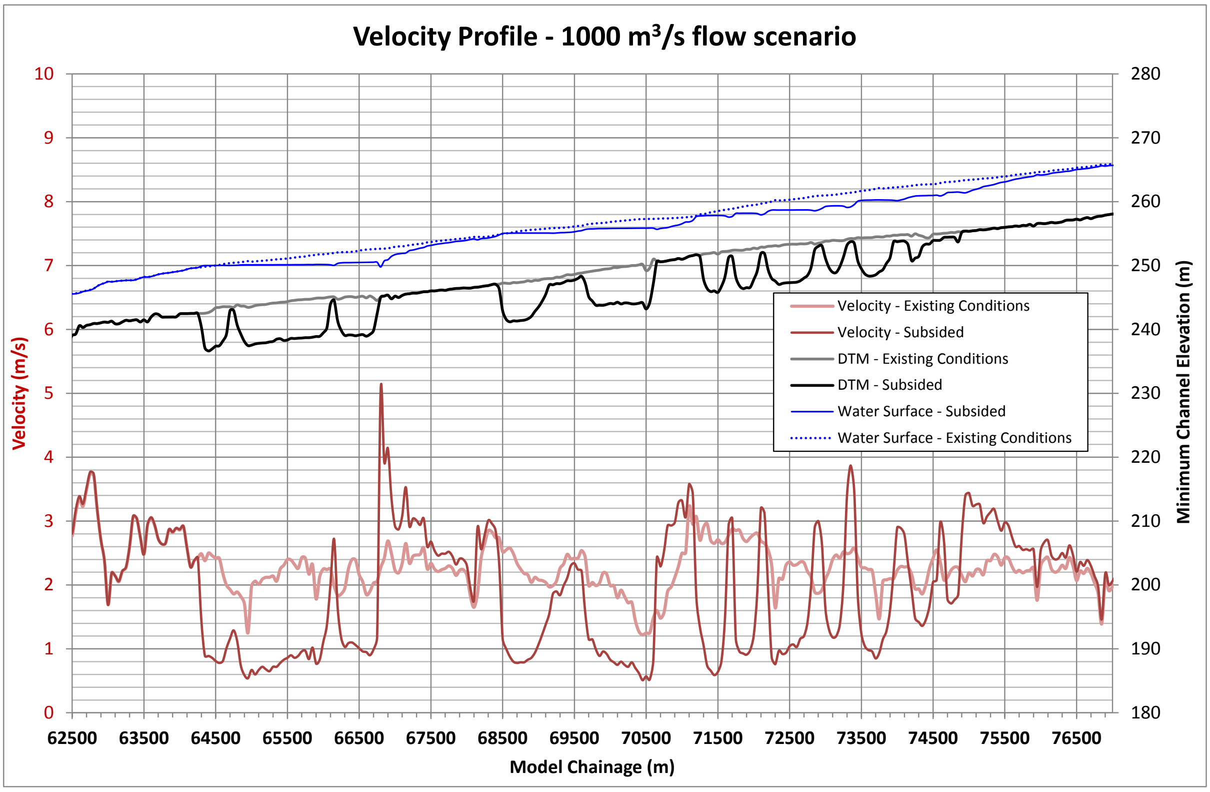
Drawing No. P211018-005 Revision No. A
Sheet No. 5 File Name: P211018 -004-006.dwg

A3

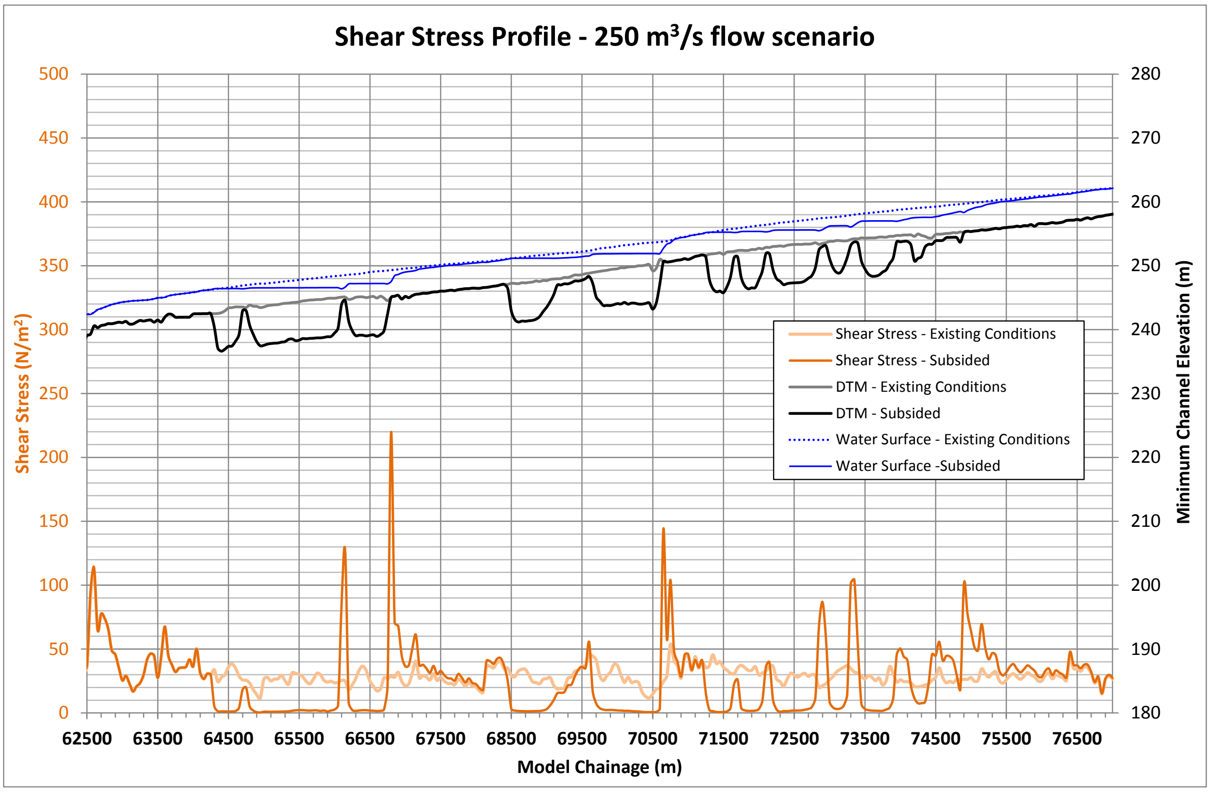
Attachment B
Hydraulic Modelling Results



Velocity Profile - 250 m³/s flow scenario
Velocity (m/s)
Minimum Channel Elevation (m)
Model Chainage (m)
0
1
2
3
4
5
6
7
8
9
10
180
190
200
210
220
230
240
250
260
270
280
62500
63500
64500
65500
66500
67500
68500
69500
70500
71500
72500
73500
74500
75500
76500
Velocity - Existing Conditions
Velocity - Subsided
DTM - Existing Conditions
DTM - Subsided
Water Surface - Existing Conditions
Water Surface - Subsided



Velocity Profile - 1000 m³/s flow scenario
Velocity (m/s)
Minimum Channel Elevation (m)
Model Chainage (m)
0
1
2
3
4
5
6
7
8
9
10
180
190
200
210
220
230
240
250
260
270
280
62500
63500
64500
65500
66500
67500
68500
69500
70500
71500
72500
73500
74500
75500
76500
Velocity - Existing Conditions
Velocity - Subsided
DTM - Existing Conditions
DTM - Subsided
Water Surface - Subsided
Water Surface - Existing Conditions



Shear Stress Profile - 250 m³/s flow scenario
Shear Stress (N/m²)
Minimum Channel Elevation (m)
Model Chainage (m)
Shear Stress - Existing Conditions
Shear Stress - Subsided
DTM - Existing Conditions
DTM - Subsided
Water Surface - Existing Conditions
Water Surface -Subsided
0
50
100
150
200
250
300
350
400
450
500
180
190
200
210
220
230
240
250
260
270
280
62500
63500
64500
65500
66500
67500
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72500
73500
74500
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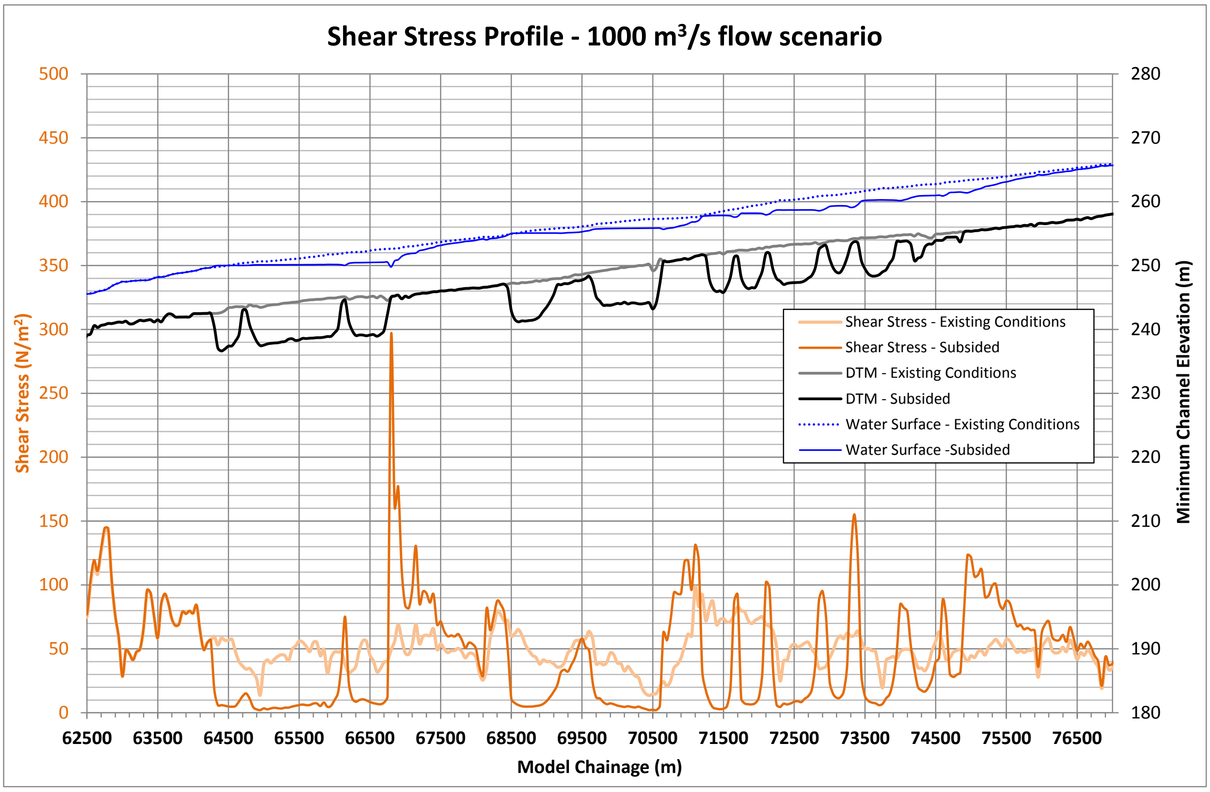
76500



Shear Stress Profile - 1000 m³/s flow scenario
Shear Stress (N/m²)
Minimum Channel Elevation (m)
Model Chainage (m)
Shear Stress - Existing Conditions
Shear Stress - Subsided
DTM - Existing Conditions
DTM - Subsided
Water Surface - Existing Conditions
Water Surface -Subsided
0
50
100
150
200
250
300
350
400
450
500
180
190
200
210
220
230
240
250
260
270
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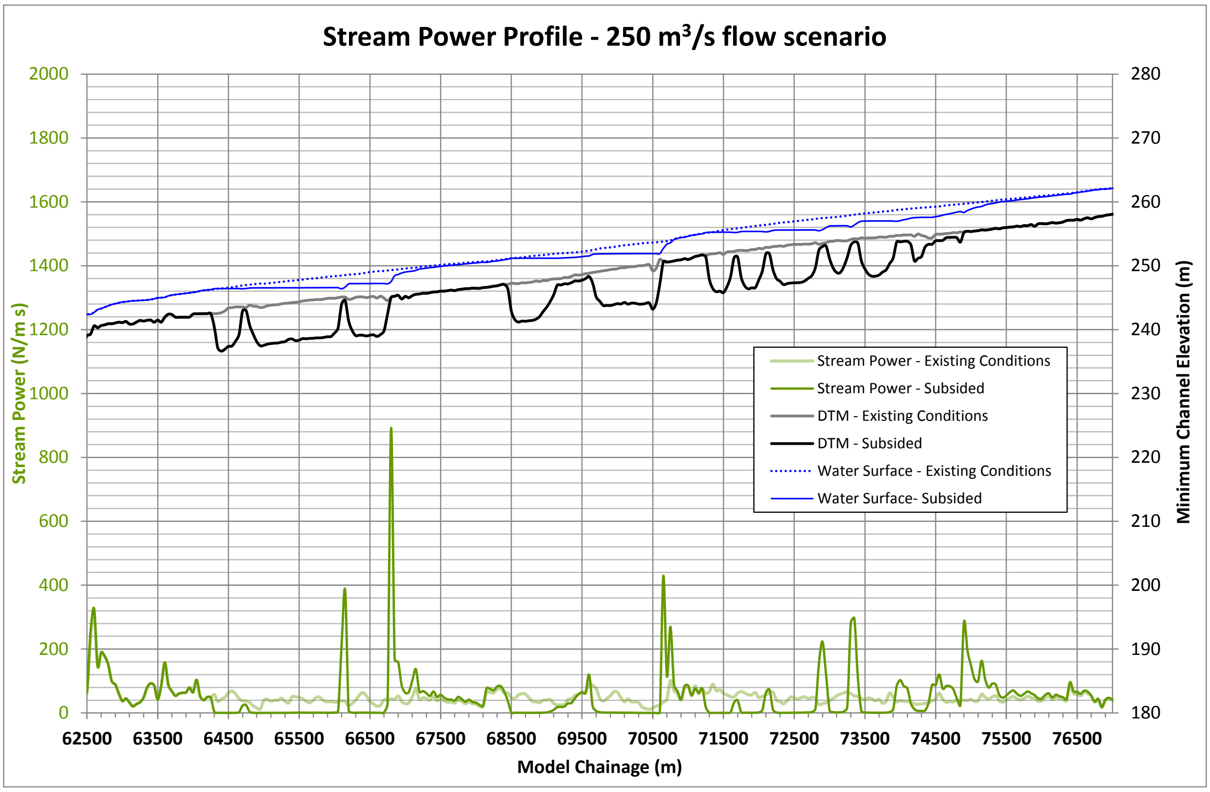

Stream Power Profile - 250 m³/s flow scenario
Stream Power (N/m s)
Minimum Channel Elevation (m)
Model Chainage (m)
Stream Power - Existing Conditions
Stream Power - Subsided
DTM - Existing Conditions
DTM - Subsided
Water Surface - Existing Conditions
Water Surface- Subsided
0
200
400
600
800
1000
1200
1400
1600
1800
2000
180
190
200
210
220
230
240
250
260
270
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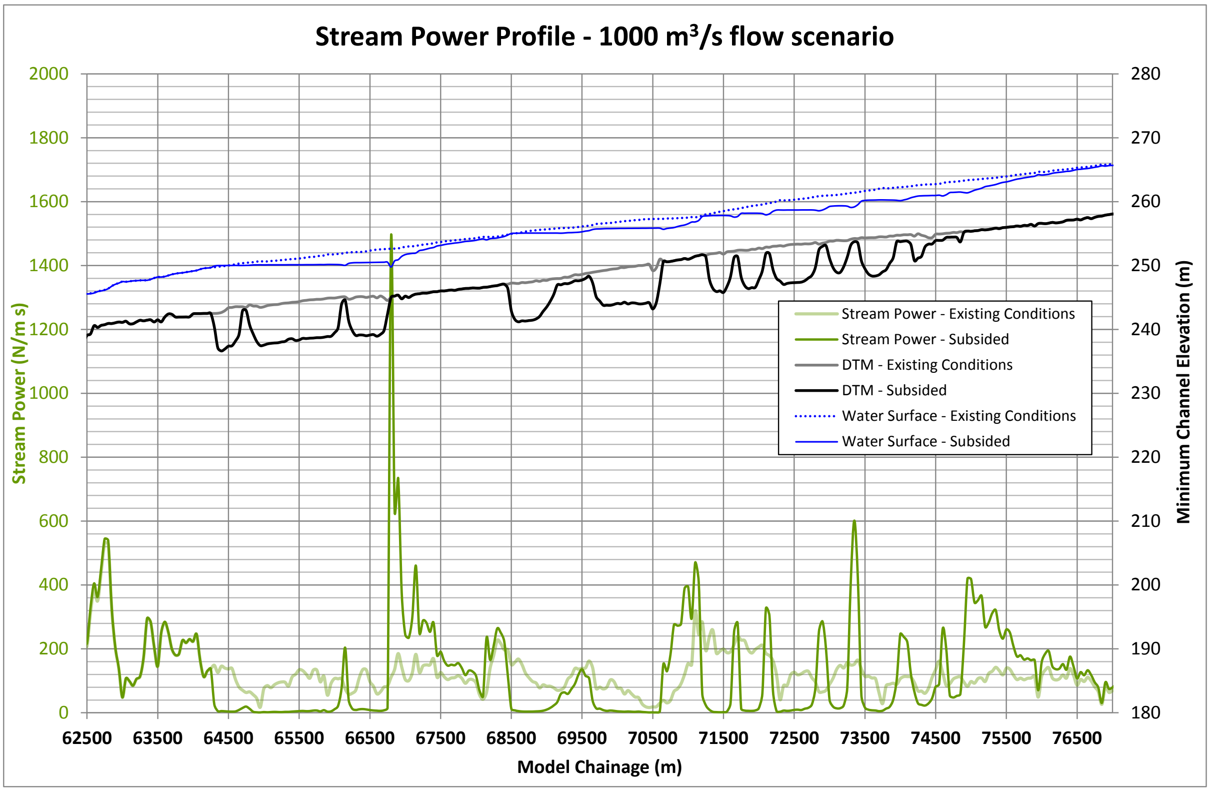

Stream Power Profile - 1000 m³/s flow scenario
Stream Power (N/m s)
Minimum Channel Elevation (m)
Model Chainage (m)
Stream Power - Existing Conditions
Stream Power - Subsided
DTM - Existing Conditions
DTM - Subsided
Water Surface - Existing Conditions
Water Surface - Subsided
0
200
400
600
800
1000
1200
1400
1600
1800
2000
180
190
200
210
220
230
240
250
260
270
280
62500
63500
64500
65500
66500
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68500
69500
70500
71500
72500
73500
74500
75500
76500