HANCOCK COAL PTY LTD

Alpha Coal Project Supplementary EIS • **ADDENDUM**

E | Stream Morphology Technical Report (June 2011)

Alpha Coal Project – Stream Morphology Technical Report

June 2011

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Certified to ISO 9001, ISO 14001, AS/NZS 4801
A+ GRI Rating: Sustainability Report 2009

2123204A-RPT0010-G:ma

Revision	Details	Date	Amended By
A	Original	August 2010	Dr Mohand Amghar
B	Review	August 2010	Dr Mohand Amghar
C	Review	August 2010	Martin Kijlstra
D	Final	September 2010	Dr Mohand Amghar
E	Final	September 2010	Dr Mohand Amghar
F	SEIS Update (Draft)	March 2011	Dr Mohand Amghar
G	SEIS Final	April 2011	Martin Kijlstra
H	Comments DERM Water Unit Meeting	June 2011	Martin Kijlstra
I	Correction Table 6.6 and figures Appendix B	Sept 2011	Martin Kijlstra

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Signed: ....

Date: Sept. 2011..

Distribution: Hancock Coal Pty Ltd, PB Library..

Contents

Page number

List of Tables

Contents (Continued)

Page number

List of Figures

List of plates

Appendices

Glossary

AEP	Annual Exceedance Probability: The probability that a given rainfall total accumulated over a given duration will be exceeded in any one year (see footnote).
AMDT	Adopted Middle Thread Distance: The distance from the mouth of the watercourse or the confluence of the watercourse with the main watercourse measured along the middle of the watercourse.
Afflux	Rise in flood level caused by a hydraulic structure.
AGD84	The coordinate reference system used in Australia prior to the introduction of GDA94.
AMG	Australian Map Grid — Cartesian co-ordinate system derived from a Universal Transverse Mercator Projection of latitudes and longitudes on the Australian Geodetic Datum (AGD) (now superseded).
ARF	Areal Reduction Factors
ARR	Australian Rainfall and Runoff.
Attenuation	The reduction of flood peaks due to storage effects.
Australian Height Datum (AHD)	The datum used for determining elevations in Australia which uses a national network of bench marks and tide gauges, and has set mean sea level as zero elevation. Elevations in metres above Australian Height Datum are annotated with the suffix m AHD (see below).
Average Recurrence Interval (ARI)	The average, or expected, value of the periods between exceedances of a given rainfall or a stream flow over a given duration (see footnote).
BoM	Bureau of Meteorology.
Catchment	The area of land which collects and transfers runoff into a waterway.
CL	Continuous loss.
Confluence	Area where two or more waterways come together to form one waterway.
Critical storm duration	The critical storm duration is the duration of rainfall that will result in the highest peak flood levels at a particular location.
DEM	Digital Elevation Model.
DERM	Queensland Department of Environment and Resource Management.
DIP	Queensland Department of Infrastructure and Planning.
Discharge	Instantaneous rate of flow measured in volume per unit time (such as m^3/s).
Downstream (d/s)	In the direction of flow of a stream or river i.e. away from the source.
DTM	Digital Terrain Model.
EIS	Environmental Impact Statement.
EP Act	Queensland *Environment Protection Act 1994*
EPP	Environmental Protection (Water) Policy 2009
Erosion	The process by which soil and rocks are loosened, worn away and removed from parts of the Earth's surface. Includes removal of debris supplied to the streams by slope wash, mass movement, and gullies.
FFA	Flood frequency analysis

Flood plain	That portion of a river valley that is covered during periods of high flood water.
Flow	Quantity of fluid measured over a period of time (such as ML/day).
Frequency	A measure of the number of occurrences per unit of time.
GDA94	Geocentric Datum of Australia. The coordinate reference system currently used in Australia to define co-ordinate systems.
GDR	Great Dividing Range.
GEV	Generalized Extreme Value
Groundwater	Water found underground in porous rock or soil strata.
HPPL	Hancock Prospecting Pty Ltd
Headwaters	Upstream Section of a river before it is joined by main tributaries. Typically smaller in width and flow than the main Section of the river.
HEC-RAS	A computer program that models water flow hydraulics of rivers and channels.
Hydraulic analysis	Refers to the assessment of flood levels, flows and velocities in waterways, creeks and rivers.
Hydrograph	A record of the discharge of a creek, stream or river over time.
Hydrological analysis	Refers to the estimation of flows that enter waterways, creeks and rivers.
Hydrology	The study of the occurrence, distribution, and chemistry of all waters of the earth.
IFD	Intensity Frequency Duration of rainfall
IL	Initial loss
Impervious Surfaces	Artificial structures such as pavements and building roofs, which replace naturally pervious soil.
Left/Right Bank	Defined for a watercourse with the observer facing downstream.
Log Pearson Type III flood frequency curve	A method described in Australian Rainfall and Runoff to relate flood peaks to annual exceedance probability.
m AHD	Metres (above the) Australian Height Datum. Refers to the number of metres above Australia's theoretical reference surface, approximately equivalent to the height above sea level.
MGA	Map Grid of Australia – current Cartesian co-ordinate system for use in Australia derived from a Universal Transverse Mercator Projection of latitudes and longitudes on the Geocentric Datum of Australia (GDA).
MIKE FLOOD	A computer program that combines the MIKE11 and MIKE21 programs.
MIKE11	A one dimensional computer program that performs a hydraulic analysis of rivers, channels and water bodies.
MIKE21	A two dimensional computer program that performs a hydraulic analysis of rivers, channels and water bodies.
ML	Megalitre (1,000,000 litres)
MLA	Mining Lease Application
MRRM	Main Roads Rational Method
PB	Parsons Brinckerhoff
Peak discharge	The maximum discharge or flow during a flood.

Photogrammetry	Remote sensing technology used to determine geometric properties about objects from photographic images.
Pluviograph	A rain gauge which automatically records, usually in graph form, the cumulative amount of rainfall with reference to time.
PMF	Probable Maximum Flood
Rainfall Intensity	Depth of rainfall per unit time.
Rational Method	A procedure for determining peak discharge, which corresponds to a critical storm duration and specified catchment characteristics.
Reach	Portion of a stream channel between two specified points.
Recharge	The process involving the infiltration of water from the surface to groundwater.
RORB	A computer program that models urban and rural stormwater drainage by analysing rainfall and runoff in any land use area.
Runoff	The portion of rainfall which becomes surface flow.
SEIS	Supplementary EIS
SP Act	Sustainable Planning Act 2009
SRTM	Shuttle Radar Topographic Mission.
Temporal	Relating to time as distinguished from space.
Topography	Concerned with local detail in general, including relief and vegetative and human-made characteristics.
Tributary	A stream or river that does not reach the sea but joins another major river (parent river), swelling its discharge. Sometimes described in terms of "left bank" or "right bank", referring to the bank of the parent river that the tributary connects to.
Upstream (u/s)	In the opposite direction of the flow of a stream or river, i.e. towards the source.
Water Act	Water Act 2000
Weir	A small overflow type dam in a stream or river, generally used to raise the water level or divert its flow.

Probabilities, ARI and AEP

For the purpose of this report, the Average Recurrence Interval (ARI) is generally used. It is recognised that other references to flood frequency are commonly used, however the ARI reference appears more widely understood by the public and has therefore been adopted in this report.

See http://www.bom.gov.au/hydro/has/ari_AEP.shtml. The Average Recurrence Interval (ARI) and Annual Exceedance Probability (AEP) are both a measure of the rarity of an event. With ARI expressed in years, the relationship is:

AEP = 1 – exp(-1/ARI)

This results in the following conversions:

ARI (years)	Percent Annual Exceedance Probability (% AEP)	Fraction Annual Exceedance Probability (AEP)
1	63.5	0.632
2	39.3	0.393
5	18.1	0.181
10	9.5	0.095
20	4.9	0.049
50	2	0.02
100	1	0.01
1,000	0.1	0.001
3,000	0.03	0.0003

1. Introduction

1.1 The Project

Hancock Coal Pty Ltd (HCPL) has commissioned Parsons Brinckerhoff (PB) to provide input into the Alpha Coal Project (the Project) Environmental Impact Statement (EIS) and Supplementary EIS (SEIS). This report provides a feasibility level assessment of the stream morphology and potential impacts and mitigation measures for creek diversions, suitable for the purposes of the Project. While the current hydraulic modelling provides a close match to the morphological requirements for the creek diversions and associated works, the detailed design phase of the Project will incorporate the stipulated design approach and parameters to ensure a compliant design and basis for the Water License application.

This Stream Morphology Technical Report is a revision of the Technical Report submitted with the Project's EIS submission (September 2010) and incorporates and responds to the comments from various stakeholders and statutory authorities, as well as the presentation and feedback from the DERM/DIP Water Unit Meeting held on 1 June 2011. This Stream Morphology Technical Report accompanies the SEIS submission.

The Project comprises the development of thermal coal resources located approximately 170 km west of Emerald, and 50 km north of the town of Alpha in the Galilee Basin. The coal reserves for this Project exist within the mining lease application (MLA) 70426. The coal resources will be developed by open cut mining with related infrastructure. Coal will be mined at a peak rate of around 40 million tonnes per annum (Mtpa) run of mine (ROM) coal. The coal will be crushed, sized and washed, with product coal transported by rail to Abbot Point. The Project covers an area of approximately 33,706 ha and will be developed by Hancock Prospecting Pty Ltd (HPPL).

The Project area is located within the Lagoon and Sandy Creek catchments, forming the south-westerly portion of the Belyando River system (refer Figure 1.1). The Lagoon Creek catchment is bounded by the Great Dividing Range (GDR) to the west and a north-south line of low hills to the east and extends to the south of the Capricorn Highway and northward to around Wendouree. The Sandy Creek catchment covers an area of approximately 7,700 km^2, while the area of interest is around 337 km^2. The creeks will be diverted within the Alpha Coal MLA to enable progression of mining activities. It should be noted that the upper reaches of Sandy Creek are named Greentree Creek on published topographic maps (refer Figure 1.2). For the purpose of this document this section of Sandy Creek will be referred to as Greentree Creek to allow ease of identification of reaches.

The Project interacts with three main watercourses (refer Figure 1.3), Lagoon Creek, Spring Creek and Sandy Creek. This necessitated undertaking a stream morphology investigation of the whole catchment as part of the EIS/SEIS. This investigation determined the existing stream morphology characteristics and appropriate and compliant design of the proposed creek diversions and levees for the Project, the potential impact of the mine development and any required mitigation works.

The primary components of this study comprise:

- preliminary geomorphic characterisation of streams in the Project area

- Lagoon Creek levee and diversion – feasibility design parameters
- Sandy Creek diversion – feasibility design parameters
- Spring Creek diversion – feasibility design parameters
- impact assessment
- watercourse rehabilitation.

The Project comprises three diversions:

- Lagoon Creek Diversion:
  - the Lagoon Creek diversion comprises the diversion of the active channel only, to another location within the natural flood plain. The 9.6 km long diversion channel is designed to connect the existing upstream and downstream natural active channels, while providing a degree of meandering to replicate the existing channel. The excavated channel is a combination of the active (2 year ARI flows) and high flow (50 year ARI flows) channel but, similar to the existing active channel does not feature a separately distinguishable low flow section set into the high flow channel
  - a levee situated on the west (left) bank of Lagoon Creek through the MLA, will provide flood immunity of up to 3000 year ARI. The EIS assumed that the levee would be set further into Lagoon Creek. However, following discussions with DERM and stakeholders, the levee was moved further uphill to provide better conveyance and storage within Lagoon Creek. The topography on Lagoon Creek's right (east) bank rises rapidly and therefore mine infrastructure on the east bank is unaffected by the floods
  - the Lagoon Creek diversion will allow unimpeded access to coal reserves. The route allows adequate offsets between the diverted creek and proposed mining operations, reducing any impact that the mining operations will have on the water flow in Lagoon Creek. The diversion is anticipated to provide a stable and sustainable creek alignment for Lagoon Creek into the future.
- North Western diversion (Sandy Creek):
  - the north western diversion totals 25.5 km in length, of which the Sandy Creek diversion comprises 11 km. The remaining length of the channel captures overland flows and discharges from unnamed creeks. The most northern section of this diversion channel is located just inside the perimeter of the MLA (refer Figure 1.3) and includes an additional levee on its left bank, to avoid flood waters from this diversion affecting the adjacent property of Kevin's Corner. The diversion is designed with a high flow channel to 50 year ARI and includes a low flow channel sized to 2 year ARI. This diversion rejoins the original Sandy Creek some 100 m before the confluence with Lagoon Creek
  - a flood levee is located adjacent to, and on the mine side of the diversion channel and provides flood immunity to the mine to 3000 year ARI. In the event of floods exceeding 50 year ARI, flood water will rise against the levee and locally temporarily inundate the adjacent (upstream) land. No third party properties are affected

- additional levees are included between the diversion and the MLA boundary to avoid break out of flows from the diversion to adjacent third party properties, and similarly to protect the Alpha infrastructure from adjacent creeks (e.g. Little and Rocky Creek).

- The adopted corridor available for this section of the diversion channel is set at 240 m between the MLA boundary and the top of the highwall. Based on the diversion and levee design, this allows an eighty to ninety meter wide strip between the levee and the highwall to take account of access arrangements and highwall instabilities. Should ongoing geotechnical investigation determine this allowance to be insufficient to ensure the safety of the mine and diversion/levees, then the mine pit strike length will be shortened to suit, and will not impact in the width of the nominated diversion corridor. It should be noted that the exposure to high wall instability is limited to the pit width only (200 m approx.) with overburden being placed back into the mined-out pit area immediately after mining. Overburden will ultimately also be placed immediately behind the levee bank.

- Southern diversion (Spring Creek):

  - the south western diversion totals 11.2 km in length, of which Spring Creek comprises 10 km, running parallel to the south-west MLA boundary. The diversion is designed with a high flow channel to 50 year ARI and an active channel to 2 year ARI. This diversion channel joins Lagoon Creek some 150 m inside the upstream boundary of the MLA boundary. As for the north western diversion, an additional levee is provided between the diversion channel and the MLA boundary to avoid breakout of flood waters onto the adjacent tenement

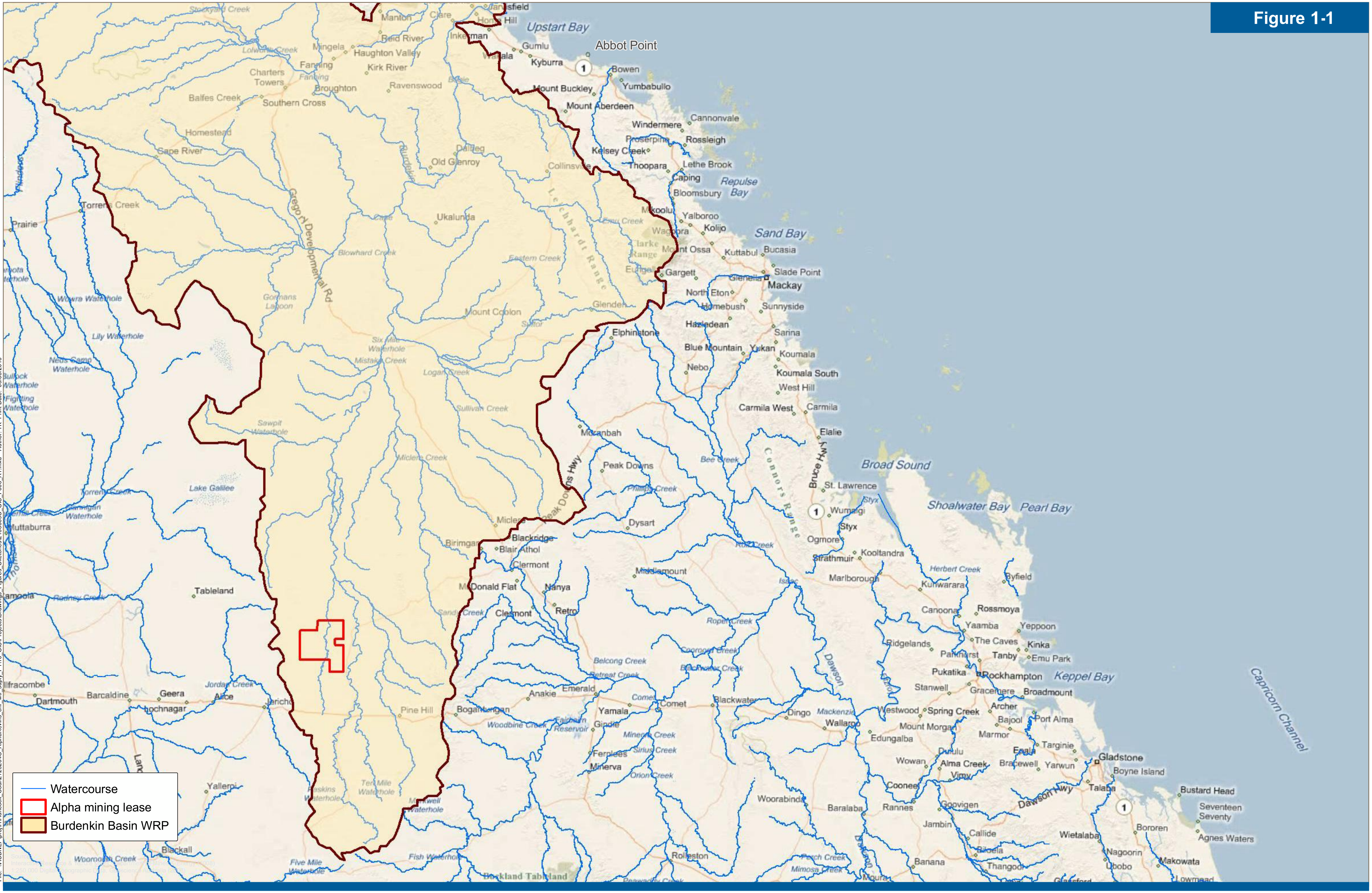
  - a flood levee is located adjacent to, and on the mine side of the diversion channel and provides flood immunity to the mine to 3000 year ARI. In the event of floods exceeding 50 year ARI, flood water will rise against the levee and locally temporarily inundate the adjacent (upstream) land. No third party properties are affected.

  - The adopted corridor available for this section of the diversion channel is set at 240 m between the MLA boundary and the top of the highwall. Based on the diversion and levee design, this allows a ninety to one hundred meter wide strip between the levee and the highwall to take account of access arrangements and highwall instabilities. Should ongoing geotechnical investigation determine this allowance to be insufficient to ensure the safety of the mine and diversion/levees, then the mine pit strike length will be shortened to suit, and will not impact in the width of the nominated diversion corridor. It should be noted that the exposure to high wall instability is limited to the pit width only (200 m approx.) with overburden being placed back into the mined-out pit area immediately after mining. Overburden will ultimately also be placed immediately behind the levee bank.

The creek diversions will generally allow mining activities to proceed with unimpeded access to coal reserves that would otherwise be inaccessible due to the risk of flooding.

Also the Lagoon Creek diversion is positioned to minimise sterilisation of coal, even though coal deposits remain sterilised under the existing channel section of Lagoon Creek. The adopted levee and active channel route allow adequate offsets between the diverted creek and proposed mining operations, reducing any impact that the mining operations will have on the conveyance capacity of Lagoon Creek. The diversion is anticipated to provide a stable and sustainable creek alignment for Lagoon Creek into the future.

This report details the feasibility design for the proposed creek diversions. The recommendations of this report will be implemented in the detailed design for the levees and creek diversions, in preparation for the licensing applications for the creek related works.



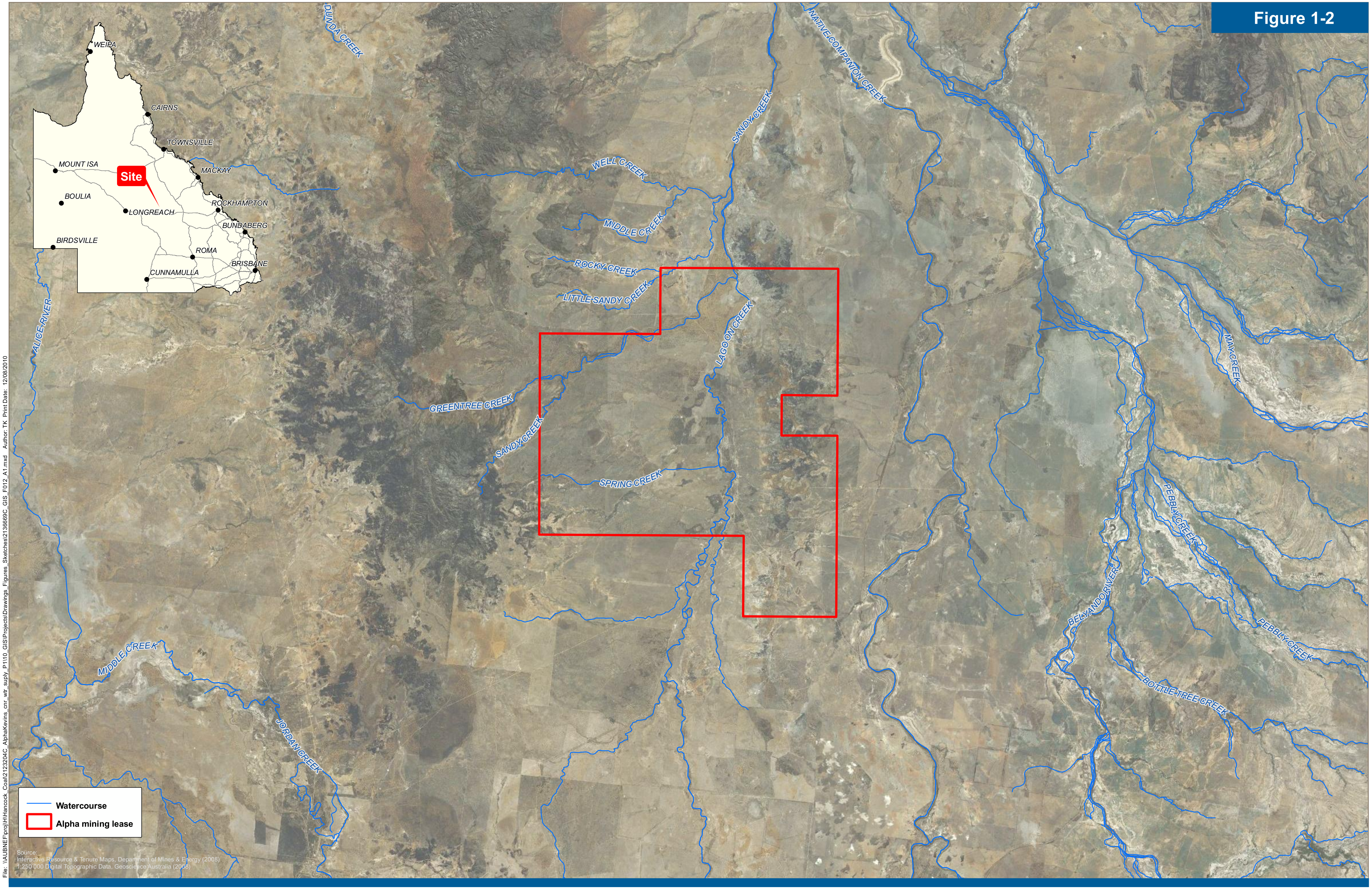
0 20 40 60 80 100
Kilometres

PARSONS BRINCKERHOFF

ALPHA COAL PROJECT

Project location

Figure 1-2



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PARSONS BRINCKERHOFF

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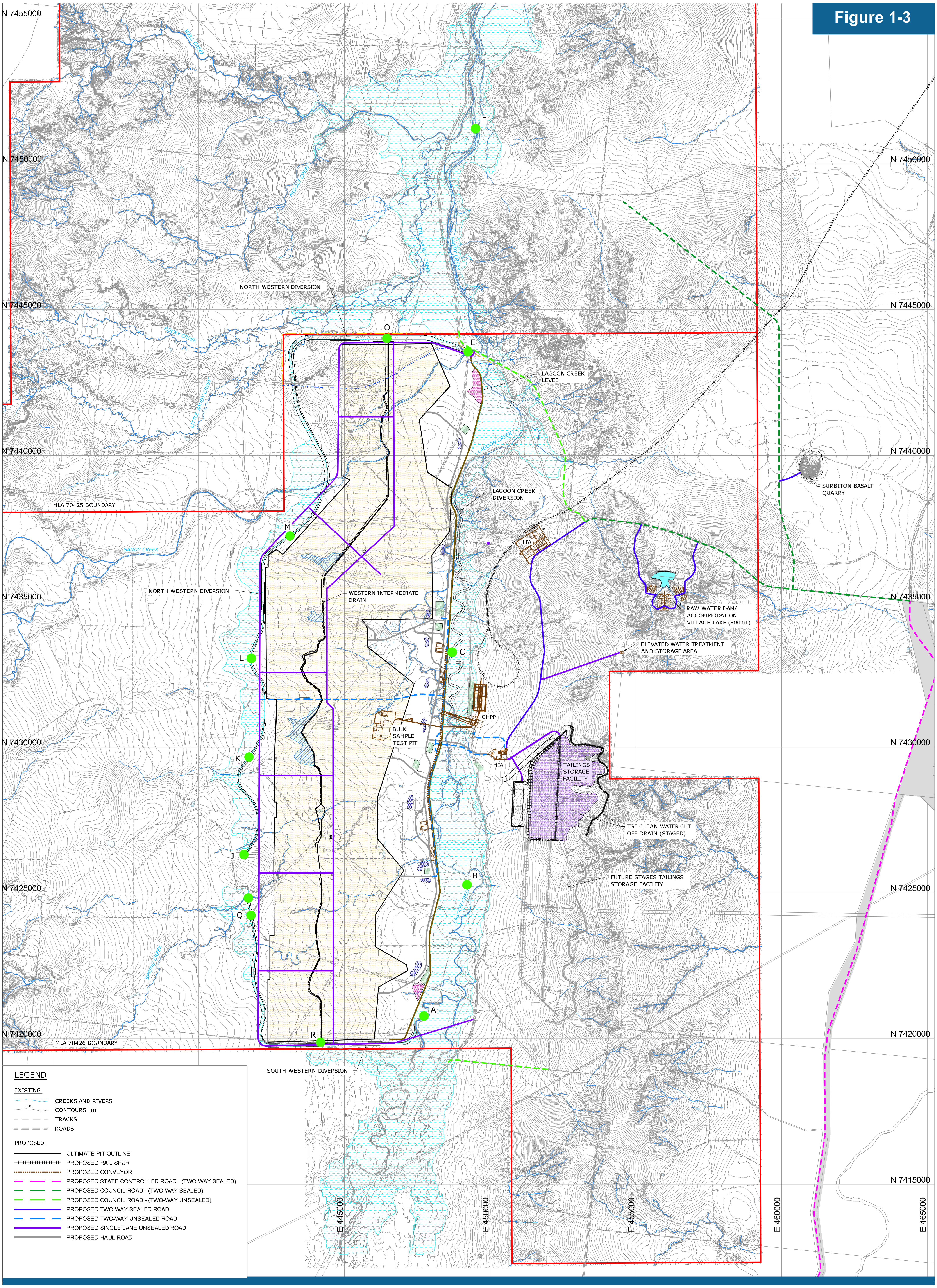
Kilometres

ALPHA COAL PROJECT

Project locality map



ALPHA COAL PROJECT

WATER INFRASTRUCTURE AND LEVEES

AND RORB INFLOW NODES

PARSONS BRINCKERHOFF

0 1 2 3 4 5 Kilometres

April 7, 2011

Plotted By: duffyt Plot Date: 07/04/11 - 15:27 Cad File: \\Aubnef\PROJ\H\Hancock_Coal\2123204A_HANCOCK_COAL_FEASIBILITY_STUD\09_CADD\Drawings\Figures\Figure_67500-1013A_Water Infrastructure & Levees - Figure 3-1.dwg

1.2 Purpose of this Report

This report has been created to provide supporting information for the development of appropriate flood management and diversions design for the Project, in accordance with DERM Central West, Water Management and Use Regional Guideline 'Watercourse Diversions –Central Queensland Mining Industry'.

This report should be read in conjunction with the Flooding Technical Report and forms part of a total of four surface water reports prepared for this SEIS, including the Flooding Technical Report, Water Quality Technical Report and the Water Management Technical Report

1.3 Overview of geomorphology significance in stream assessment

The significance of geomorphology in stream assessment and diversion design is described in the ACARP report (2002) and summarised below.

Fluvial geomorphology is the study of stream forms and processes that define the state of streams. The streams are viewed as part of an overall environmental system, dependent on various controls. These controls are divided into:

- **Independent catchment controls** (e.g. geology, basin physiography, land use, etc.). These controls are applicable for the whole region and are outside the control of the proponent of a diversion.
- **Independent channel controls** (e.g. valley slope, stream discharge, sediment load, etc.) are local controls that can only be partially manipulated for a diversion. Generally, the alignment selection is the only influence at this scale.
- **Dependent channel and flow geometry** including channel slope, channel width, floodplain characteristics, velocity, meander wavelength and other parameters. These variables are dependent on each other and will influence the variation of other dependent variables within a reach scale diversion.

Assessment and understanding of the dominant geomorphic processes and key parameters, the independent channel controls and the dependent channel and flow geometry, within a stream reach is essential in the design of a sustainable diversion.

2. Methodology

The methodology used for this study to assess geomorphic characterisation of streams in the Project area, contribute to the development of feasibility designs for the watercourse diversions which flow through the Project area. This stream morphology assessment also estimates the hydraulic parameters, assesses the performance and likely success of the proposed diversion alignments and channel features as described below.

2.1 Data compilation

Data used in the assessment was derived from information collected in the field as well as from existing data sets. Topographic surveys were derived from a digital terrain model (DTM) using information sourced from AAM Global, ecological data from AARC report (2010) and hydrologic data collected from the DERM gauging stations network. Spatially referenced data sets of land use, topography, soil type, and hydrographs were obtained from several sources and were used primarily to develop hydrologic models for the catchment.

2.2 Stream characterisation

Assessment of the stream characterisation involved selection of target stream reaches for preliminary analysis and field inspection of the selected streams. Some basic stream-channel characterisation was done at selected point reference cross-sections in addition to collecting the survey data. Field inspections for the selected creeks included site inspection and photography; vegetation assessment; visual observation of bed, bank and floodplain material; the identification of bank-full discharge (as indicated by geomorphic indicators) using the method of ACARP (2002); the estimation of bed width and notably physical features including absence of multiple channels and in-channel benches; the planform flow condition (meander, cross-over, or straight); flow type (riffle, run, pool, backwater, or dry), floodplain characteristics, whether or not tree roots appeared to be stabilising the stream banks; the presence of toe erosion; and the presence of sand in the streambed (to provide evidence of mobile sediment).

This Technical Report provides a preliminary stream characterisation, deemed appropriate for an SEIS Technical Report and does not provide the detail required for Water Licensing. The geomorphic conditions of the existing creeks will be analysed in future stages of the Project, to allow feasibility design. Existing stream geomorphic parameters will be replicated in the diversion design where feasible.

2.3 Reports and guidelines

For the assessment of fluvial geomorphology and design of creek diversions the following documents are used:

- Queensland Government, DERM, Central West Water Management and Use Regional Guideline – Watercourse Diversions – Central Queensland Mining Industry (1995)
- ACARP, Bowen Basin River Diversions, Design and Rehabilitation Criteria, Australian Coal Association Research Program (2002)
- ACARP, (Feb 2001), Monitoring and Evaluation Program for Bowen Basin River Diversions (2001)

- AARC, (2010), Stream Morphology Assessment for the Project
- Fryirs and Brierley, (2005), Practical Application of the River Styles – Framework as a tool for Catchment-Wide River Management: A case study from Bega Catchment, NSW.
- C&R Consulting (2010), Hancock Coal Flood Risk Study. This report commented on the flood modelling parameters and associated flood risk to the mine. The finding and recommendations have been taken into consideration for the hydrological and hydraulic studies as well as the Stream Morphology.

2.4 Data analysis

Data analysis included catchment hydrology and hydraulic modelling. Catchment hydrology was assessed to characterise the effects of runoff. A hydrologic model was developed for the entire catchment that estimated peak streamflows (Qp) caused by design rainfall events of varying magnitude.

A hydraulic model was then developed for the study area that estimated the water-surface elevation (WSE) corresponding to each Qp estimate. The hydraulic analysis was to provide information on various criteria outlined in ACARP (2002) (stream power, velocity and shear stress) in order to characterise the behaviour of natural streams in the Project area. This assists in formulating guidelines regarding future diversion design and rehabilitation.

3. Mine schedule and diversion requirements

Reaches of Lagoon, Spring and Sandy Creek require diversion due to their proximity to proposed mining operations. The diversion requirements for each of these creeks, together with the proposed mine schedule are discussed in this section. Figure 1.3 provides details of the mining infrastructure and diversions.

The adopted mine schedule for the Project, which includes the progression of the pits as well as overburden deposition, is based on the bankable feasibility mine plan for the Project. The open cut pit will be formed over the full north-south length of the mine site and progress from the left bank of Lagoon Creek, in westerly direction over a distance of approximately 5 ½ km. This is a positive change from the EIS mine plan where the east west distance was approximately 8 km.

In order to protect the mine from flooding, a levee is planned along the left (east) bank of Lagoon Creek. The levee will be designed to provide a 3,000 year ARI flood immunity. Similarly, along the western, north and south pit boundaries, levees will be provided to provide a 3,000 year ARI flood immunity.

Discussion with various stakeholders including DERM, has resulted in the levee being moved further from the creek centreline, thus widening the flood plain and proving improved conveyance and flood plain storage for Lagoon Creek. This has indirectly resulted in a reduction of afflux upstream of the site and a reduction of velocities, stream power and shear stress within the creek's active channel and flood plain.

The mine lease extends to the eastern side of Lagoon Creek, where much of the mine's infrastructure is located. No mining will take place to the eastern side of the creek. However, the tailings storage facility (TSF), as well as product coal stockpiles and other mine related infrastructure will be located on the eastern side of Lagoon Creek.

4. Overview of existing conditions

4.1 Geomorphic characterisation of waterways in Alpha area

4.1.1 Regional geology

The Project area lies in the Galilee Basin within a sequence of Late Carboniferous to Middle Triassic sedimentary rocks overlying Late Devonian to Early Carboniferous sedimentary and volcanic rocks of the Drummond Basin.

Reference to the Queensland Geological Survey 1:250 000 geology series Jericho sheet indicates that the Project area is underlain by the following geological units:

- quaternary age alluvium with some gravel, and valley fill deposits comprising sand, gravel and rubble
- tertiary age, partly lateritised argillaceous sandstone, sandy mudstone, and limestone
- lower Triassic age Dunda beds comprising labile sandstone, siltstone and mudstone
- lower Permian age Colinlea Sandstone comprising labile and quartz sandstone with minor siltstone and coal.

The published regional mapping does not indicate the presence of major fault or fold structures in the Project area.

The oldest rocks in the study area and its surrounds were formed during the Upper Carboniferous and Lower Permian. These include mudstone, siltstone, and sandstone and along with the Tertiary age laterised sandstones, are the main hard rocks in the region. They exist as steep sided hills and ridgelines, east and west of the Project, with high relief and represent the highest ground in the area.

Long term erosion of these sedimentary rocks was the source of sediments that formed extensive alluvial fan plains at the foot of the hills. Transfer of finer grained sediments from these alluvial fans towards the centre of the valley formed alluvial plain and outwash deposits. Both of these landforms are gently undulating and the transition between them is non-distinct. The alluvial fan plain deposits are generally coarser grained than the outwash and alluvial sediments.

Currently, ephemeral drainage lines still transfer water and sediments from the uplands, across the alluvial-colluvial plains, towards the centre of the valley during heavy seasonal rainfall events. Erosion occurs along these drainage lines and creeks. Actively eroding gullies have developed in the transitional area between the foothills and the alluvial fan deposits and within the alluvial fan sediments.

4.1.2 Drainage

The principal drainage within the catchment is Lagoon Creek, which together with other minor creeks in the Project area flow over Quaternary age alluvium dominated by valley fill sediments. The alluvium is characterised by inter-bedded sands and clays, and varies in thickness from 30 m to 125 m. The streams are also long term sediment stores, in which sediment only migrates downstream during infrequent flood events.

The valley fills in the confined and steeper upper catchments are often dissected by short bedrock controlled sections where the longitudinal profile steps down. Downstream of those sections, the waterways flood out into the broader valley floors of the higher order waterway.

Energy conditions are generally low in the broad valley floors where the flows are dispersed.

These watercourses retain runoff and release it slowly, particularly when vegetation is intact. In low-lying areas, such as along Lagoon Creek, the water table was encountered between 8 m and 10 m depth from ground surface and at up to 15 m depth further west of Lagoon Creek, in slightly elevated ground. The Tertiary sand aquifers are semi-confined and in some instances the hydraulic head can be 20 m above the top of the aquifer.

4.1.3 Geomorphic characteristics of local streams

The Project area is divided into three local sub-catchments:

- Sandy Creek
- Spring Creek
- Lagoon Creek.

The characteristics and behaviour of each of the above streams and reach types are summarised on the following pages. Appendix A provides a compendium of photos of sites around the Project area used in this assessment. Channel pattern classification is based on that described in Selby (1985) and channel geometry classification in accordance with ACARP (2002).

4.2 Sandy Creek geomorphic condition

Waterway and position in catchment	**Sandy Creek is located in the north-western and northern portion of the Project area**
Active channel geometry	Varies between symmetrical and asymmetrical and generally compound cross section. Variable width to depth ratio. Width varies from 10 m to 20 m and channel depth from 0.5 m to 2.5 m. Incised channel.
Channel Pattern	Low to moderate sinuosity single continuous channel with discontinuous secondary channels, classified as wandering meander system. Rare impingements on valley margin. Banks appear stable and mostly vegetated with dead trees and grass on the channel bed. Bed sediment mainly comprises coarse sand with occasional gravel.
Geomorphic Units	**Channel zone:** Sandy Creek is mostly a third order stream with pools and riffles, waterholes, mid-channel islands and bars. In channel bench complexes occur. Occasional clay plugs exposed. **Floodplain zone:** low or absent bank levee, very gentle back slope to floodplain margin. Narrow, up to 1 km wide floodplain sub-parallel to the channel. Floodplain coalescing with Lagoon Creek floodplain to form wide flat area.
Geomorphic Behaviour	Limited lateral adjustment, dominated by vertical and oblique accretion and potential for avulsion in long term. Trees along the banks provide stability by trapping sediment in place and capturing additional debris. Creek morphology can be considered as moderately intact with areas under grazing impacts. Channel migration through secondary channels and floodout splays.

Waterway and position in catchment	**Sandy Creek is located in the north-western and northern portion of the Project area**
Sediment Transfer Behaviour	Sandy Creek catchment is a low relief with a little hydraulic driver of sediment transport, which leads to a natural discontinuous channel form in the upper section. Acts as a sediment source in the western section of the Project area and a sediment deposition at downstream section. Slow rate of accretion in long term.

Plate 1 Sandy Creek channel

Plate 2 Sandy Creek floodplain

4.3 Lagoon Creek geomorphic condition

Waterways and position in catchment	**Lagoon Creek is a south to north trending stream along the central portion of the Project area**
Active channel geometry	Meandering channel of limited capacity. Waterholes covered with vegetation. The channel width varies from 1.0 m to 20 m and depth from 0.5 m to 3.0 m. Channel has a high width:depth ratio with asymmetrical compound on bend apex. Banks slope at 5° to 30° and are moderately stable.
Channel Pattern	Multiple low flow, secondary channels, except a few single channel sections, such as the Hobartville Road crossing. Extensive lateral and mid channel bars. High lateral migration potential within the area occupied by the secondary channels. When channelised; often symmetrical and trapezoidal. Lagoon Creek is classified as having wandering meanders. Basin drainage pattern appears to be dendritic with distinct northerly trend. Channel banks are vegetated and stable through the majority of Lagoon Creek, with isolated occurrences of bank instability, such as slumping.
Geomorphic Units	**Channel zone:** Bed load is mainly sand. Appears to have oversupply of sediment. Channel bed stability is low given high rates of temporary sediment accumulation. Low flow channel within active channel is curved and moving from one bank to other. During high flow, bank erosion and migration occurs. **Floodplain zone:** Two to four kilometre wide floodplain that is generally wide at the confluence of western tributaries.
Geomorphic Behaviour	Prior to European settlement, the stratigraphy of valley fills in Lagoon catchment reflects recurrent phases of cutting and filling over recent geologic time. Sediment movement is vegetation dependent. Where the channel bed is not grazed, the bed acts as sediment store. Where the channel bed is grazed, it acts as a sediment source.
Sediment Transfer Behaviour	Slow rate of accretion in long term.

Waterways and position in catchment	**Lagoon Creek is a south to north trending stream along the central portion of the Project area**
	
Plate 3 Waterhole in Murdering Lagoon	**Plate 4 Typical channel pattern**

4.4 Spring Creek geomorphic condition

Waterways and position in catchment	**Spring Creek located south-western area of the Project**
Channel geometry	Discontinuous channel of limited capacity. Highly variable shape, ranging from asymmetrical compound to symmetrical in some straight sections. Channel is relatively narrow (1 m to 5 m width) and shallow (0.2 m to 1.5 m depth). When channelised; often symmetrical and trapezoidal.
Channel Pattern	High lateral migration potential due to shallow channel. Classified as wandering meanders. Spring Creek catchment exhibits the dendritic channel pattern with vegetated banks.
Geomorphic Units	**Channel zone:** Bed load comprises mainly medium grained, mobile sand. **Floodplain zone:** Spring Creek mainly crosses a denuded alluvial fan/outwash complex comprising mainly coarse grained sediments with surfacial fine grained deposits. The flood plain is poorly defined within the outwash plain. The discontinuous channel pattern and poorly defined floodplain are anticipated to be due to the very low, and discontinuous, gradient of this plain and low flow regime.
Geomorphic Behaviour	High rates of material reworking and sediment transport. Acts as a sediment source and transport of valley fill (i.e. older alluvial fan/outwash sediments). Depositional zone at the confluence with Lagoon Creek.
Sediment Transfer Behaviour	Source and transport zone, very little accumulation except for benches.
	
Plate 5 Spring Creek channel within valley fill sediments	**Plate 6 Spring Creek channel**

4.5 Field observations on Lagoon, Spring and Sandy Creeks

Morphologic diversity in channel in the study area is anticipated with a pool–riffle–run bed profile and compound asymmetrical cross section with benches on one side of the channel. Backwater pools appear to persist for long periods with a distinct vegetation growth level on banks and undercut of the creek bed. Hydraulic conditions (velocity, depth and turbulence) during flows will be dominated by the vegetation.

Lagoon Creek traverses the Project site through several geomorphic reach types, ranging from steep confined valley fill, to broad unconfined valley fill, to chain of ponds (Murdering Lagoon), and finally to flood-outs. The minor changes in gradients create a dendritic pattern within Lagoon Creek and associated watercourses. The areas creeks can be classified as a sediment source and sink mode (area of deposition). Irreversible anthropogenic alterations have occurred along some reaches on the floodplain to improve grazing capacity.

The upstream start point for the Lagoon Creek active channel diversion is at a location where Lagoon Creek emerges out of a broad valley floor with a valley fill that has been altered by anthropogenic activity. However, there is still minimal channel development and flows are largely unconfined.

Plate 7 Typical view of the Lagoon Creek floodplain near creek diversion off-take site

Little Creek, which is a tributary of Sandy Creek, is classified as a limited capacity alluvial stream with limited incision into the landscape and high hydraulic connectivity with the floodplain (typically less than the 2yr ARI event),(refer Plate 10).

Plate 8 Soil profile of banks on Lagoon Creek

Plate 9 Typical bed-load sediment comprising coarse sand in Sandy and Lagoon Creeks

Plate 10 **Active channel section of middle Little Creek near proposed diversion bend**

Plate 11 **View of floodplain near the proposed north-west creek diversion finish and tie-in point**

Plate 12 Chain of pools in confined floodplain, upper Lagoon Creek

The fluvial geomorphic processes in the Project area include erosion, sand transport and deposition of sediments along the creek system, contributing to the spontaneous development of new natural channel forms. The Sandy Creek catchment manifests natural erosion and deposition processes with dynamic channel forms within a relatively stable river bank and healthy in-stream and floodplain habitats.

The high variability of flow regimes in the Sandy Creek catchment has a widespread impact on the channels and associated flood plain. An example of this is Murdering Lagoon ((Plate 13) located in Lagoon Creek within the MLA, just upstream of the MIA), where links between the creek systems (channels, waterholes) and floodplain, provides for a healthy ecological system. Low and high flows are also important hydrologic process, in providing critical water for waterholes and wetlands in drier periods, assisting with the movement and migration of aquatic organisms and maintaining channel forms (Bunn et al., 2006 and Bunn and Arthington, 2002).

The preservation of wetlands and their role in trapping and removing sediment and other contaminants are an important water resources issue. Determination of wetland budgets (inflows and outflows) and impacts are paramount to our ability to understand and maintain wetland functions (this is outside of the scope of the EIS/SEIS)).

Plate 13 View of one of two Murdering Lagoon Creek Wetlands

5. Creek diversions

Valuable coal deposits have been identified beneath and immediately adjacent to the natural alignments of Lagoon Creek, Sandy Creek and Spring Creek. As such, reaches of these creeks require confinement and/or local diversion due to their proximity to proposed mining operations. Therefore the possibility of confining or diverting the creeks was investigated.

5.1 Design criteria for creek diversions

5.1.1 General

There are two recognised design processes for the design of a creek diversion: the ‘reference reach’ approach and the ‘design criteria’ approach.

The ‘reference reach’ approach requires the diversion to replicate the existing natural channel reach as much as possible. This includes, but is not limited to, replicating the floodplain width, channel meanders, vegetation, velocities and geomorphic characteristics. This approach is suitable when the diversion is to be constructed in an area of similar topography to the existing reach.

The ‘design criteria’ approach requires the diversion to perform in accordance with the criteria set out in the design specification. For example, the design specification for the Australian Coal Association Research Program (ACARP, 2002) guideline includes, but is not limited to, limiting velocities, limiting shear, limiting stream power, providing vegetation and maintaining geomorphic processes. This approach is suitable when the diversion is to be constructed in an area of different topography to the existing reach, or when the original channel conditions are not easily replicated (e.g. due to diverse channel conditions).

While sections of the Lagoon Creek diversion have been designed using the ‘reference reach’ approach, the overall morphology of Lagoon Creek is so diverse, with channel sections ranging from narrow incised channels to wide flat floodplain areas with dispersed channel sections, that it is not feasible to establish typical design parameters, based on the reference reach approach alone. For the purpose of the SEIS we have therefore adopted a mix of the two approaches for Lagoon Creek with the key objective to ensure no worsening of the in channel conditions. Typically the active channel is set within the natural flood plain and is sized similar to the active channel upstream of the diversion (or the combined active channel section if appropriate). Although the original active channel was greater in length, the meanders are mimicked and the overall floodplain gradient is retained.

The Sandy Creek and Spring Creek diversions have been designed using the ‘design criteria’ approach, as the topography encountered, together with the mine plan and associated optimal pit dimensions, make the ‘reference reach’ approach impractical. In particular the efficiency of mining is severely compromised by adopting an irregular pit shape and variable strike length. As a consequence the channel sections running along the northern and southern MLA boundaries are formed by a straight flood corridor defined by levees to both sides of the high flow channel. Within the high flow channel the low flow (active) channel will meander, creating a more natural appearance but also increasing the roughness of the overall channel during high flow conditions. Together with appropriate vegetation and strategically placed rock, natural conditions will be mimicked and sustainable, stable channel will be established.

Australia does not have a generally recognised standard or set of design criteria for creek diversions. For the purpose of the Project, the commonly used ACARP guideline has been adopted, as discussed below.

ACARP has funded a series of projects related to river diversions. Research in the Bowen Basin in Central Queensland culminated in a set of design and rehabilitation criteria that has since been adopted by the Queensland Department of Environment and Resource Management (DERM), as its Central West Water Management and Use Regional Guideline for Watercourse Diversions. This guideline has been adopted for the Project's creek diversions as it is the best available guideline and is directly applicable to this Project.

Before the ACARP research, the design of river diversions was mostly based on knowledge gained from processes occurring in perennial streams of North America, Europe and South-east Australia. Their application to ephemeral streams has often resulted in the under-design of river diversions, increasing the risk of ongoing failure, or in the over-design of river diversions, resulting in excess cost (ACARP, 2002).

The ACARP investigations involved developing an understanding of stream processes within the Bowen Basin region and a detailed assessment of approximately 30 selected streams and six constructed diversions. The selection of streams was mainly based on achieving a dataset, comprising natural rivers and streams of similar type to those diverted at the mine sites. Relationships could then be identified between key parameters and incorporated into criteria for diversion design and rehabilitation.

Following field investigation, hydrologic analysis was used for each creek and diversion. Design storm events were then modelled using HEC-RAS, a one-dimensional hydraulic model developed by the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Centre. The model was developed to identify the range of three parameters — velocity, shear stress and stream power. The information was used to develop an understanding of the link between the hydrologic and hydraulic parameters and the shape, size and occurrence of geomorphic reach types within the natural creek systems, for comparison with the constructed diversions.

5.1.2 Key hydraulic parameters

Preliminary investigations took place to select a channel profile capable of conveying the 3000 year ARI flow in the diverted Lagoon, Sandy and Spring Creeks. The selected profile was for an active channel (i.e. in this document the same as the low flow channel) to accommodate up to a 2 year ARI event and a high flow channel to accommodate up to a 50 year ARI event. However, the selection of 3000 year ARI design floods has been used to design the surrounding levees.

The hydraulic parameters for which values were derived in this study are:

Stream power:

Stream power is a product of channel slope and discharge that represents the excess energy available to do work in and on the channel. Equilibrium and/or recovery usually involves a balance of deposition and erosion. If the flow is too powerful then the channel would typically erode. Alternatively, if the stream power is too low, aggradation (i.e. sediment deposition) will occur.

$$Stream\ Power\ (\omega) = \frac{\rho g Q S}{W}$$

ρ = density of water (kg/m^3)
g = gravitational acceleration constant (m/s^2)
Q = discharge (m^3/s)
S = hydraulic gradient (m/m)
W = water surface top width (m)

Stream velocity:

Velocity is the speed at which water flows through the stream. It is a product of discharge and cross-sectional area (A).

$$Velocity\ (v) = \frac{Q}{A}$$

Shear stress:

A shear stress, denoted τ(tau), otherwise known as tractive force, is described as the force exerted on the channel bed and banks by the action of flowing water. It is also a function of channel slope and discharge.

Shear stress (τ) = ρgds

ρ = density of water (kg/m^3)
g = gravitational acceleration constant (m^2/s)
d = depth of water (m)
s = water surface slope (m/m)

The *Bowen Basin River Diversions – Design and Rehabilitation Criteria* (ACARP, 2002) report established a range of stream powers, velocities and shear stresses that are considered to be the upper limits within which natural stable streams of the Bowen Basin operate. Longitudinal profiles of the above parameters for the 2 year and 50 year ARI events under the existing and developed conditions, for Lagoon, Sandy and Spring Creek are included in Appendix B.

While the suggested values for the design criteria are particular to diversions in the Bowen Basin, they can also be applied in this instance to the design of all three creek diversions. Natural creek characteristics should also be considered and replicated where practical.

Table 5.1 DERM guidelines for watercourse diversion – hydraulic criteria adopted for the Project

Flood event	Stream power (W/m^2)	Velocity (m/s)	Shear stress (N/m^2)
2 year ARI (no vegetation)	<35	<1.0	<40
2 year ARI (vegetated)	<60	<1.5	<40
50 year ARI (vegetated)	<220	<2.5	<80

The DERM guidelines do not provide details for flow events greater than a 50 year ARI event. For the 2 and 50 year ARI event, the criteria are derived from the *Central West Water Management and Use Regional Guideline: Watercourse Diversions – Central Queensland Mining Industry* (Queensland Department of Natural Resources and Mines), which is also based on the ACARP guidelines.

5.1.3 Creek diversion approach

In designing new or rehabilitated creek diversions, the aim is to demonstrate Australian best practice for design, construction, rehabilitation and management of waterways. This is achieved, wherever practical, by adhering to a number of fundamental principles:

- create a creek that operates as part of a self-sustaining stream system and promotes nutrient processing, ecological connectivity, and sediment storage and transport
- whenever practical, avoid the use of artificial grade control structures or other structures that are likely to require maintenance beyond life of mine (for the three diversions, no control structures are required)
- include natural, locally and regionally occurring geomorphic and habitat features
- create a creek where the diversion and adjoining reaches establish a state of dynamic equilibrium (equal rates of sediment erosion and deposition).

The design of the creek diversions follows the following design objectives:

- the creek diversions are proposed to achieve long-term geomorphic stability
- the creek diversions have used a diversion channel bank batter slope of 1:3 (v:h). This design was adopted as a preliminary assumption based on limited geotechnical information, with the intention of refining these channel bank batter slopes as the design process progresses
- adopting a diverted creek bed grade similar to that of the natural creek, which is achieved by designing sufficient length and cross sectional area in the diversion alignment and incorporating meanders of adequate geometry where appropriate
- where flows from tributaries and overland flows are redistributed, the receiving channel will be assessed for its capacity to carry the revised flows to the appropriate gradient, stream power values and velocity.

It is expected that designs using these principles should create a morphologic stable creek in dynamic equilibrium, requiring minimal management in the short and medium term, with no ongoing management in the extended term beyond mining operations.

5.1.4 Route selection

In the selection of a creek diversion alignment, various options were assessed with respect to their capability to:

- provide an alternative route for the active channel of Lagoon Creek. The new active channel will remain within the current flood plain area but be aligned away from the proposed mining activity. The active channel varies in depth to suit channel gradient and local flood plain ground levels. Typically the active channel conveys flows between 2 and 50 year ARI flows, however where the channel capacity is exceeded, flows will break out into the (natural) flood plain. The new active channels are designed primarily to reflect the existing conditions as closely as possible and secondly to adhere to the guidelines.

- convey the 50 year ARI flow event in Sandy Creek from the western boundary of the mine to the confluence with the downstream stretch of Sandy Creek, just before the confluence with Lagoon Creek. It is noted that the diversion channel high flow channel is capable of diverting the 50 year ARI flows. Further capacity is provided by levees, which ensure that a 3000 year ARI event can be safely passed without effecting the mine site or adjacent tenements.

- convey the 50 year ARI flow in Spring Creek, from the south western boundary of the mine to the confluence with the Lagoon Creek. As for Sandy Creek, levees are provided to ensure that a 3000 year ARI event can be safely passed.

- provide mine pits and infrastructure with the required protection and freeboard for the 3000 year ARI flood event within the creeks.

- along the northern and southern MLA boundary, ensure that a sufficiently wide corridor is provided to ensure stability of the diversion channel and associated levees. Currently a 240 m wide corridor is provided between the MLA boundary and the (top of) highwall, which incorporates a 90 m -110 m width between the toe of the mine-side levee and the highwall. If ongoing geotechnical investigations determine that this corridor needs widening, to ensure the stability of the highwall, diversions and levees is not compromised, then the pit strike length will be reduced. The corridor width will not be compromised.

- maintain an average velocity of less than 2.5 m/s within the high flow channel for the 50 year ARI event, to mitigate erosion.

- maintain velocities similar to or lower than those determined in the existing active channel for the existing (base case) where these are significantly higher that the maximum allowable velocities in the *Central West Water Management and Use Regional Guideline: Watercourse Diversions – Central Queensland Mining Industry* (Queensland Department of Natural Resources and Mines).

- be located wholly within MLA 70426, and be able to be sequenced within the overall mine plan.

6. Permanent diversion feasibility design

6.1 General design features

6.1.1 Typical cross-section

The typical cross section for the diversions is separated into a low flow channel and a high flow channel. The low flow channel (active channel) is sized to nominally contain a 2 year ARI event. It is typically 20 m wide at the base and 1.5 m deep on the main Lagoon Creek. The low flow channel is 8–10 m wide at the base and 1.0 m deep on Sandy Creek (north-western diversion channel) and 7–10 m wide at the base and 1.0 m deep on the Spring Creek diversion (south-western diversion channel) channels. Batter slopes have been nominally set at 1:3 (V:H). The active low flow channel is completely contained within the high flow channel. It ties into the existing natural low flow channel at the start and end of each diversion channel. The high flow channel is sized to contain a 50 year ARI event. Details of the creeks, including dimensions and water depths are provided in the Flooding Technical Report in Volume 5, Appendix F of the EIS. Typical cross sections for the various diversion channels are included in Appendix D.

The approach to the cross sections for Lagoon Creek diverted active flow channel slightly differs from the western diversions, in that the upstream and downstream bed levels are set by the existing channel and the diversion depth is controlled by the floodplain ground level. Consequently at low lying locations the channel is limited to the 2 year ARI capacity or less, while at other locations it may meet capacities equivalent to the 50 year ARI event.

It is proposed to rehabilitate the Project with native grasses, locally occurring (endemic) trees and shrub species to protect against erosion and manage sediment control. For further discussion on the proposed revegetation of the landscape, see Section 6.5.

6.1.2 Horizontal alignment

Low flow channel

The low flow channel is generally accommodated within the ‘active channel’. However, for the purpose of this document the terms active and low flow channels are interchangeable.

As part of the proposed design, the low flow channel is recommended to meander within the high flow channel. This will improve the geomorphic characteristics of the diversions. In Lagoon Creek, the meanders were originally assessed based on calculated wavelength, amplitude and radius. This however resulted in an unnatural looking channel with over intensive meandering. For the SEIS the design was determined visually by replicating the existing meander shape and intensity, and by observing topography. The resulting hydraulic modelling has shown the adopted approach to be favourable. Minor meanders have been introduced in the other diversion channels as shown on the plans, with emphasis on meandering in areas where velocities and gradients are likely to be higher. Hydraulic modelling has adopted increased roughness values in these areas to reflect the additional meandering in the channel.

To ensure the meanders are stable in the diversion channels, a minimum offset of 9.5 m between the top of the active channel batter and the toe of the high flow channel batter should be maintained. The parameters (wavelength, radius, amplitude and minimum offset) were determined using equations and graphs developed by Langbein and Leopold, 1966) and Julien (1985). The active channel should be trapezoidal, with varying base widths, batters of 1:3 (v:h), a total depth of approximately 1.0–1.5 m, and lined with clay material in some sections of the creek to provide a low permeability layer. Other than the floor of the active channel, the creek diversions should be covered with topsoil and appropriately vegetated. All the above proposed parameters will be reviewed after detailed assessment of existing streams.

High flow channel

The high flow channel (designed for flood events from a 2 year ARI event to a 50 year ARI event) will also be trapezoidal with base width of 10–240 m and batters of 1: 3 (v:h). The active channel will meander within the base alignment of the high flow channel.

While the designed profile is rectangular, it is anticipated that in time the channel will establish its own equilibrium and that the profiles will become more rounded and natural looking. The design cross section is generally generous and has been modelled with a high roughness factor to ensure that any reshaping of the channel does not impact on conveyance capacity of the diversion.

Floodplain

The high flow channel sits in the natural flood plain and is limited by high ground to one side and the flood protection levee to the mine side. For Lagoon Creek, the flood plain area will be maintained as wide as reasonably possible, without affecting the mining processes.

6.1.3 Drainage works

To prevent scour on the batter slopes of the proposed creek diversions, construction of catch/diversion drains parallel to and external to the top of the high flow channel batter will be required in some areas. The catch drains will divert runoff into rock protected batter drains discharging into the high flow channel.

6.1.4 Geotechnical

Geotechnical studies have not been carried out to determine the suitability of in situ material for the proposed diversion design and construction material. The proposed design is based on general assumptions of the likely materials only.

6.1.5 Slope stability

The proposed batter slope of 1:3 (V:H) is considered suitable when excavated in the cohesive soils that are likely to be encountered. These batter slopes are not considered suitable for areas where silty or clayey sands are the dominant soils. The sands, when encountered, are recommended to be cut back at angles anticipated to be no steeper than 1:4 (V:H), over-excavated and sealed with clayey materials to reduce the risk of slope instability and excessive erosion. The exact batter slopes will be determined during detailed design and following extensive geotechnical investigations specific to creek diversion design.

6.2 Conceptual flows for Lagoon, Spring and Sandy Creeks diversions

This section details the feasibility design of the proposed creek diversions. It is proposed to resolve further details of diversion management, including construction staging and long-term monitoring, in a later detailed design phase of the Project implementation.

The geomorphic design was developed from the initial criteria selected as described in the Flooding Technical Report in Volume 5, Appendix F of the EIS.

6.2.1 Conceptual flows design

Feasibility design inflows from the individual sub-catchments for the Lagoon Creek, north western and south western diversion channels were developed for the 2 year, 50 year and 3000 year ARI flood events. The peak sub-catchment inflows for design storm events are listed in Tables 6.1 and 6.2. Figure 1-3 shows the location of sub-catchment flows contributing to the creek diversions (shown as green dots).

Table 6.1 Peak flows for Lagoon Creek diversion channel

ARI	Peak flows into creek diversion (m^3/s)						
	Sub-catchments						
	US	A	B	C	JJ	E	F
2 year	19.7	24.6	23.5	23.0	23.0	29.3	31.8
50 year	408.4	503.5	480.6	469.3	457.0	584.8	629.3
3,000 year	2,029.3	2,428.0	2,342.0	2,295.0	2,247.0	2,947.0	3,240.0

Table 6.2 Peak flows for north western and south western diversion channels

ARI	Peak flows into creek diversion (m^3/s)							
	Sub-catchments							
	J	K	L	M	O	I	Q	R
2 year	1.1	3.0	5.7	11.7	13.6	2.5	4.7	4.9
50 year	8.0	27.6	47.8	244.3	256.9	34.3	95.5	95.1
3,000 year	21.7	80.1	185.5	1,100.0	1,198.0	134.3	389.0	398.7

6.2.2 Permanent diversion design features

The Lagoon Creek active channel diversion has been designed to connect the upstream and downstream active channels, providing a constant slope in between. The channel meanders to extend the length to a reasonable extent, while retaining a natural appearance. The depth of the channel varies, depending on topography and where the flows exceed the channel capacity, these will break out into the floodplain, creating temporary pools, similar to that observed in Murdering Lagoon.

The feasibility design for the two other creek diversions consists of two main diversions designed within the constraints of the present mine plans. The north western diversion, which conveys Sandy Creek and other small watercourses around the north western side of the mine pit, while the south western diversion, conveys Spring Creek around the south western side of the mine pit.

An overview of the feasibility design and channel parameters is presented in Table 6.3. Long and cross section details are provided in Appendix D.

Table 6.3 Overview of creek diversion feasibility design for low and high flows channel

Locations	Depth (m)	Channel gradient (average) (%)	Length (m)	Side slope
Lagoon Creek	varies	0.075	9,600	1:3 (V:H)
NW diversion	3	0.15	11,000 / 25,500	1:3 (V:H)
SW diversion	2.5	0.03	11,200	1:3 (V:H)

Typically, the low flow channel maintains a constant channel gradient as shown in Table 6.3. This low flow channel meanders within the high flow channel to improve the geomorphic characteristics of the diversion. The high flow channel will have varying gradient and width. In the case of the north western and south western diversions, the focus will be to maintain the natural gradient as much as possible. To this end, the meandering will be narrow in areas of a steeper gradient, while meandering will be less intensive in flatter reaches of the diversion channel.

The gradient of both the high and low flow channels will be optimised in the detailed design phase to improve the hydraulic performance in areas where hydraulic modelling has shown that there will be adverse impact on channel stability due to high velocities. It is however recognised that the natural occurrence of scour and deposition will occur in the diversions, although this will primarily be limited to the active channel. As such this channel will at times fill with sand and sediment, and then be flushed out again during the next flow event.

6.2.3 Hydraulic modelling

Hydraulic modelling was used to assess the impact of the proposed Lagoon Creek, North western and South western creek diversions for the 2, 50, 1000 and 3000 year ARI flood events. A detailed description of the hydraulic modelling is provided in Technical Flood Modelling Report.

A one- and two-dimensional unsteady state hydraulic model of combined Sandy Creek catchment, including the Lagoon, Sandy and Spring Creek diversions was developed using the DHI MIKE FLOOD model which integrates the MIKE11 and MIKE21 models into a single, dynamically coupled modelling system. By applying this coupled approach, the best features of the two models were utilised, while at the same time avoiding some limitations that may be encountered when using the components separately. The MIKE FLOOD model is designed to perform one-and two-dimensional unsteady flow river hydraulics computations for a full network of natural and constructed channels. The cross-section geometry point elevations have been extracted from the digital terrain model (DTM) of the Project. Other inputs included the Manning's roughness coefficient (n), turbulence parameters, flow data and model boundary conditions.

MIKE FLOOD modelling was used to design the creek diversion according to the specifications detailed in ACARP (2002). The MIKE FLOOD model boundary conditions detailing the downstream and upstream channel flow characteristics were estimated and entered into the model. Non-uniform flow characteristics were assumed using flow rates for upstream and downstream (gradients were calculated from existing survey data).

The hydraulic model was used to assess the performance and likely success of the proposed diversion alignment and channel features. A summary of model inputs is provided in Table 6.4.

Table 6.4 Model inputs

Parameter	Value
Upstream boundary condition	Peak inflows for 2 year, 50 year, 1000 year and 3,000 year ARI events and normal depths
Channel roughness (Manning's n)	Variable roughness (0.045, 0.035 and 0.045)

Lagoon Creek and the proposed north western and south western creek diversions were modelled for the range of flow events summarised in Table 6.5. In addition to the 2 and 50 year ARI event cases, which are of relevance to the stream morphology, additional ARI events were modelled for the flood assessment (refer Flooding Technical report (Volume 2, Appendix K of the SEIS).

Table 6.5 Ranges of hydraulic parameters for existing and developed case along the Lagoon Creek diversion

ARI		Velocity (m/s)	Shear stress (N/m^2)	Stream Power (N/m.s)
2 year	existing	0.2 – 1.1	50 - 125	-
	developed	0.2 - 0.4	< 62	0 - 0.33
50 year	existing	< 1.4	40 - 72	
	developed	< 1.5	5 - 105	25 - 189

In reviewing the model outputs for hydraulic parameter values for the existing and developed channels, it is noted that the values tend to fluctuate. This is largely due to the fact that the longitudinal profile does not in all cases follow the prevalent active channel (as this is braided and generally not continuous). Typically the lower values may be associated with the flood plain areas and wider pools, while the higher value coincides with the key flow channels. The inflows from the proposed diversions (Spring and Sandy) show a clear increase in hydraulic parameters values at the confluence with Lagoon Creek.

Reviewing the results of the hydraulic modelling (Table 6.5 and Figures B–1 to B–27 in Appendix B), it can be seen that high values for velocity, stream power and shear stress are evident through the existing, naturally steep and confined sections of Lagoon Creek. From Table 6.5, it can be seen that maximum velocities for the 2 year and 50 year ARI events are almost similar for both cases.

Through the transition zone from Murdering Lagoon into the Lagoon Creek where the gradient is almost 1% and the top width extends to approximately 150m for a 2 year ARI flow event, values are generally below the design criteria for diversions. However, peaks in velocity, stream power and shear stress are noted where there is a constriction of flow (<30m top width).

Through the broad unconfined floodplain where the gradient is less than 0.5%, all values for hydraulic parameters of velocity, stream power and shear stress are below the design criteria for diversions.

The upper limits design criteria detailed in the DERM report are detailed in Table 6.6. A summary of the modelling results is presented in Table 6.6 with a comparison against the range of hydraulic parameter values adopted for the 'design criteria' approach. Profiles for each parameter — stream power, velocity and shear stress — for each of the three diversions, are included in Appendix B.

Table 6.6 Upper values of hydraulic parameters for creek diversions (Developed)

Parameters	Units	Diversion criteria (ACARP)	Creek diversion		
			Lagoon Diversion	Sandy (NW)	Spring (SW)
2 year ARI stream power	N/m.s	< 60	0.4	0.2	1.0
50 year ARI stream power	N/m.s	< 220	200	48	205
2 year ARI velocity	m/s	< 1.5	1.40	0.14	0.43
50 year ARI velocity	m/s	< 2.5	2.5	2.8	3.4
2 year ARI shear stress	N/m^2	< 40	380	1.2	2.6
50 year ARI shear stress	N/m^2	< 80	180	180	280

Table 6.6 and the graphs contained in Appendix B, demonstrates that generally the design parameter values for the 2 year ARI event are below the ACARP guidelines. This is due to the small flows and relatively high roughness. Spiking of values are due to tributary inflows into the system. The 50 year ARI parameters demonstrate high values due to the high flow volumes and channel shape. Increased roughness of the channel and introduction of localised water holes will improve the hydraulic parameters in the channel and provide long term channel equilibrium. Although some values are above the ACARP guidelines, they are still well below the existing channel parameter values, and therefore under the reference reach design approach, still acceptable.

The hydraulic modelling results for the diversion design in the Alpha Coal Project are as follows:

Lagoon Creek diversion

1. The proposed levee and diversion (Refer Figure B-1, Appendix B) may to some extent affect the flows at the existing natural constriction in the channel where velocities are naturally high. While the developed case velocities do not appear to worsen the conditions throughout the diversion, the detailed design phase will need to confirm that channel stability is not compromised and whether mitigation measures are required. Appropriate solutions to mitigate channel erosion may include a rock ramp or rock filled wire mesh mattresses or boxes (e.g. gabions) to dissipate energy for the 50 year flood events.

2. Design parameters within the diversion channel appear low for the 2 year ARI case. These can be increased by narrowing the lower section of the diversion channel. Alternatively this will be achieved through ongoing sedimentation, where equilibrium will be achieved. Overall the design parameters average out to values within the ACARP guidelines, with some localised variations, which will be absorbed within the channel system (e.g. by the receiving waters downstream).

3. The maximum stream power results are less than the calculated threshold erodibility values using the Annandale methodology (refer Figures B-2 to B9, Appendix B)

North Western diversion (Sandy Creek)

1. The velocity, shear stress and stream power for the Sandy Creek and north western diversion (refer Figure B-10, Appendix B) are generally similar to those of the existing Sandy Creek section traversing the MLA, where channels are braided and irregular in shape and nature. Velocities in the 2 year ARI channel are slightly elevated and will be further controlled and reduced using vegetation and rock (to be detailed during the detailed design phase).

2. The velocity, shear stress and stream power values through the downstream reach of the diversion comprising extremely weathered rock, are within those recommended in the DERM guidelines (refer Figures B-11 to B18, Appendix B).

3. The maximum stream power results are less than the calculated threshold erodibility values using the Annandale methodology.

South Western diversion (Spring Creek)

1. The velocity, shear stress and stream power for the Spring Creek (south western) diversion (refer Figure B-19, Appendix B) are generally similar to that of the existing creek reach and are within those recommended in the DERM guidelines for the 2 year ARI flows. The 50 year ARI flows are however significantly larger in volume and generate high design parameter values. This will be mitigated by increasing roughness and providing local pools in the channel. The design parameter values downstream of the confluence with Lagoon Creek remain similar to those of the existing case, although a slight increase in values is evident due to the increased flows contributed by Spring Creek. For longitudinal sections of the water levels, velocities, stream power and shear stress, refer to the Figures in Appendix B.

The values presented in Table 6.6 rely upon establishing vegetation cover on the batters and banks of the diversions and should only be used as a guide to help design and rehabilitate creek diversions in the Project associated catchments. Rock protection will be required for the section of channel where criteria are exceeded. This is discussed further in Section 6.3 Rock Armouring.

The modelling conservatively assumes a low roughness, equivalent to a grassed channel, for the feasibility design. Roughness would be expected to increase as vegetation matures, densities increase and woody debris accumulates.

The diversion channel designs for all three diversions are designed to contain the 3000 year ARI event. Hydraulic modelling predicted a maximum channel depth of 4.0 m for the north western diversion and 3.0 m for the south western diversion (refer drawings in Appendix D).

The creek diversions are designed to require no or minimal ongoing maintenance and modification, achieved through maintaining a constant diversion bed slope and utilising no flow control structures such as drop structures.

The model results for the revised diversion designs indicate that:

- the diversion channel will have a similar hydraulic performance to the existing creek and will convey similarly sized bank-full flood flows

- the diversion channel will be relatively “stable” over the mine life and beyond including for local flood events with no concurrent flooding in the Lagoon Creek
- the channel diversion will be subject to significant erosion or sediment deposition until it reaches dynamic equilibrium; also then the natural sequence of erosion and deposition will be a normal occurrence
- the diversion channel will not result in detrimental impacts to the existing Lagoon Creek upstream of the diversion.

6.3 Rock Armouring

While no structures are anticipated for the diversions, rock armouring may be required to provide bed and bank protection at locations that will become subject to elevated hydraulic stream parameters as may be the case within the lower reach of the Lagoon Creek active channel diversion. Based on the availability of material, it is proposed to use sandstones (subject to strength and durability) to line the channel bed and banks. The design of a sandstone armoured channel essentially replicates them.

The critical rock size (D_{50}) has been preliminary determined through the application of the Riprap software package developed by the CRC for Catchment Hydrology. The software is an Excel based spreadsheet and input parameters include rock density, angle of repose, maximum depth, energy gradient and allowance is also made for a factor of safety (CRC for Catchment Hydrology, 2005).

For this application, a critical rock size (D_{50}) has been estimated for each stream diversion based on a bank slope of 1v:3h (18.5^{o}) and the maximum energy slope for a 1000 year ARI of 0.7%. Input and output Tables are provided in Appendix C.

The rock has a D_{50} of 370mm and a minimum design thickness of 740 mm (2 x D_{50}) for Lagoon Creek Stream Diversion. The finished surface of rock rip-rap is to be flush with the adjacent channel surfaces to minimise the chance of future instabilities developing.

6.4 Construction overview

Fill Material

The diversion corridor will be constructed using a cut/fill balance wherever possible. However, fill material used for the construction of the diversion will need to be a clayey material similar to that of the existing Lagoon, Spring and Sandy Creek. Geotechnical testing of soils will be required to ensure that the material proposed for use satisfies stability and permeability criteria when tested to Australian Standards.

Compaction

The levels of compaction specified for the diversion should be based on existing in-situ densities of Sandy and Lagoon Creeks. Some consideration will need to be given to the effect of compaction on vegetation establishment and ripping may be required following construction.

Settlement

All three diversions are intended to be constructed on natural ground. Therefore no settlement is envisaged. This notwithstanding, the progressively developed drainage channels within the MLA may be influenced by adjacent excavations and fill activity. Regular monitoring of the diversion drains will be undertaken to ensure differential settlement does not initiate major erosion response within the Project site.

Timing of construction

The diversion design in this report is the permanent alignment, which is based on pit and dump outlines in the proposed mine schedule. Temporary in-pit diversions will also be required while the pit is progressing and the dump rehabilitated for diversion construction.

The temporary diversions have not yet been designed.

6.5 Revegetation and habitat enhancement

The establishment of riparian vegetation should be a key component of all waterway diversions. Riparian vegetation plays an integral role in creating and maintaining the stability of newly constructed channels and in providing habitat. There is always a risk that a large flow event, in excess of the design storm event could occur in the diversion before riparian vegetation has become established to the point where it resists large flows. Contingency for maintenance following a large flow event early in the life of a diversion should be considered by mine staff.

Assessment of riparian vegetation will be undertaken as part of the detailed design to provide a basis for developing the detailed revegetation plan. Revegetation will include the use of a mixture of locally indigenous groundcover, shrubs and over storey species and, if available, the introduction of woody debris for additional habitat once the vegetation has established.

6.6 Potential creek diversion impacts and mitigation measures

The impacts of the proposed Project on the geomorphic characteristics of the waterways are discussed throughout the assessment and summarised in this section. The main impacts on the geomorphic characteristics of the waterways are:

- changes in the character of watercourses contributing to Lagoon Creek
- permanent creek diversions
- water and sediment management infrastructure for the mine site
- changes to downstream flow regimes.

6.6.1 Change in character of watercourses contributing to Lagoon Creek

The geomorphic characteristics, and hence the flow characteristics of the waterways in the Project area, have been discussed through the assessment. They are dominated by valley fill sediments and watercourses with continuous channels that are efficient conveyors of flows when intact. Land use has directly or indirectly channelised some of these valley fills, increasing conveyance efficiency.

The mining operation would alter the majority of the watercourses on site. In general, the second and third order watercourses would be replaced with dump runoff or constructed drains. With permanent diversions in place, it is unlikely the broad valley fills would be replicated on site. It is more likely they would be replaced with drains confined by levees, roads, dumps and natural gradients. These will potentially create higher peak runoff to downstream reaches.

To mitigate this impact during mining operations, it is intended that mining affected runoff will be captured in sediment runoff control dams to allow for controlled release and reduced sediment exports.

6.6.2 Permanent diversion of Lagoon, Spring and Sandy Creeks

Parts of Lagoon, Spring and Sandy Creeks would be diverted permanently around the mine pit. The diversions are designed to provide locally occurring geomorphic characteristics and to meet criteria adopted by DERM for creek diversions. Riparian vegetation is vital to maintaining these values. A revegetation plan will be developed during the detailed design phase for the diversion to suit the physical characteristics and requisite environmental values of the waterway.

Further analysis and risk assessment during detailed design will determine the necessity, degree and timing for establishment of vegetation along the diversion. Ground cover should be established as a minimum. Using existing topsoil material from Lagoon and Sandy Creeks, which may contain seed stock, as the topsoil in the diversion should also improve the likelihood of success. It is recognised that limited quantities of quality topsoil is available on site.

Throughout the design and construction of the Lagoon Creek diversion, it is important to ensure that levels are adopted that will encourage flow dispersion. The diversion will in part be constructed from engineered soils forming the levee. The capacity of the diversion corridor has been designed to convey the 3000 year ARI flood event.

6.6.3 Role of sediment runoff capture dams

Runoff from mining affected areas on the MLA area will report to a network of Sediment Dams. The Sediment Dams receive water from overburden dump areas, which are most likely not contaminated but are prone to sediment runoff. The site water management requires that water from these areas is temporarily stored, sediment settled out and then preferentially reused on site (refer to the Site Water Management System and Water Balance Technical Report (Volume 2, Appendix L of the SEIS).

7. Diversion monitoring

A monitoring program is an essential component of the complete design and construction process for creek diversions and is required as part of the regulatory process. The recommended monitoring program for Sandy, Spring and Lagoon Creeks Diversion is based upon the 'Monitoring and Evaluation Program for Bowen Basin Diversions' (ID&A, 2000) undertaken for the Australian Coal Association Research Program.

The total monitoring package for the diversions through their lifetime from pre-construction to licence relinquishment comprises four components as shown in Table 7.1. The aim is for the diversions to be considered as a reach or stream operating in dynamic equilibrium in order to achieve diversion license relinquishment. Application for diversion license relinquishment will occur 30 years after flow is diverted.

Table 7.1 Diversion monitoring package components

Monitoring package components	Objective
Baseline monitoring	To establish a baseline data set that can be used for comparison when applying for licence renewal and relinquishment. This occurs one year before construction and is to establish data that be used for comparison to assess the performance of the diversion
Construction monitoring	To demonstrate works have been undertaken to specification.
Operations monitoring	To monitor and evaluate the diversion's performance to ensure it is operating in dynamic equilibrium. Occurs for ten years after construction.
Relinquishment monitoring	To attain licence relinquishment by demonstrating the diversion is operating in dynamic equilibrium and not adversely impacting on adjoining reaches. Occurs ten years after operations, preceding application for relinquishment.

These monitoring packages are described in more detail below.

7.1 Baseline monitoring

Baseline monitoring should be undertaken prior to construction. The purpose of this stage is to establish a baseline data set that can be used for evaluating diversion performance during operation and relinquishment monitoring.

Index of Diversion Condition

Index of Diversion Condition (IDC) is a method of recording and monitoring the condition of diversions and the adjacent upstream and downstream reaches. It was developed for diversions as part of the ACARP program 'Monitoring and Evaluation Program for Bowen Basin Diversions' (ID&A 2000). IDC provides a rapid assessment of the condition of diversions and adjoining stream reaches.

The purpose of the IDC is to flag potential management issues rather than provide a scientific assessment of a diversion or stream. It is an integrated suite of indicators that measures the geomorphic and riparian condition of a diversion and its upstream control and downstream reaches.

For the Baseline Monitoring Report, the upstream and downstream reaches are surveyed for the IDC. Within each reach, four transects, spaced reasonably evenly apart, and are used to calculate the IDC. The indicators for the geomorphic index and riparian index are then assessed within each transect. The indicators for the geomorphic index and riparian index are listed below:

Indicators for Geomorphic Index

- width of high flow, flow channel and active channel
- bank condition
- piping of banks
- bed condition
- spoil piles
- recovery
- in-stream structures.

Indicators for Riparian Index

- width of riparian zone
- structural intactness
- regeneration
- longitudinal continuity.

Each indicator is assigned a score at each transect. The average scores for each indicator from the four transects are then used to calculate the overall score for the geomorphic index and riparian index in each reach. The sum of the geomorphic and riparian index is then calculated to determine the score for the IDC.

Location of monitoring points

Within each transect a photo monitoring point is established. Where practical, the photo monitoring points should be established at sites that are judged to be representative of the transect. The location of IDC transects and photo points will be established formally with a steel star picket. The star picket must then be located in the centre lower frame of each photograph for purpose of identification and orientation. Additional upstream and downstream photographs will also be taken from the stream bed adjacent to the star picket.

At each photo point GPS coordinates will be recorded to assist with future location. Details of all photographs will be recorded on a spreadsheet and added to the Monitoring Program Database.

Vegetation

The diversion channels and levees will be revegetated to improve erosion control. Vegetation contributes to erosion control in the following ways:

- roots provide reinforcement and stability to watercourse bed and bank materials
- ground hugging vegetation shields bed and bank materials, providing direct protection from the erosive action of water
- vegetation can considerably reduce water velocity by contributing to the roughness of a watercourse.

The revegetation will consist of two main areas: a Riparian zone and a Terrestrial zone.

The Riparian zone will occupy an area 3 m either side of, and including, the active channel. It will be densely populated with endemic grasses, trees and shrubs. For functional purposes grasses, reeds, rushes, sedges and shrubs will be the focus of revegetation efforts as these have a greater impact on erosion than trees. Faunal habitats will also be constructed in the Riparian zone using hollow logs.

In addition to the Riparian Index assessment, riparian and terrestrial vegetation will be assessed in the upstream and downstream control reaches using detailed site assessment and Regional Ecosystem mapping. This will allow for future comparison with the diverted reach to identify key species absent from the diversion reach, but present in control reach, and to determine the success of the vegetation management plan, which aims to re-create a 'natural' reach of channel that will be sustainable over the long term.

The Terrestrial zone will occupy the remainder of the high flow channel. It will be well grassed and sparsely populated with endemic trees and shrubs. This is consistent with the existing flood plain vegetation.

Areas external to the channels (earthworks not within the Q_{100} inundation area) will be rehabilitated with topsoil and grass seeding.

Flow events

Lagoon, Spring and Sandy Creeks is an ungauged catchment and as such no baseline flow data is available. Peak flow rates for 2, 5, 10, 20, 50 and 100 year ARI events were estimated from hydrologic modelling. These events have been modelled as part of the design process for the diversion.

Flow information will be an essential element of monitoring data when assessing monitoring results as part of licence relinquishment for diversions. Installing a station that monitors for both water quantity and quality is recommended.

Summary

All of the information collected from the baseline monitoring is collated into a monitoring database for comparison with future monitoring of the diversions. A summary of the baseline monitoring requirements is provided in Table 7.2.

Table 7.2: Baseline monitoring requirements

Baseline monitoring undertaken	
Index of Diversion Condition	Photographs shall be taken to record the condition of the stream before works are initiated. Photographs shall be taken of the Control reach, the reach to be diverted and the Downstream reach. Photographs are to be taken from fixed points along the Control and Downstream reaches to allow future comparisons. Refer to Appendix C of ACARP (2001) for an aerial photograph showing recommended photo locations and directions. Further details of fixed photo monitoring points are provided in Appendix C of ACARP – 'Monitoring and Evaluation Program for Bowen Basin River Diversions'.
Vegetation	The species, abundance and diversity of vegetation in the reach to be diverted will be recorded before the diversion in conducted. This information will be used for revegetating the new diversion and used for comparison during relinquishment monitoring.
Aerial Photographs	Take aerial photos displaying the existing condition of Lagoon, Spring and Sandy Creeks and also the location of the new diversion before works begin. The scale of the aerial photo should be sufficient to allow accurate measurements of the diversion and adjoining river or creek. Further details of aerial photographs are provided in ACARP (2001).
Flows events	Information regarding the size and frequency of flow events may be assessed by checking debris marks and hydrologic data compiled as part of the engineering design process should there not be a flow gauging station. This will be a key part of DERM's assessment process as to what range of flow the diversion has been subjected to.
Survey	Cross-section and long-section surveys are required for all monitoring reaches. The sections generated should be included as part of the monitoring database and will be used to monitor the performance of the diversions during their operation by comparison with future sections. This will also contribute to relinquishment monitoring.

7.2 Construction monitoring

Construction monitoring should be undertaken during and immediately after construction. The purpose of this stage is to demonstrate that works have been undertaken to specification, which is expected to be a requirement in the licence conditions. Key requirements for construction monitoring are listed in Table 7.3.

Table 7.3: Construction monitoring requirements

Construction monitoring requirements	
Execution outputs	An execution output database should be established to record descriptions of the construction activities completed. The date of activity completion should be noted along with details of any accompanying photographs. Construction activities not completed to specification should be recorded in the database along with an explanation and details of the modified design.
Photographs	It is recommended that photographs are taken during construction/rehabilitation and immediately after the work is finished. Photographs should be taken from fixed photo monitoring points (refer Appendix C of ACARP - 'Monitoring and Evaluation Program for Bowen Basin River Diversions').
Aerial Photographs	If practical, an aerial photo should be taken immediately after diversion construction or rehabilitation has been completed. These photographs would accurately display the extent of change and provide a baseline reference for changes that may occur in the future.
Issued for Construction Drawings	Design drawings issued to the contractor for construction are to be supplied.
As Constructed Drawings	As Constructed Drawings to be supplied upon completion of works.

7.3 Operations monitoring

Operations monitoring is undertaken to ensure if the diversions are operating as expected. This will be quite a sensitive time for the diversions as they are new and have not had time to develop dynamic equilibriums. All of the monitoring results should consider the flow event/s experienced, as any event greater than 10 year ARI may result in large changes to the system. Events in excess of 10 year ARI, will require separate analysis and falls outside the normal scope for diversion monitoring.

In accordance with the ACARP – 'Monitoring and Evaluation Program for Bowen Basin River Diversions', the qualitative monitoring tasks listed in Table 7.4 should be undertaken:

Table 7.4: Operations monitoring requirements

Operations monitoring requirements	
Survival of works	The survival of creeks' structures and works such as riprap and vegetation should be assessed during this phase of monitoring. Early detection of any damage is likely to increase the options for remedial action.
Photographs	Photographs should be taken from fixed photo monitoring points along all of the reaches on an annual basis. Refer to Appendix C of ACARP - 'Monitoring and Evaluation Program for Bowen Basin River Diversions' for more details.
Aerial Photographs	Aerial photographs of the control reaches, diversion reaches and downstream reaches should be taken on an annual basis.
Visual assessment	The control reaches, diversion reaches and downstream reaches should be visually assessed using the IDC, which should be repeated in the following years after construction:

<table>
<tr><td></td><td colspan="2">1st 2nd 5th, 10th, 15th, 20th years and after significant flow events.</td></tr>
<tr><td rowspan="2">Index of Diversion Condition</td><td colspan="2">Inspection would include assessment of:</td></tr>
<tr><td>▪ bank condition
▪ piping
▪ bed condition
▪ recovery
▪ proximity of spoil piles from bank</td><td>▪ stability of creek structures
▪ structural intactness of vegetation
▪ regeneration of vegetation
▪ longitudinal continuity of vegetation</td></tr>
<tr><td>Survey</td><td colspan="2">Longitudinal section and cross section surveys should be conducted in the Control reaches, Diversion reaches and Downstream reaches. These surveys should be repeated every five years or after a major flood event (e.g. 20 year ARI event). Refer to Appendix C of ACARP - ‘Monitoring and Evaluation Program for Bowen Basin River Diversions’ for more details.</td></tr>
<tr><td>Flow events</td><td colspan="2">Flow events shall be monitored to determine the size of events the diversions have carried. Refer to Appendix C of ACARP – ‘Monitoring and Evaluation Program for Bowen Basin River Diversions’ for more details.</td></tr>
</table>

The field data should be transferred into the IDC spreadsheet and added to the database established during baseline monitoring. The data can then be used to assist with comparing any changes.

7.4 Relinquishment monitoring

The objective of this phase is to demonstrate that the diversions are operating as waterways in dynamic equilibrium and not having an adverse impact on adjoining reaches. The key monitoring requirements are listed in table 7.5.

Table 7.5: Relinquishment monitoring requirements

Relinquishment monitoring requirements	
Survey	Long section and cross section surveys should be conducted during the first year of relinquishment monitoring. The surveys should include the Control reaches Diversion reaches and Downstream reaches. Final long section and cross section surveys should be conducted prior to application for licence relinquishment.
Vegetation Assessment	Detailed vegetation assessment should be conducted during the first year of relinquishment monitoring to determine key species absent from the diversion reaches but present in control reaches where this is appropriate. The diversion reaches may therefore have different geomorphic and ecological characteristics than the reaches being replaced.
Photographs	Photographs should be taken from the fixed photo monitoring points in the control, diversion and downstream reaches.
Aerial Photographs	Aerial photos of diversions and controls, diversion and downstream reaches should continue to be taken on an annual basis.
Flow events	Flow events should be monitored to determine the size of events the diversions have been subjected to.

7.5 Data evaluation

Following a comprehensive comparison of monitoring data post construction with the baseline data, an evaluation of the results to distinguish if the diversion can attain a relinquishment licence should be undertaken. It is important that the data compared have occurred during similar flow events, as large flow events will affect data quite dramatically. If it is found the system does not achieved dynamic equilibrium, introduce solutions to rectify the problem. The relinquishment evaluation criteria are listed in Table 7.6.

Table 7.6: Relinquishment monitoring requirements

Relinquishment evaluation requirements	
Survey	Quantitative assessment of data. Assess against flow data and baseline data. This survey should be compared to the 'as constructed' long sections to assess the changes in bed elevation.
Vegetation Assessment	Qualitative assessment of all data. Assess against flow data and baseline data.
Photographs	Qualitative assessment of all data. Assess against flow data and baseline data. Compare visually with previous photographs.
Aerial Photographs	Qualitative assessment of all data. Assess against flow data and baseline data. Compare with previous years to detect changes in vegetation and topography.
Stage 1 Evaluation	Survey data from baseline and operation monitoring should be compared with data from relinquishment monitoring.
Stage 2 evaluation	All data should be evaluated and photographs collated for presentation to regulators. An example of relinquishment monitoring and evaluation is presented in Appendix F of ACARP – 'Monitoring and Evaluation Program for Bowen Basin River Diversions'.

8. References

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Appendix A

Geomorphic assessment site photos

Plate A-1 Lagoon Creek – Looking upstream (23.047S, 146.472 E)

Plate A-2 Lagoon Creek – Looking upstream (23.060 S, 146.503 E)

Plate A-3 Rocky Creek – Looking upstream (23.110 S, 146.444 E)

Plate A-4 View from western creek diversion (23.110 S, 146.451 E)

Plate A-5 View from western creek diversion (23.114 S, 146.483 E)

Plate A-6 Sandy Creek – Looking downstream (23.119 S, 146.503 E)

Plate A-7 Little Creek – Looking downstream (23.126S, 146.447E)

Plate A-8 View from western creek diversion (23.126 S, 146.447 E)

Plate A 9 View from western creek diversion (23.140 S, 146.448 E)

Plate A-10 Sandy Creek – Looking upstream (23.149 S, 146.470 E)

Plate A-11 Sandy Creek – Looking down-stream (23.158 S, 146.439 E)

Plate A-12 Sandy Creek – Looking down stream (23.168 S, 146.437 E)

Plate A-13 Lagoon Creek – Looking upstream (23.172 S, 146.502 E)

Plate A-14 Lagoon Creek – Looking down stream (23.177 S, 146.493 E)

Plate A-15 Lagoon Creek – Looking down-stream (23.194 S, 146.489 E)

Plate A-16 Lagoon Creek – Looking upstream (23.194 S, 146.489 E)

Plate A-17 View from western creek diversion (23.220 S, 146.420 E)

Plate A-18 Lagoon Creek – Looking downstream (23.236 S, 146.499 E)

Plate A-19 Lagoon Creek – Looking down-stream (23.239 S, 146.498 E)

Plate A-22 Lagoon Creek – Bank erosion (23.255 S, 146.495 E)

Plate A-20 Spring Creek – Looking down-stream (23.257 S, 146.454 E)

Plate A-23 Spring Creek – Looking upstream (23.279 S, 146.440 E)

Plate A-21 Lagoon Creek – Looking down-stream (23.255 S, 146.495 E)

Plate A-24 Murdering Lagoon Creek – Looking upstream (23.274 S, 146.493 E)

Plate A-25 Lagoon Creek – Looking downstream (23.281 S, 146.503 E)

Plate A-26 Lagoon Creek – Looking upstream (23.284 S, 146.507 E)

Plate A-27 Lagoon Creek – Looking upstream (23.294 S, 146.504 E)

Plate A-28 Lagoon Creek – Looking downstream (23.304 S, 146.507 E)

Plate A-29 View from southern creek diversion (23.305 S, 146.457 E)

Plate A-30 Lagoon Creek – Looking upstream (23.324 S, 146.495 E)

Plate A-31 Lagoon Creek – Looking downstream (23.324 S, 146.495 E)

Plate A-32 Lagoon Creek – Looking upstream (23.324 S, 146.495 E)

Plate A-33 Lagoon Creek – Looking down-stream (23.324 S, 146.495 E)

Plate A-34 Lagoon Creek – Looking downstream (23.324 S, 146.495 E)

Appendix B

Stream Diversion – Hydraulic Parameters

Figure	Description	
B-1	**Lagoon Creek** - Detailed plan diversion	
B-2	Lagoon Creek - Longitudinal bed / water level Profile for 2 Year ARI	(Exist / Dev'd)
B-3	Lagoon Creek - Longitudinal bed / water level Profile for 50 Year ARI	(Exist / Dev'd)
B-4	Lagoon Creek - Longtitudinal velocity profile for 2 Year ARI	(Exist / Dev'd)
B-5	Lagoon Creek - Longtitudinal velocity profile for 50 Year ARI	(Exist / Dev'd)
B-6	Lagoon Creek - Longtitudinal shear stress profile for 2 Year ARI	(Exist / Dev'd)
B-7	Lagoon Creek - Longtitudinal shear stress profile for 50 Year ARI	(Exist / Dev'd)
B-8	Lagoon Creek - Longtitudinal stream power profile for 2 Year ARI	(Dev'd)
B-9	Lagoon Creek - Longtitudinal stream power profile for 50 Year ARI	(Dev'd)
B-10	**Sandy Creek** - Detailed plan diversion	
B-11	Sandy Creek - Longitudinal bed / water level Profile for 2 Year ARI	(Dev'd)
B-12	Sandy Creek - Longitudinal bed / water level Profile for 50 Year ARI	(Dev'd)
B-13	Sandy Creek - Longtitudinal velocity profile for 2 Year ARI	(Dev'd)
B-14	Sandy Creek - Longtitudinal velocity profile for 50 Year ARI	(Dev'd)
B-15	Sandy Creek - Longtitudinal shear stress profile for 2 Year ARI	(Dev'd)
B-16	Sandy Creek - Longtitudinal shear stress profile for 50 Year ARI	(Dev'd)
B-17	Sandy Creek - Longtitudinal stream power profile for 2 Year ARI	(Dev'd)
B-18	Sandy Creek - Longtitudinal stream power profile for 50 Year ARI	(Dev'd)
B-19	**Spring Creek** - Detailed plan diversion	
B-20	Spring Creek - Longitudinal bed / water level Profile for 2 Year ARI	(Dev'd)
B-21	Spring Creek - Longitudinal bed / water level Profile for 50 Year ARI	(Dev'd)
B-22	Spring Creek - Longtitudinal velocity profile for 2 Year ARI	(Dev'd)
B-23	Spring Creek - Longtitudinal velocity profile for 50 Year ARI	(Dev'd)
B-24	Spring Creek - Longtitudinal shear stress profile for 2 Year ARI	(Dev'd)
B-25	Spring Creek - Longtitudinal shear stress profile for 50 Year ARI	(Dev'd)
B-26	Spring Creek - Longtitudinal stream power profile for 2 Year ARI	(Dev'd)
B-27	Spring Creek - Longtitudinal stream power profile for 50 Year ARI	(Dev'd)

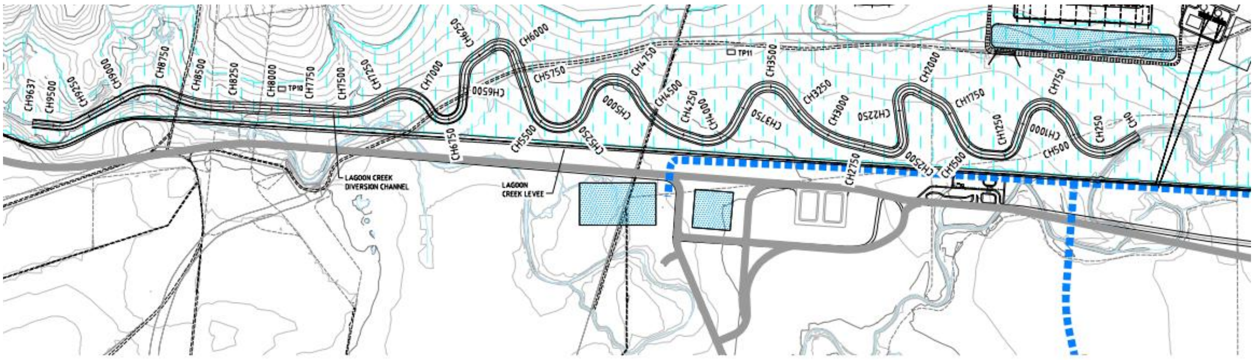


Figure B-1 Lagoon Creek - Detailed plan diversion

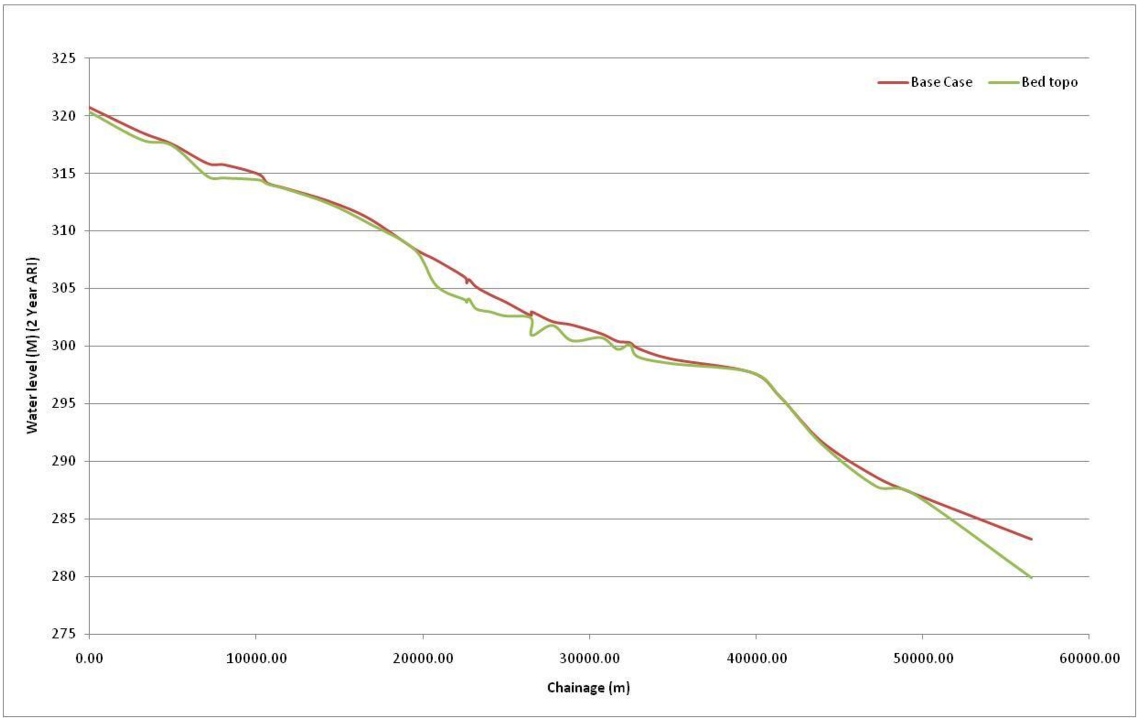
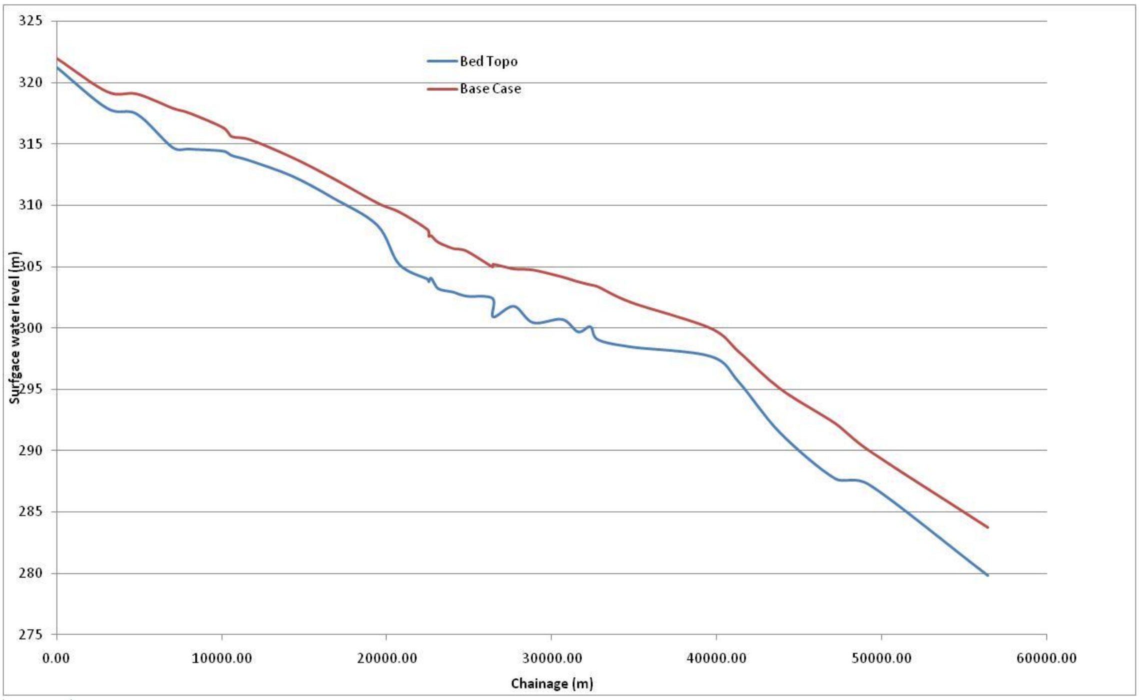


Figure B-2 Lagoon Creek - Longitudinal bed / water level Profile for 2 Year ARI(Exist / Dev'd)



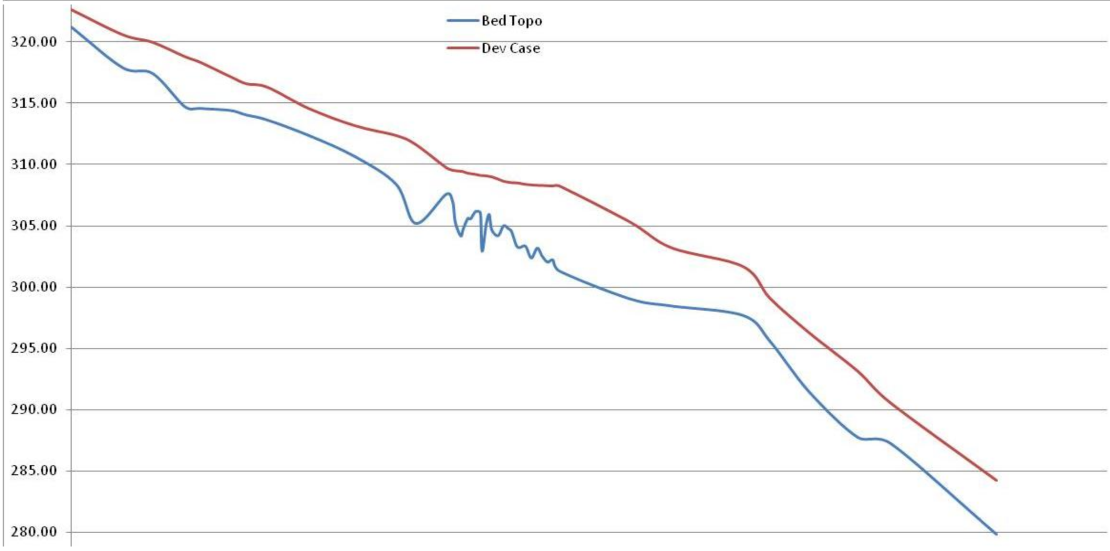


Figure B-3 Lagoon Creek - Longitudinal bed / water level Profile for 50 Year ARI (Exist / Dev'd)

Note that Figures B4 to B9 reflect the existing and developed case profiles with the existing case profile length shrunk to provide the same length. The chainages are of a linear profile through the flood plain (not necessarily following the active channel), which causes occasional spikes in values rather than gradual rising and falling profiles.

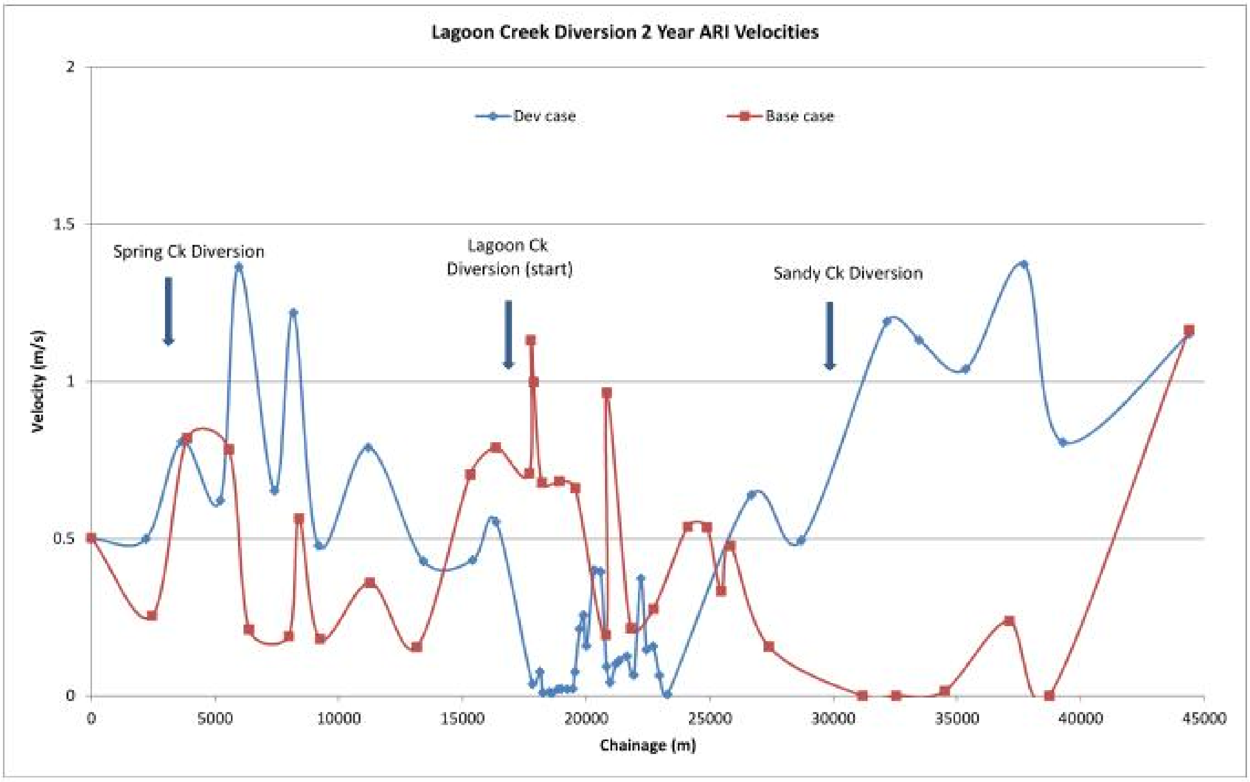


Figure B-4 Lagoon Creek - Longitudinal velocity profile for 2 Year ARI (Exist / Dev'd)

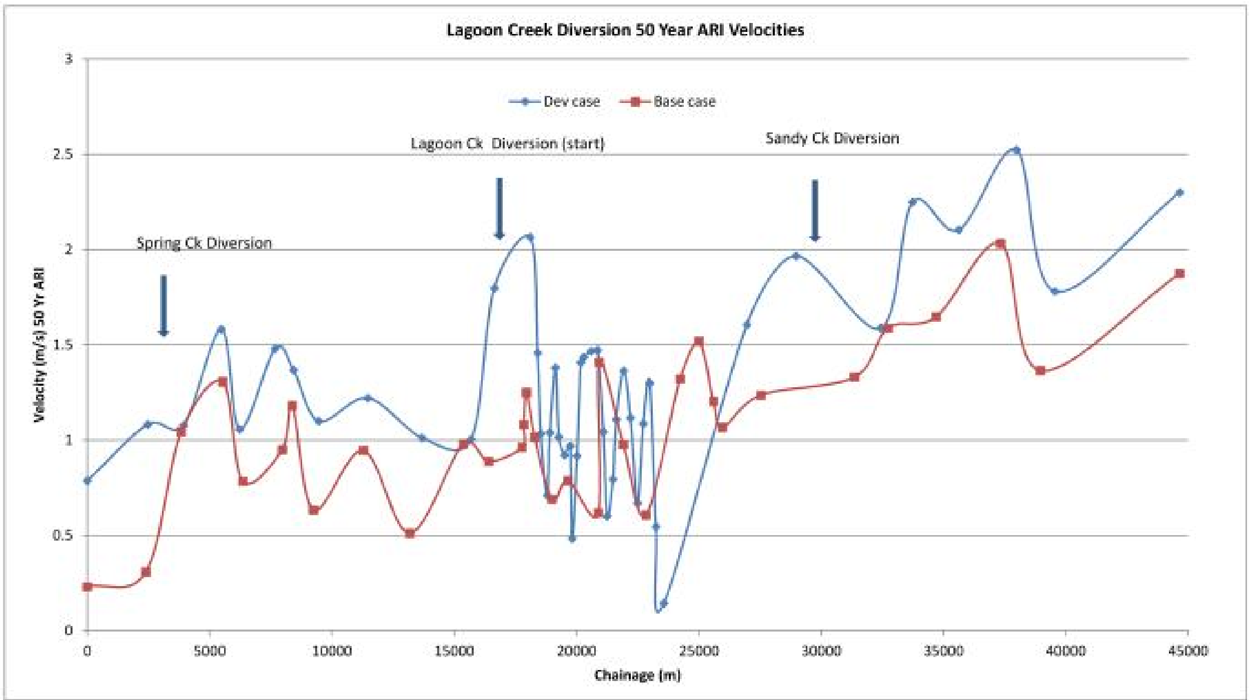


Figure B-5 Lagoon Creek Diversion - Longitudinal velocity profile for 50 Year ARI (Exist / Dev'd)

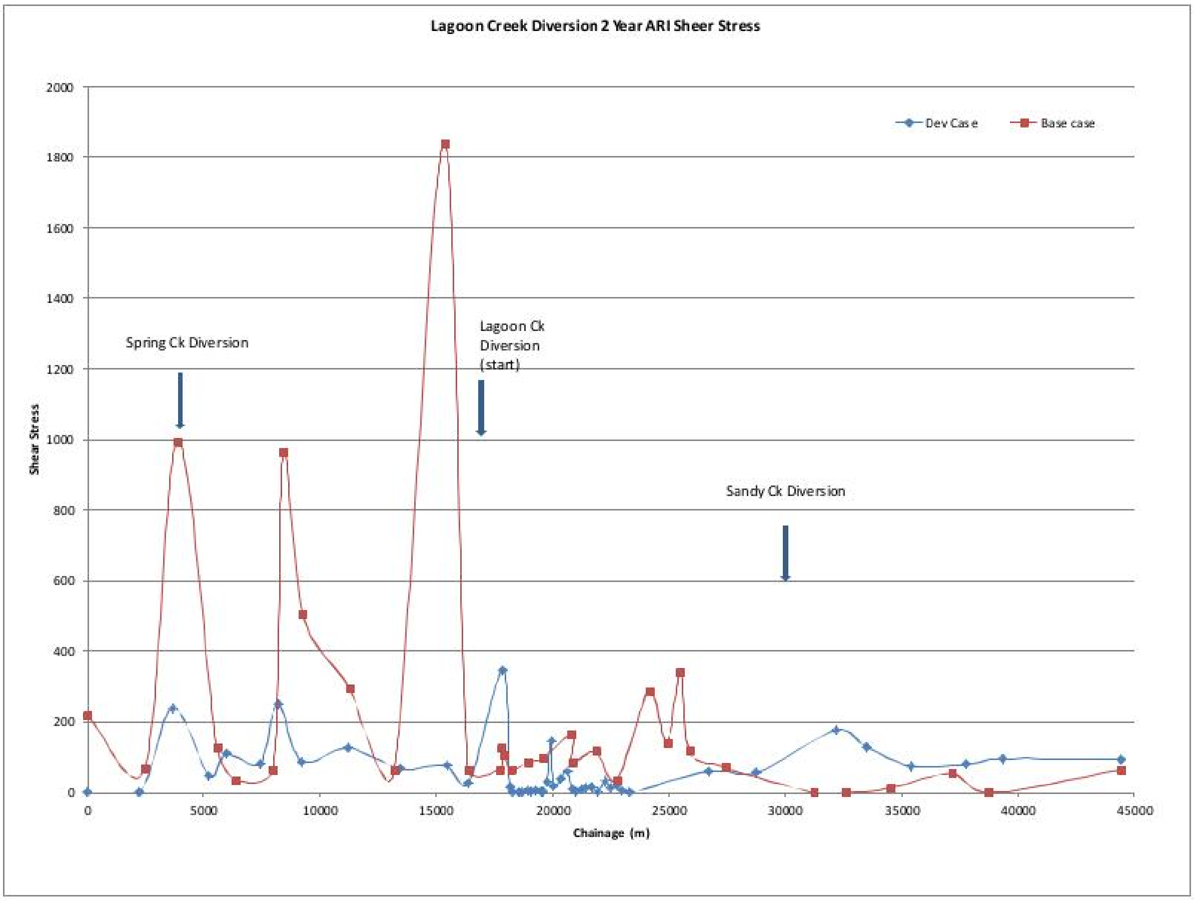


Figure B-6 Lagoon Creek - Longitudinal shear stress profile for 2 Year ARI (Exist / Dev'd)

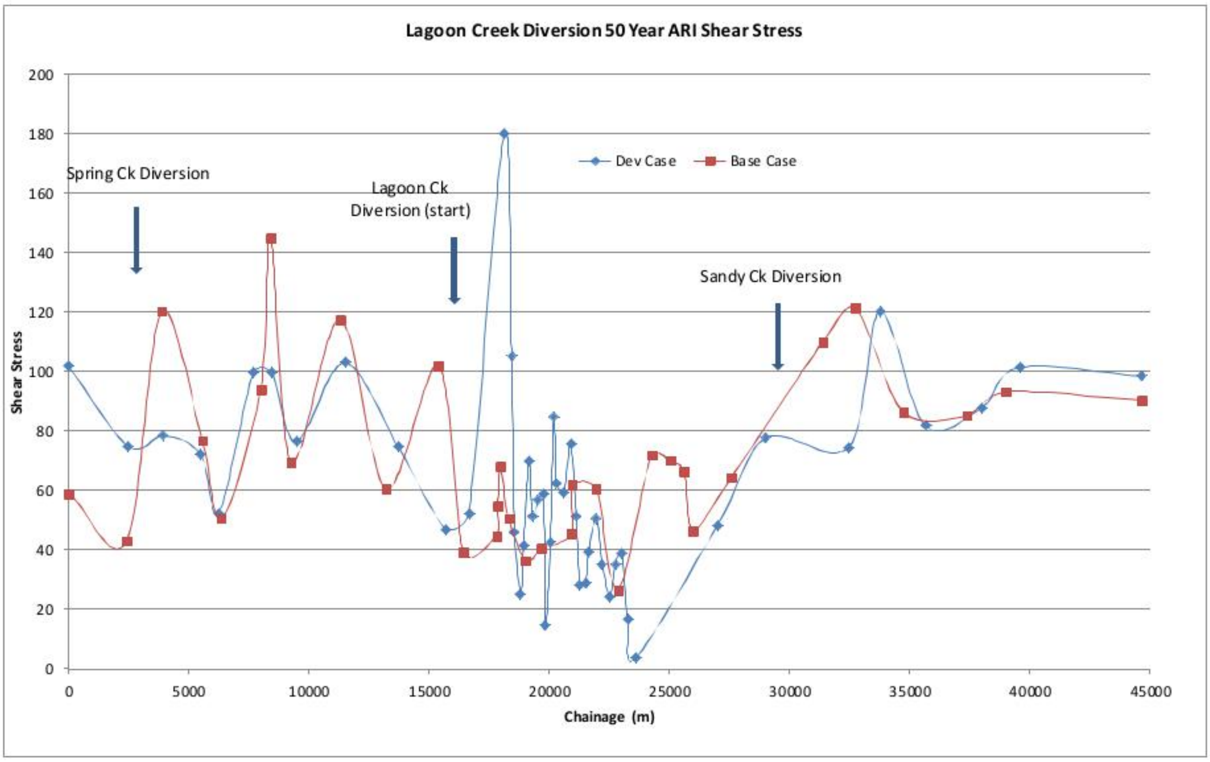


Figure B-7 Lagoon Creek - Longitudinal shear stress profile for 50 Year ARI (Exist / Dev'd)

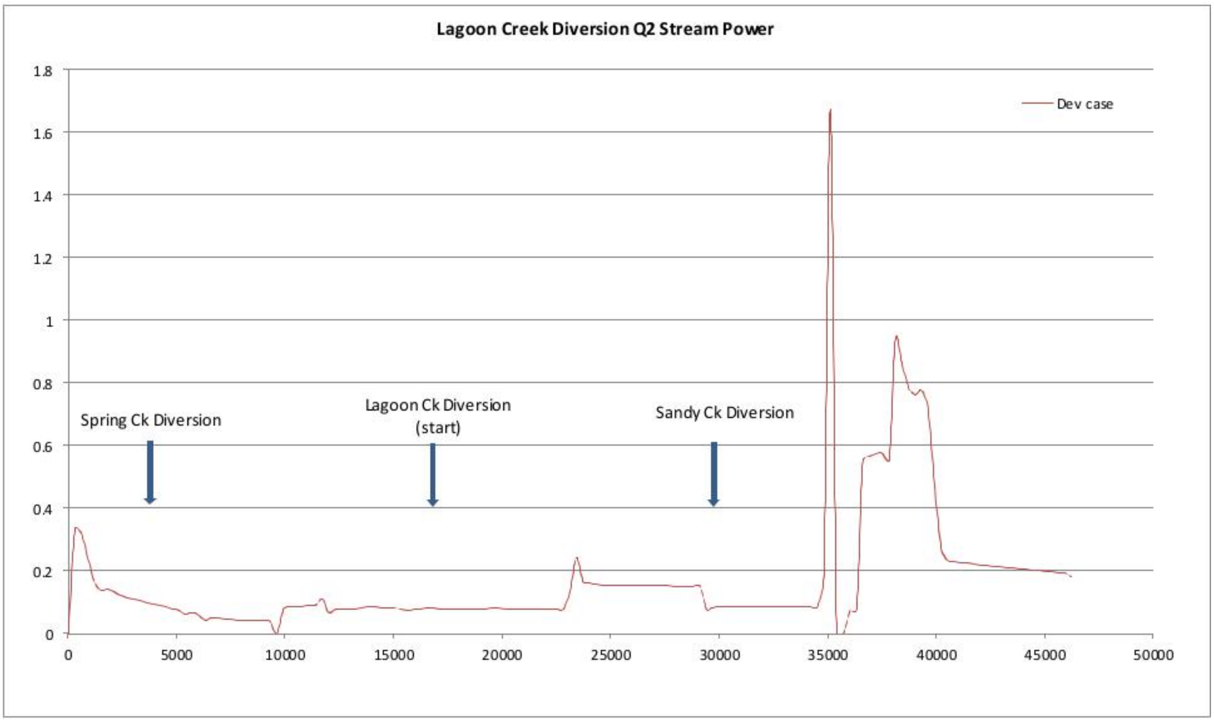


Figure B-8 Lagoon Creek - Longitudinal stream power profile for 2 Year ARI (Dev'd)

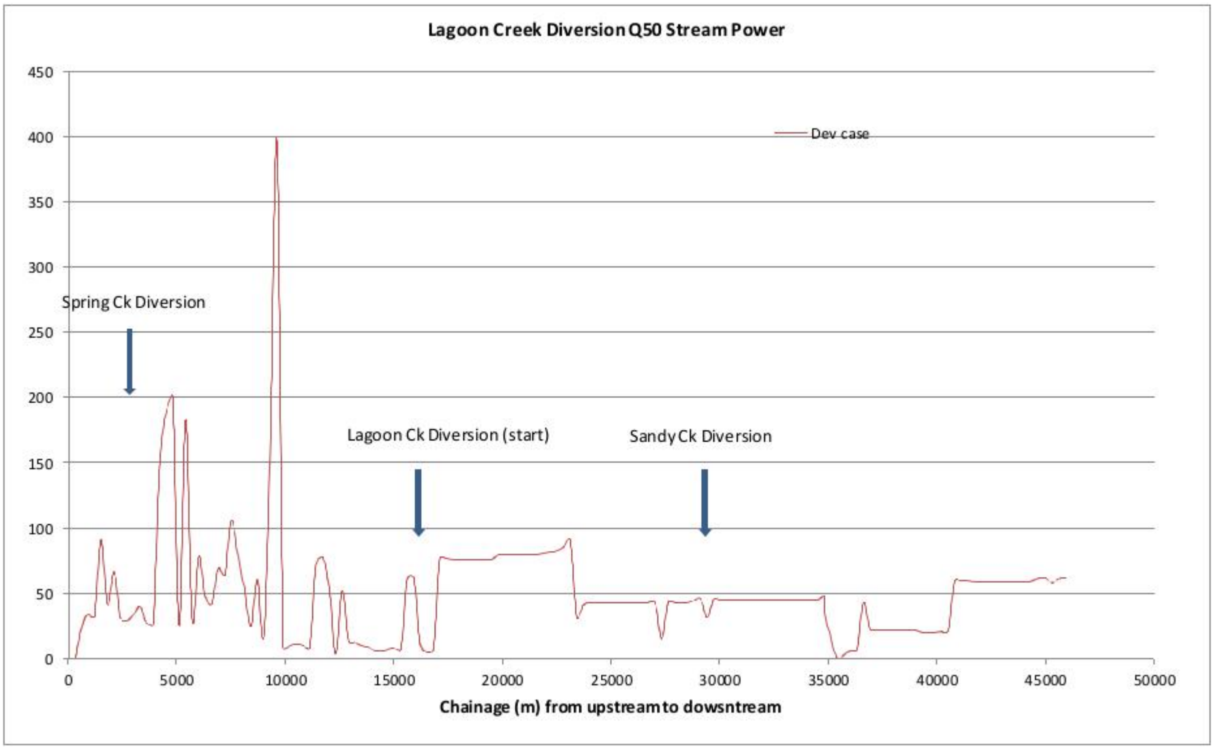


Figure B-9 Lagoon Creek - Longitudinal stream power profile for 50 Year ARI (Dev'd)

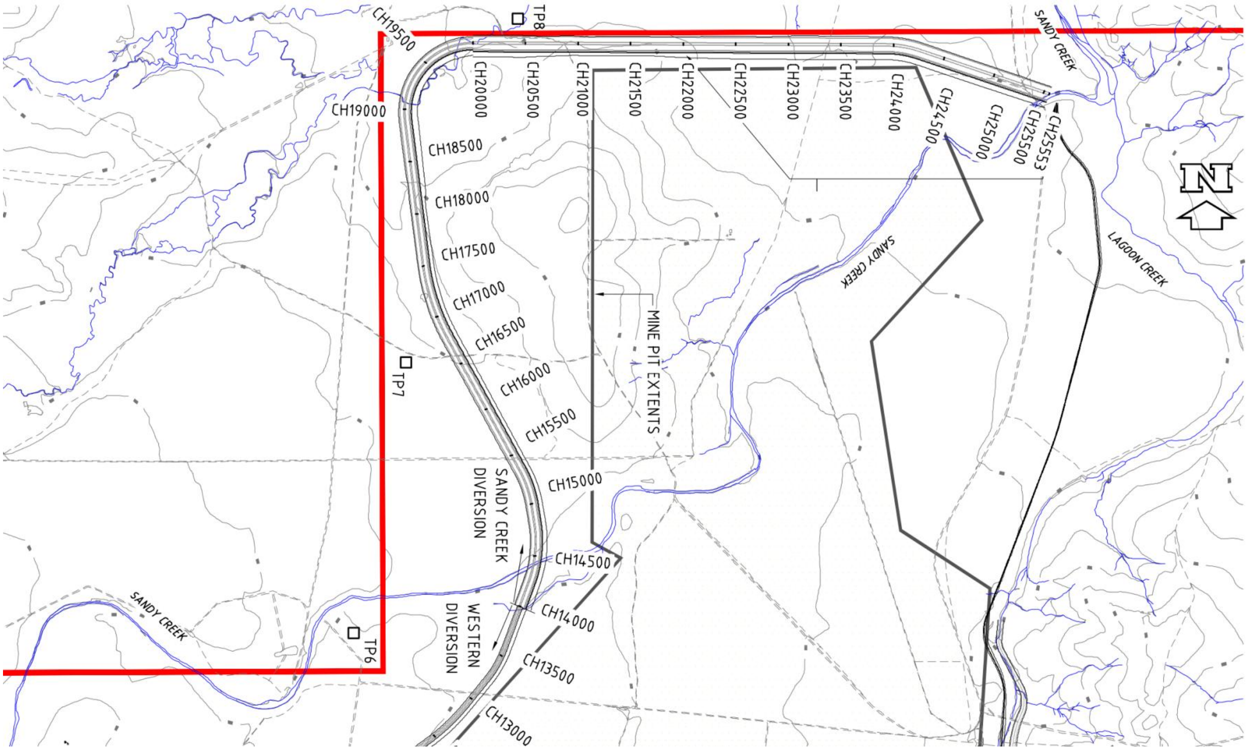


Figure B-10 Sandy Creek - Detailed plan diversion

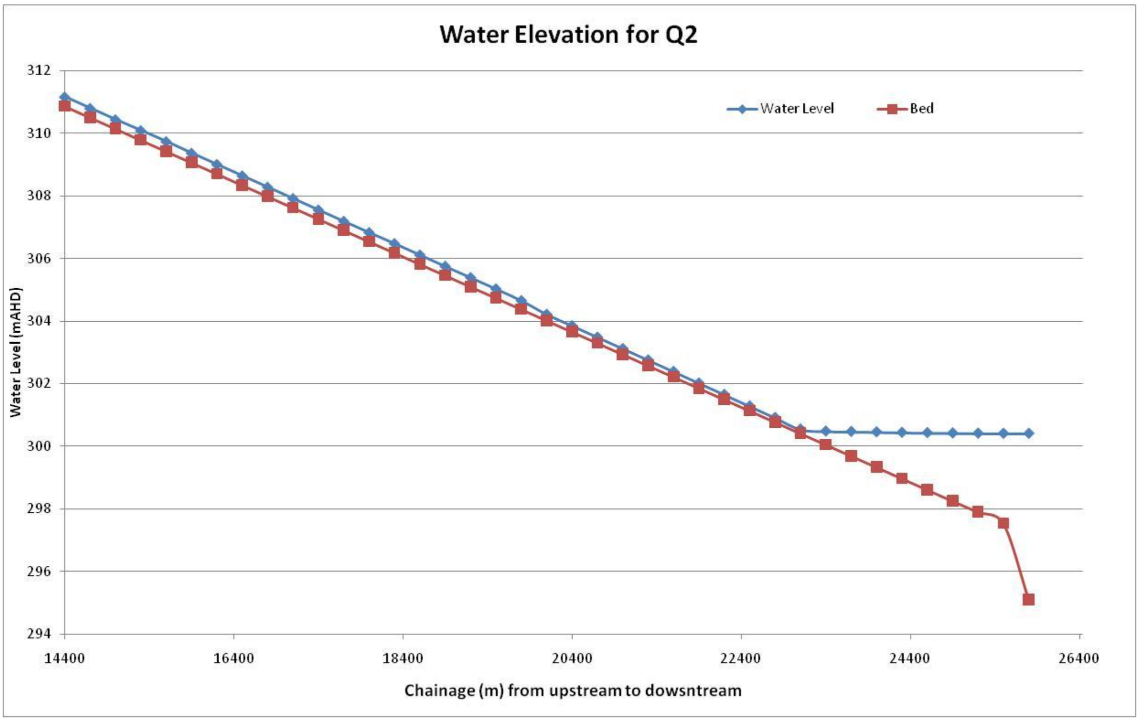


Figure B-11 Sandy Creek - Longitudinal bed / water level Profile for 2 Year ARI (Dev'd)

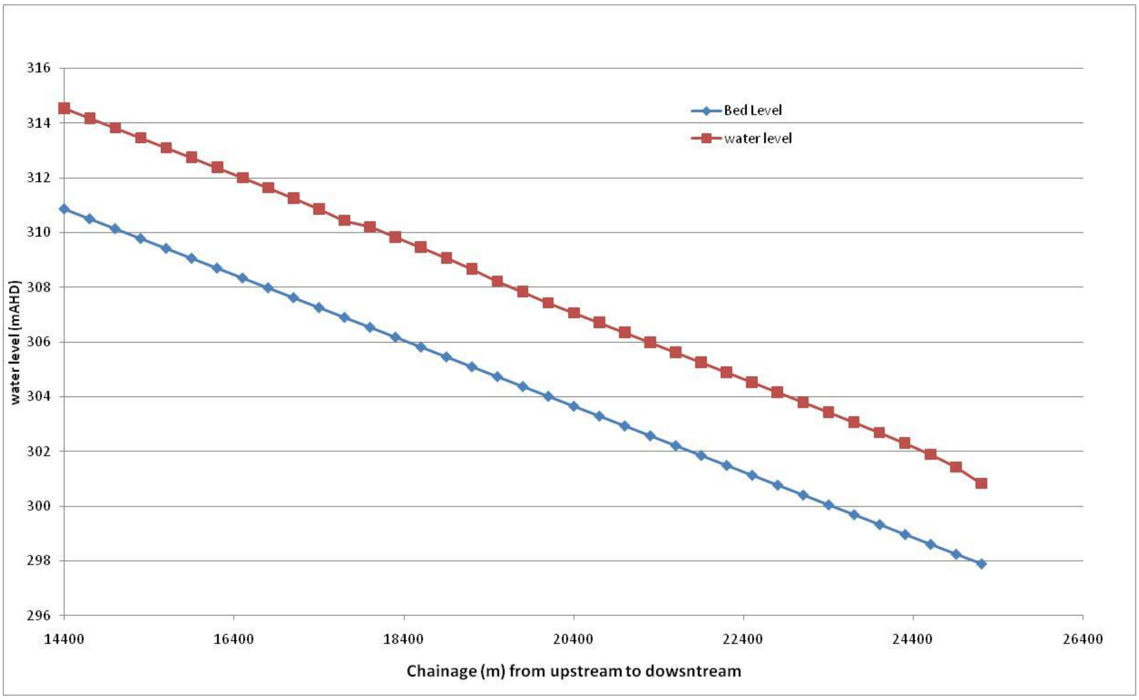


Figure B-12 Sandy Creek - Longitudinal bed / water level Profile for 50 Year ARI (Dev'd)

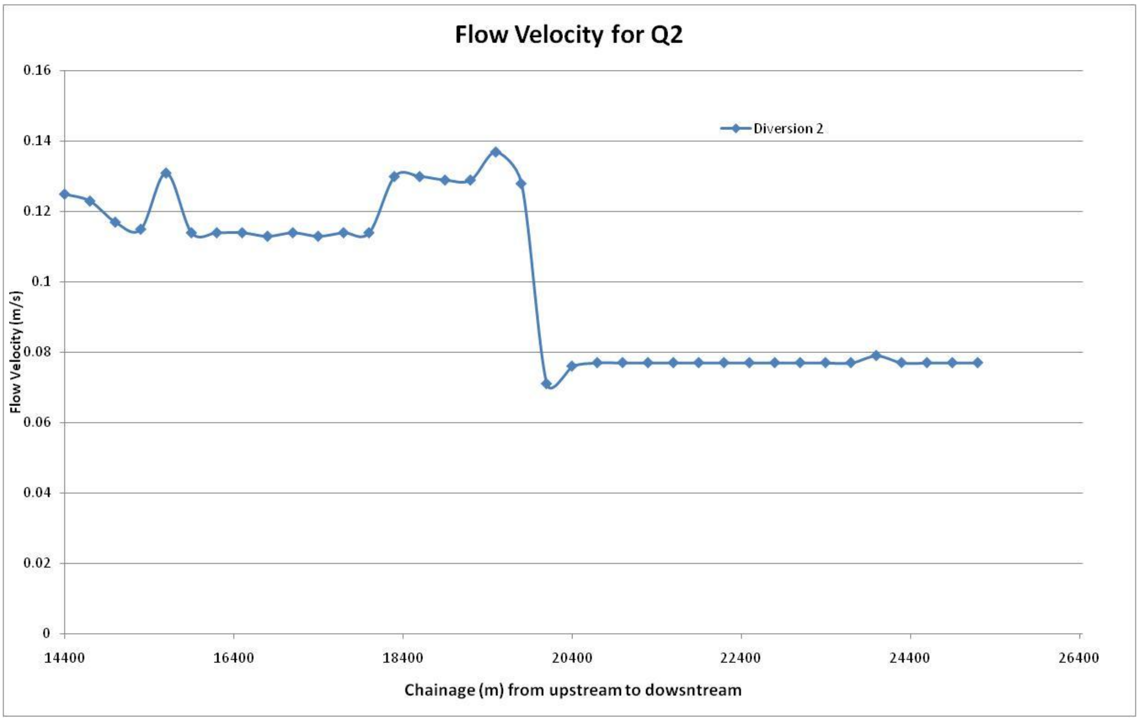


Figure B-13 Sandy Creek - Longitudinal velocity profile for 2 Year ARI (Dev'd)

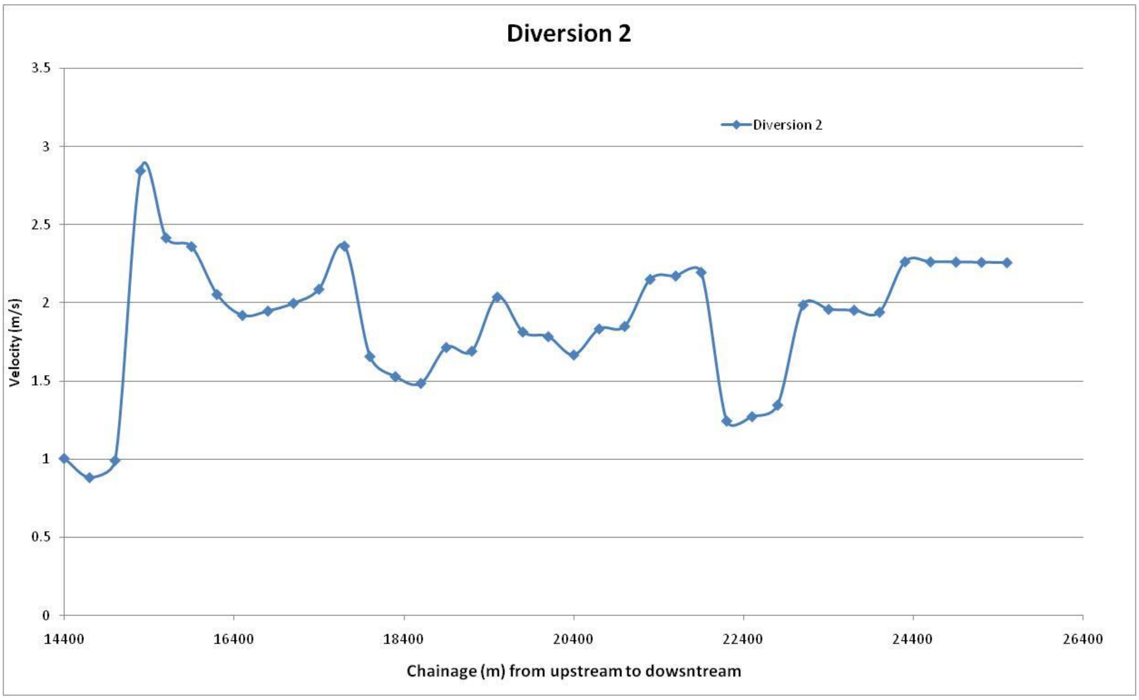


Figure B-14 Sandy Creek - Longitudinal velocity profile for 50 Year ARI (Exist / Dev'd)

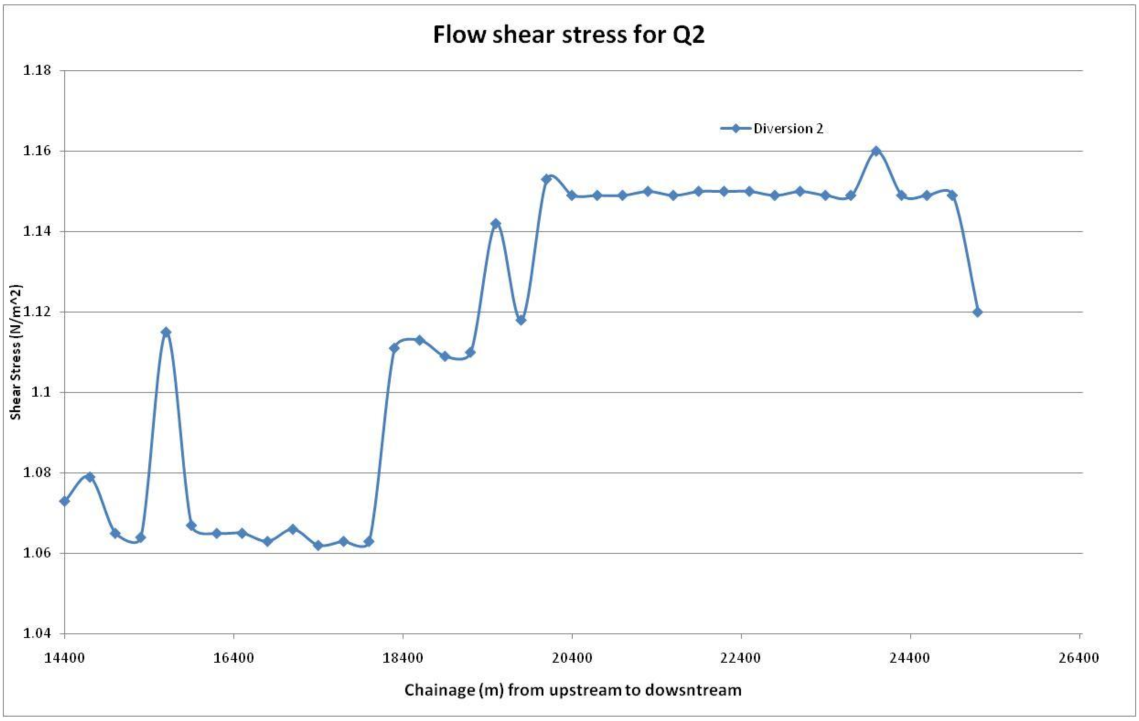


Figure B-15 Sandy Creek - Longitudinal shear stress profile for 2 Year ARI (Dev'd)

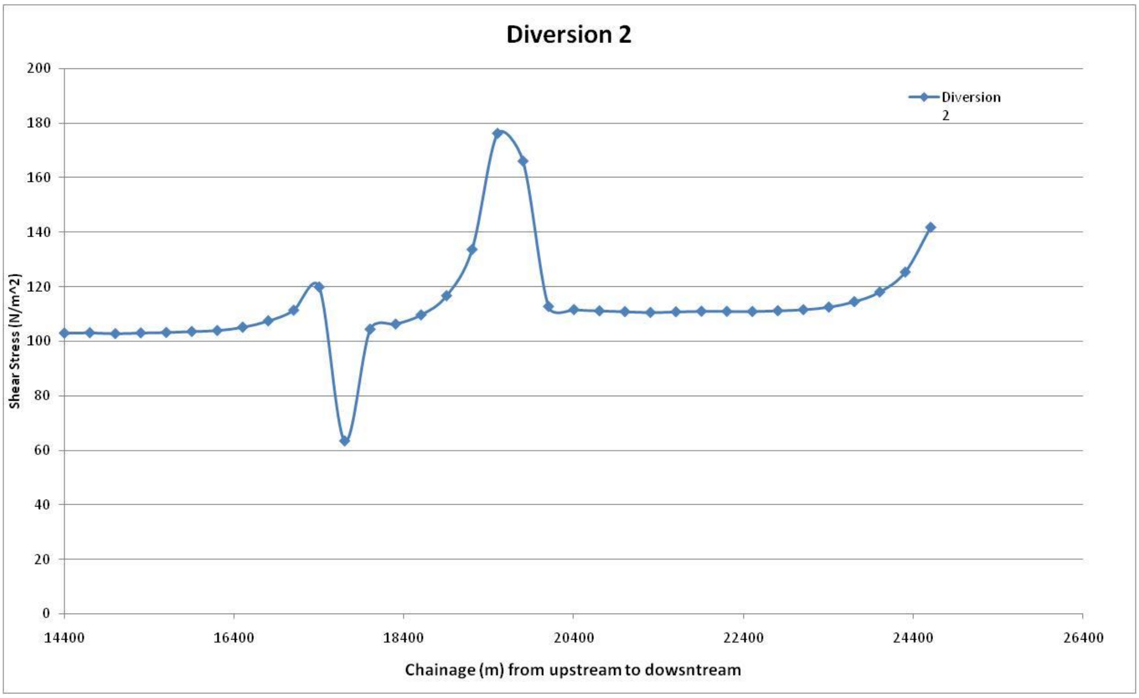


Figure B-16 Sandy Creek - Longitudinal shear stress profile for 50 Year ARI (Dev'd)

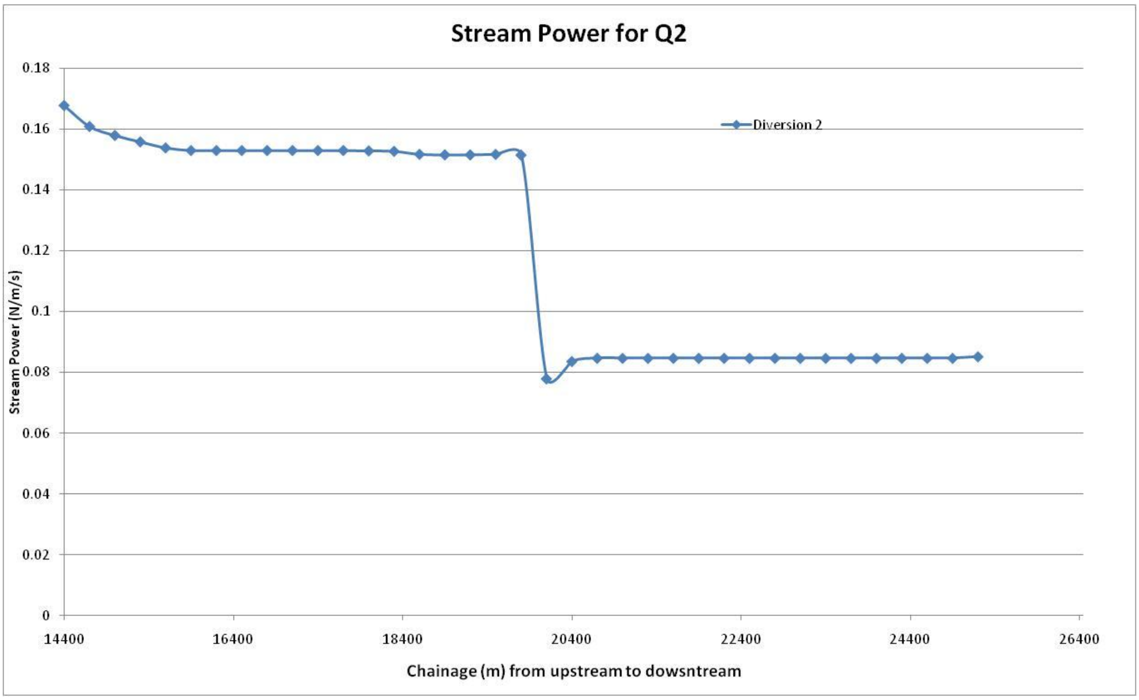


Figure B-17 Sandy Creek - Longitudinal stream power profile for 2 Year ARI (Dev'd)

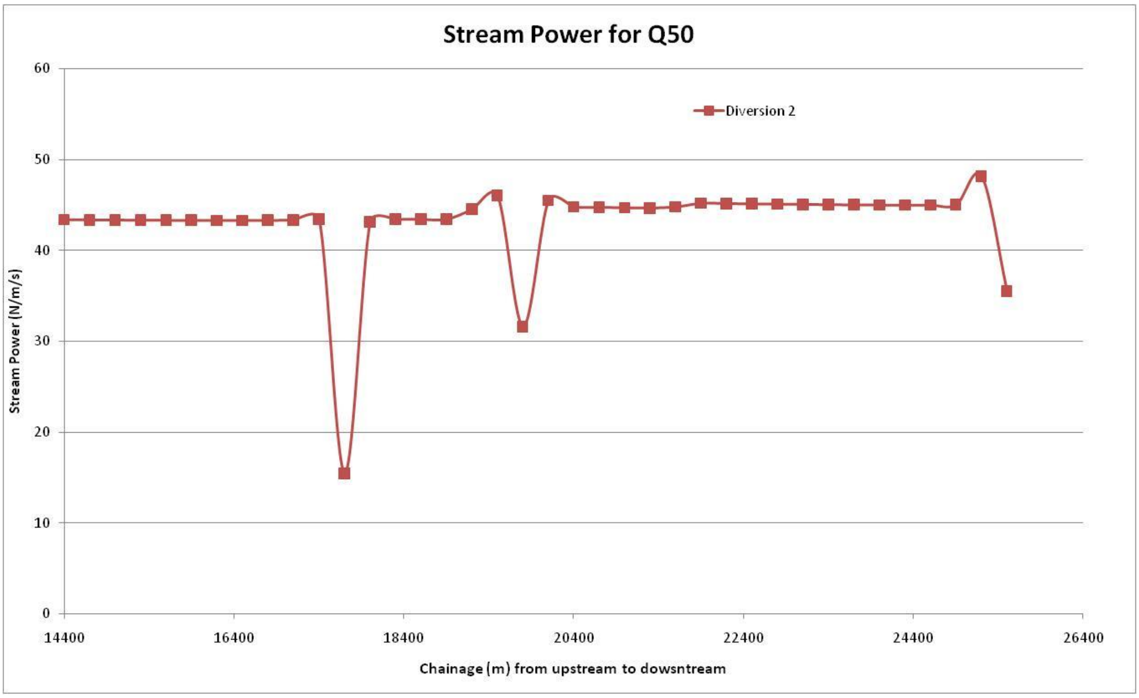


Figure B-18 Sandy Creek - Longitudinal stream power profile for 50 Year ARI (Dev'd)

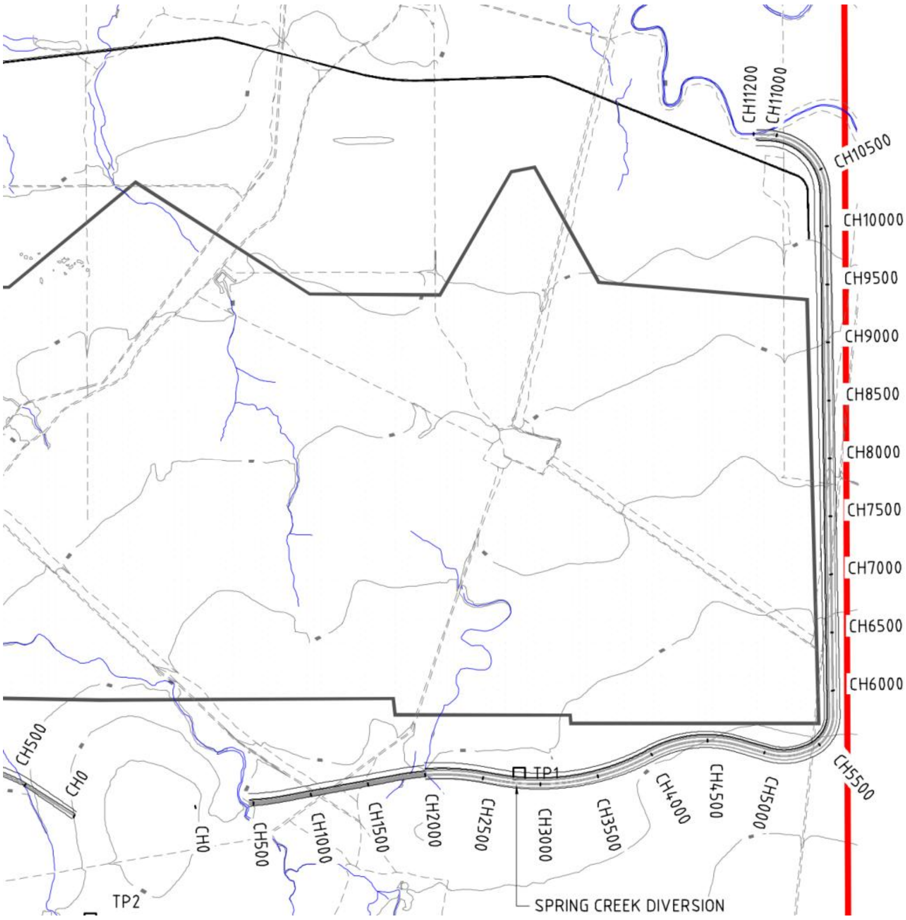


Figure B-19 Spring Creek - Detailed plan diversion

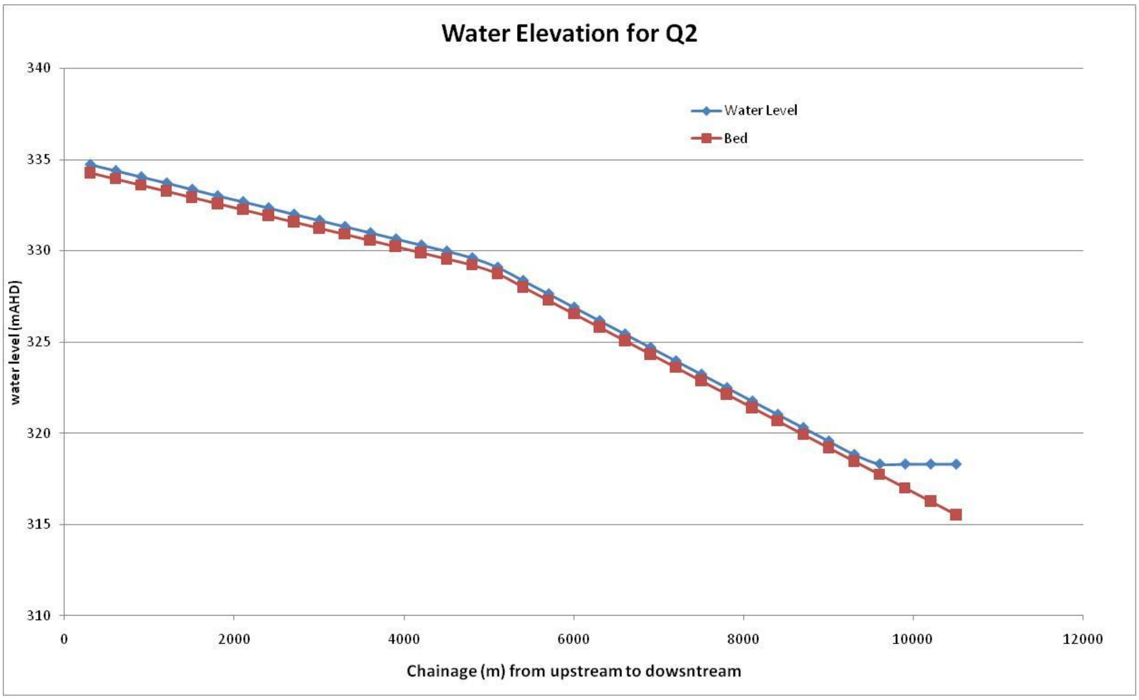


Figure B-20 Spring Creek - Longitudinal bed / water level Profile for 2 Year ARI (Dev'd)

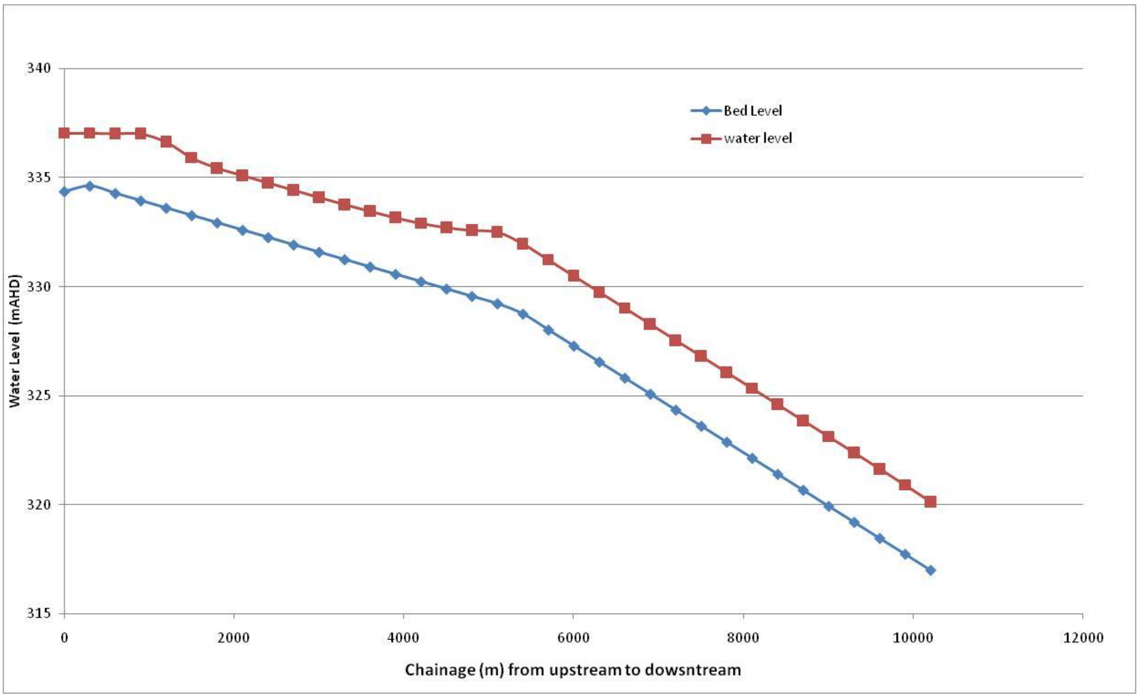


Figure B-21 Spring Creek - Longitudinal bed / water level Profile for 50 Year ARI (Dev'd)

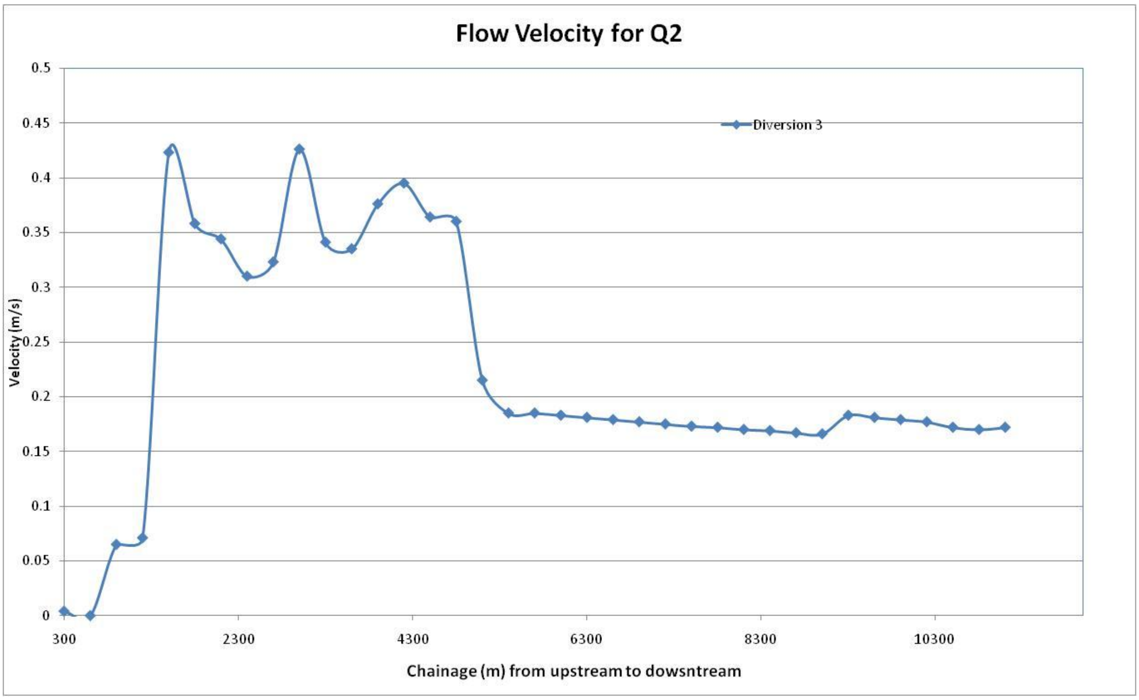


Figure B-22 Spring Creek - Longitudinal velocity profile for 2 Year ARI (Dev'd)

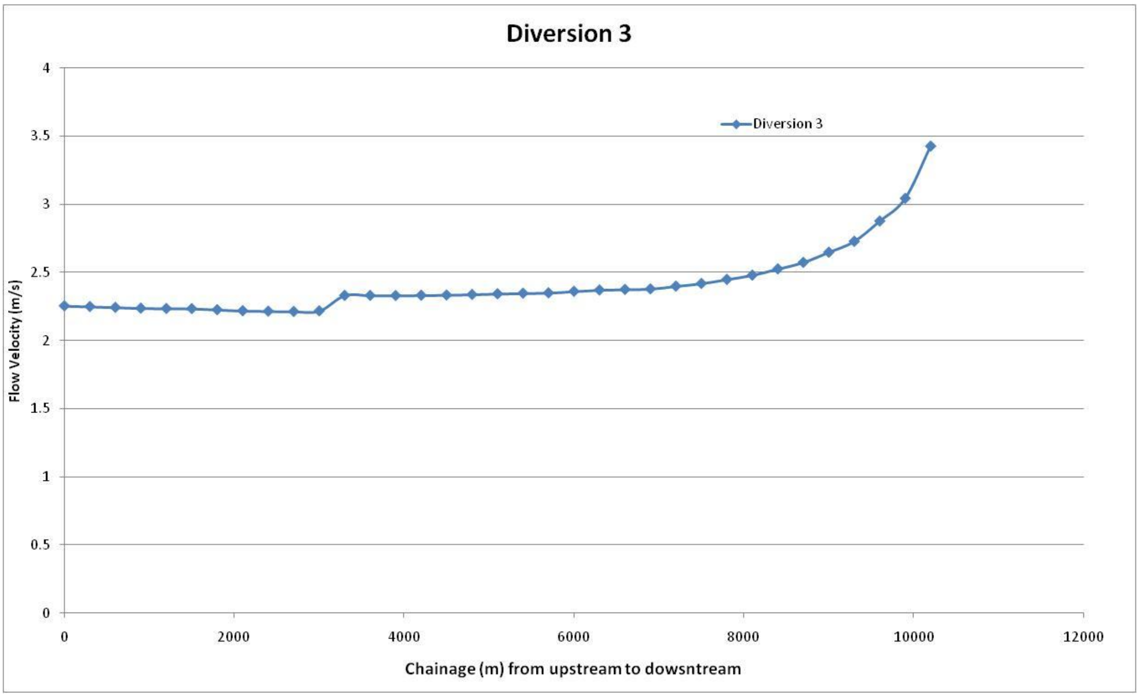


Figure B-23 Spring Creek - Longitudinal velocity profile for 50 Year ARI (Dev'd)

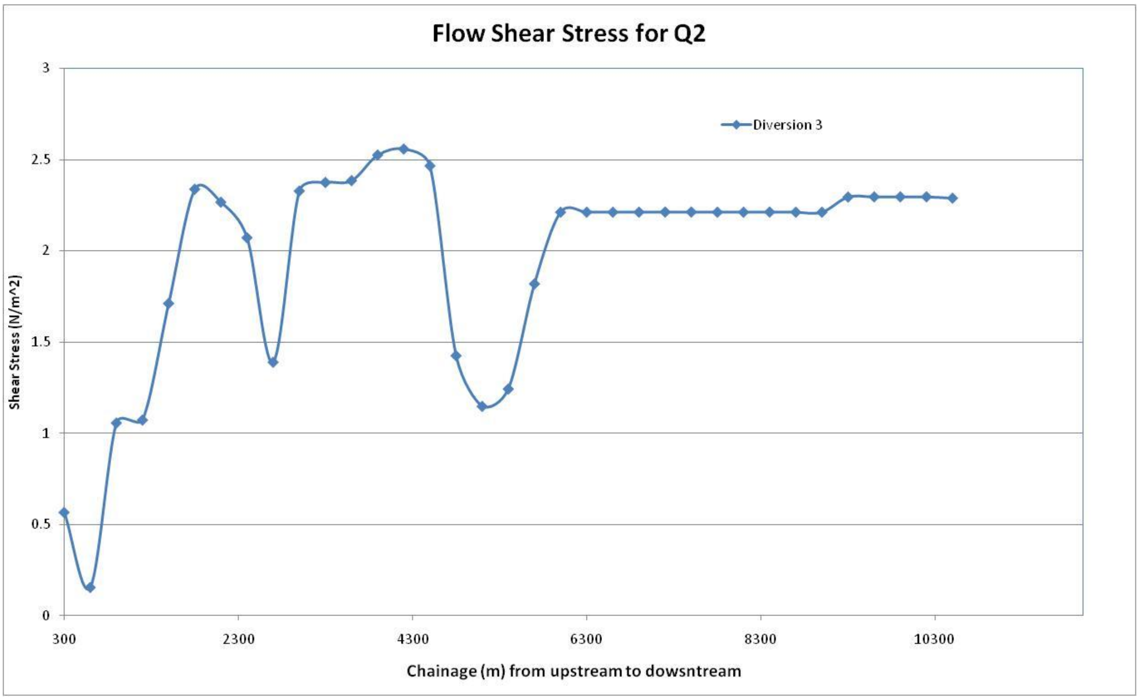


Figure B-24 Spring Creek - Longitudinal shear stress profile for 2 Year ARI (Dev'd)

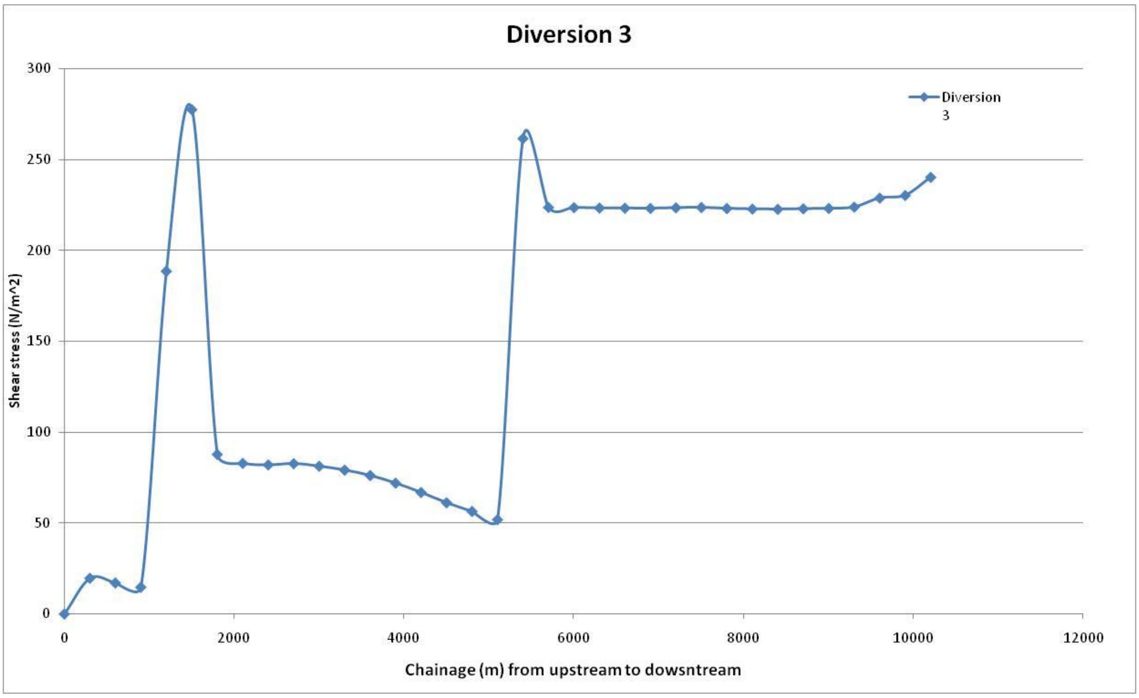


Figure B-25 Spring Creek - Longitudinal shear stress profile for 50 Year ARI (Dev'd)

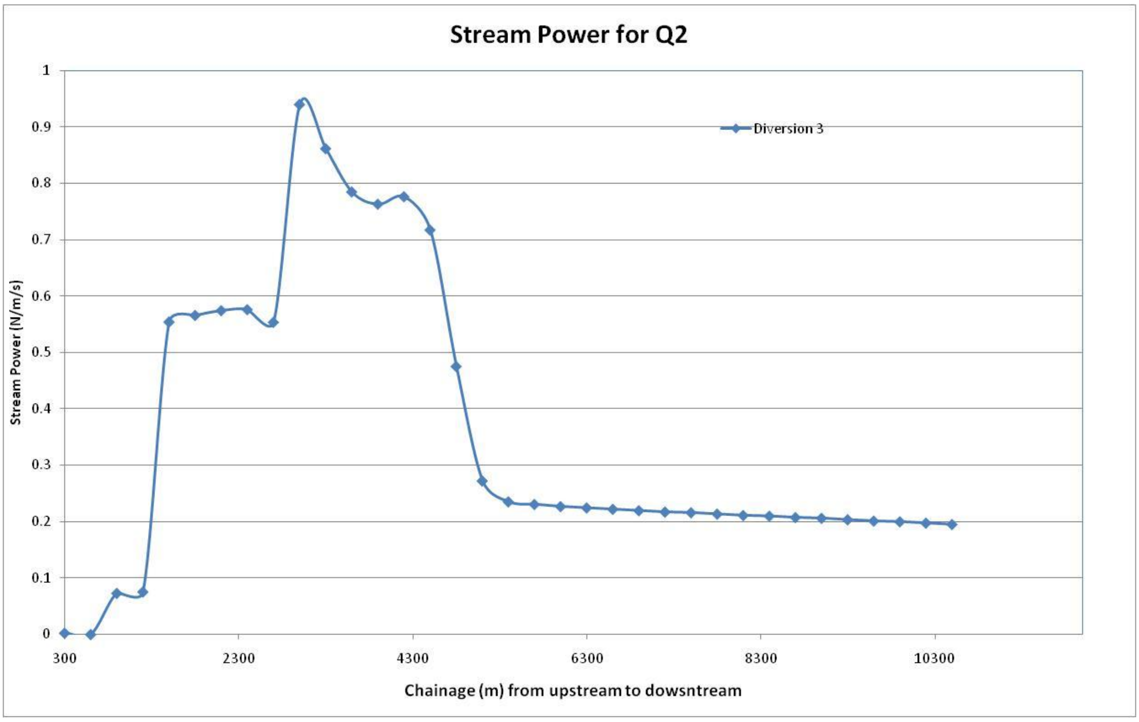


Figure B-26 Spring Creek - Longitudinal stream power profile for 2 Year ARI (Dev'd)

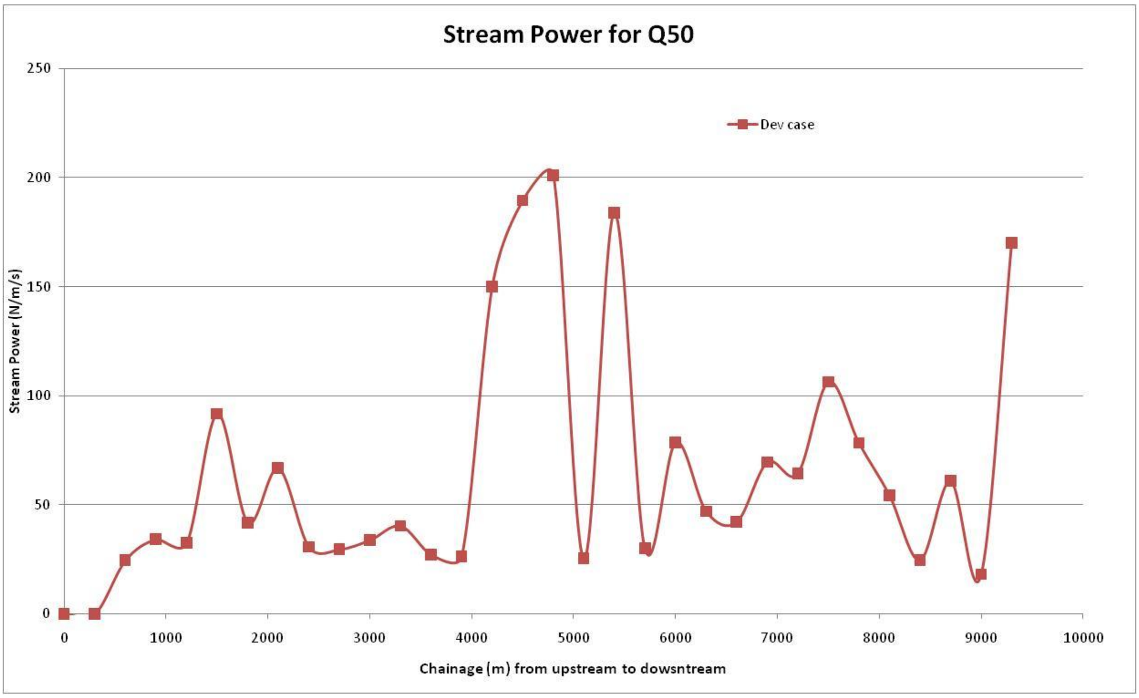


Figure B-27 Spring Creek - Longitudinal stream power profile for 50 Year ARI (Dev'd)

Appendix C

Rip Rap Calculations

About

RIPRAP - Input Table

A design program for stabilisation of river banks with rip- rap

Input Table			
Variable Name	Allowed Range	Value	Units
Energy Slope		***7.00E-03***	-
Bank Angle		***18.5***	degrees
Rock Specific Gravity	>1	***2.65***	-
Rock Angle of Repose	1-46	***46***	degrees
Maximum Depth		***4.5***	m
Depth of Interest		***4***	m
Factor of Safety	1-5	***1.2***	-
Maximum Safe Bank Angle	Calculated	40.7922861	degrees

Output Table

Output Table D50 (mm)

		Bank Angles									
		0	10	15	18	20	25	30	35	40	40.6
Depth (m)	0.45	47	38	40	41	43	48	57	76	204	410
	0.9	95	76	80	83	86	96	114	153	410	830
	1.35	142	114	119	124	129	144	170	229	610	1250
	1.8	189	152	159	166	172	192	227	310	820	1650
	2.25	236	190	199	207	215	240	280	380	1000	2050
	2.7	280	228	239	249	260	290	340	460	1250	2500
	3.15	330	270	280	290	300	340	400	530	1450	2900
	3.6	380	300	320	330	340	380	450	610	1650	3300
	4	420	340	350	370	380	430	500	680	1800	3700
	4.05	430	340	360	370	390	430	510	690	1850	3750
	4.5	470	380	400	410	430	480	570	760	2050	4150

Appendix D

Creeks and Diversions details