Marillana Creek Diversion Management Plan

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Contents

Executive Summary 1

1 Introduction 5
1.1 Background 5
1.2 Purpose of Document and Structure 5

2 Environmental Management Framework 9
2.1 BHP Billiton HSE Management System 9
2.2 BHP Billiton Charter 9
2.3 BHP Billiton Iron Ore Policy and Standards 9
2.4 Regional Management Strategies and Plans 10
2.5 Other Environmental Management Plans and Programmes at Yandi 10
2.5.1 Yandi Environmental Management Plan 10
2.5.2 Other Management Plans and Programmes required by Ministerial Statements 679 and 1039 10
2.6 Project Environmental Aboriginal Heritage Review (PEAHR) 11
2.7 Adaptive Management 11

3 Project Background 12
3.1 Project Description 12
3.2 Existing Environmental Approvals 12

4 Existing Environment 14
4.1 Climate 14
4.2 Hydrology 14
4.3 Surface Water Quality 16
4.4 Geology 20
4.5 Geomorphology 20
4.5.1 Anabranching Reaches 22
4.5.2 Incised Reaches 24
4.5.3 Bedrock Reaches 25
4.6 Flora and Vegetation 26
4.7 Fauna 30
4.7.1 Vertebrate Fauna 31
4.7.2 Short-range Endemic Invertebrate Fauna 33
4.7.3 Aquatic Fauna 33
4.8 Aboriginal Heritage 36
4.8.1 Current Heritage Knowledge - Pilbara 36
4.8.2 BHP Billiton Iron Ore – Cultural Heritage Management Principals 36
4.8.3 Management of Cultural Landscapes 37

4.8.4 BHP Billiton Iron Ore – Native Title Agreements 37
4.8.5 BHP Billiton Iron Ore – Management, Compliance and Sustainability 37

5 Hydrological, Hydraulic and Sediment Transport Modelling 38
5.1 Hydrological Modelling 38
5.1.1 Evaluation of the Flat Rocks rating curve 38
5.1.2 Yandi hydrological model 39
5.2 Hydraulic Modelling 40
5.2.1 2D TUFLOW Modelling 40
5.2.2 1D HEC-RAS Modelling 41
5.3 Sediment Transport Modelling 42
5.3.1 1D and 2D Modelling 42
5.3.2 Transport Functions 43
5.3.3 Sediment Transport Results 44

6 Management Actions 45
6.1 Design Approach 45
6.1.1 Concept Evaluation 45
6.1.2 Design Objectives 46
6.1.3 Design Method 46
6.2 Proposed Design 48
6.2.1 Channel alignment and planform 48
6.2.2 Cross-sectional channel form 49
6.2.3 Hydraulic roughness 51
6.2.4 Shallow aquifer design 52
6.2.5 Rock bars 54
6.2.6 Interface with existing channels (transitions and levees) 55
6.2.7 Interface with tributary channels 56
6.2.8 Spillways 56
6.3 Construction Programme 59
6.3.1 Construction method 59
6.3.2 Project staging 60
6.3.3 Interface with existing operations and overburden infill program 60
6.4 Revegetation Programme 60
6.4.1 Site Treatments and Natural Regeneration 60
6.4.2 Topsoiling 60
6.4.3 Direct Seeding 61
6.4.4 Weed Management 62
6.5 Closure 62
6.5.1 Revised Yandi Closure Strategy 62
6.5.2 Key Considerations for Creek Diversion 63

7 Assessing Design Performance 64

7.1 Hydraulic Modelling Results 64
7.2 Sediment Transport Modelling Results 66
7.3 Independent Design Review 66
7.4 Definition Phase Study Engineering 67

8 Management Targets, Monitoring and Reporting 69
8.1 Management Targets 69
8.2 Monitoring 71
8.3 Inspection and Maintenance 75
8.4 Review and Revision of Management Actions 76
8.5 Reporting 76

9 Audit and Review 77

10 Abbreviations 78

11 References 79

APPENDIX A: Hydraulic Modelling Results 81

APPENDIX B: Sediment Transport Modelling Results (100 year ARI event) 112

Executive Summary

The Marillana Creek Diversion Management Plan details management measures to be implemented so that diverted sections of Marillana Creek will function as a fluvial system in a similar manner to the existing creek system.

The Marillana Creek (Yandi) orebody is a near-surface Channel Iron Deposit (CID) sub-divided into a series of mine pit areas currently separated by the contemporary creek. Permanent diversion of Marillana Creek provides the most feasible option to access the CID constrained by the current creek alignment.

The "*Marillana Creek (Yandi) Life-of-Mine Proposal*" was approved in July 2005 under Ministerial Statement 679 (MS 679). Conditions of approval related to Marillana Creek diversion were amended in Ministerial Statement 1039 (MS 1039) in October 2016. A key characteristic of the approved proposal is *"diversion of sections of Marillana Creek to maximise resource use in the W5 mine area and the E1 to E6 mine area"*. The proposed diversion of Marillana Creek is schematically depicted in **Figure E-1** below. Specific detail regarding the location and design of the diversion is presented in this Diversion Management Plan.

A Selection Phase Study (SPS) has been completed to optimise the configuration and scope of the conceptual diversion design. Refinement of the diversion design has focused on achieving the following design objectives:

- *Hydrology* – Surface water flow volumes are maintained within acceptable ranges to minimise downstream ecological impacts.
- *Water quality* – Diversions do not have an adverse impact on water quality.
- *Hydraulics* – Velocity, shear stress and stream power throughout diversions are similar to those seen through existing channel reaches.
- *Sediment regime* – The volume of sediment exiting diversions is similar to that entering.
- *Geomorphology* – The channel incorporates, and has the capacity to develop, geomorphic features that are similar to those seen through existing channel reaches.
- *Ecology* – A diversity of habitats is established that supports representative flora and fauna species and provides ecological function and connectivity through the system.
- *Cost* – The design should be practicable such that the capital investment required should achieve an acceptable return on investment.

Recognising that fluvial systems are inherently dynamic in nature, the design philosophy has been to construct diversions in which their form and function will continue to evolve over time. This will particularly be the case as features in diversions naturally develop and adjust during flood events in the early years of operation.

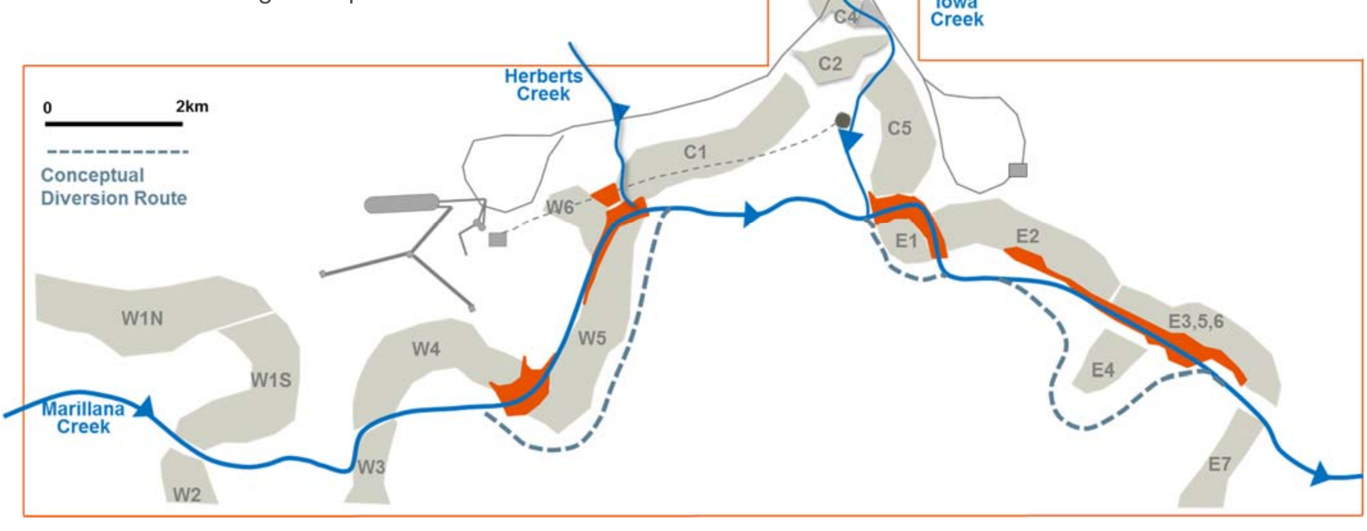


Figure E-1: Marillana Creek diversion conceptual alignments

Diversions consist of:

- a channel designed to produce hydraulic behaviour consistent with Marillana Creek;
- cut-off levees to redirect flow from the existing creek into the diversion channel and back again;
- flood levees to attenuate flows and provide operational flood protection; and
- a series of high flow by-pass spillways, cut in at closure, to allow some floodwater in excess of the spillway height to pass safely and in a controlled manner into pits.

Diversion alignments were selected to reduce the amount of cut volumes by favouring flatter terrain and managing changes in grade by minimising channel lengths to as close to those being replaced as possible. Minimum curvatures of diversion channel bends were based on analysis of bend radii in the existing creek. Setbacks from mine voids were also specified to provide a buffer between pits and diversions.

While geomorphic characteristics in Marillana Creek are highly variable, the morphology at Yandi can be principally divided into two reach types:

- *Anabranching:* Unconfined to semi-confined reaches characterised by multiple channels separated by elongated, vegetated alluvial bars; and
- *Incised:* Reaches confined by vertical cliffs of outcropping bedrock with a relatively wide, planar channel bed.

Reaches within diversions were nominally identified as either anabranching or incised and design geometries then applied based on their respective natural analogues. Channel width and slope were adjusted to achieve hydraulic conditions within ranges seen through existing channel reaches.

A range of options, such as the placement of boulders and large woody debris, have been included in the design to mitigate stream velocities and act as an important catalyst for the development of geomorphological features.

The creation of a shallow aquifer was also included in diversion designs to support eco-hydrological behaviour. A combination of blasted bedrock (overblast material) and placed alluvium is proposed to create a shallow aquifer up to 5 m deep below the base of the low flow channel. The subsequent volume of water in storage is expected to support tree densities similar to those observed in natural channel reaches.

In addition, rock bars have been included in the design to provide grade control of the diversion bed levels and contain water in the shallow aquifer to further promote re-establishment of vegetation.

Independent technical review of the diversion design confirmed that the approach taken to identify a range of design parameters from natural analogues and use them to inform the design was a reasonable first premise to base the design on. The review concluded that the diversion studies and design are adequate and with considered implementation should produce diversions that meet expected performance criteria. While it is recognised that there is further opportunity to refine the design as engineering progresses, the current design is considered suitable and practicable, consistent with current best practice.

Independent technical review concluded that the diversion design is considered suitable and practicable, consistent with current best practice.

It should be noted that diversions, like existing channel reaches, are expected to undergo morphological change. The likely phases of morphological development are:

- *Adjustment Phase:* Diversions will have substantial changes for the first few floods. A large flood in the first few years of the life of the diversion is likely to cause substantial channel changes (redistribution of sediment through scour and aggradation);
- *Establishment Phase:* Basic features of the channel are beginning to form (e.g. benches and anabranch ridges) and the bed is likely to be covered by a dense cover of saplings.
- *Equilibrium Phase:* The morphology of the diversions reflects the natural system as far as is practicable.

Given the event-based nature of flow in Marillana Creek, the nature and rate of morphological change in the diversions (and hence duration of development phases described above) will be subject to the magnitude and frequency of flood events that occur.

Monitoring of diversion performance will be undertaken to evaluate channel condition, manage risk to mining infrastructure and confirm that the trajectory of diversion performance is progressing towards equilibrium. The monitoring programme proposed is designed to meet the requirements of MS 1039 and tailors industry guidelines to application in the Pilbara. This approach includes a heightened monitoring effort in the early life of diversions followed by an ongoing risk-based approach to monitoring intensity thereafter, with consideration also given to the flow regime of Marillana Creek.

The principal criteria for assessing diversion performance will be the Index of Diversion Condition (IDC), developed through the Australian Coal Association Research Program (ACARP) which has been adopted by the Queensland government as a guideline against which diversions are assessed and licenced. The IDC provides a rapid assessment of the condition of stream diversions through an integrated suite of indicators that measures their geomorphic and riparian condition (ACARP, 2001).

Evaluation of performance using IDC scores will be supplemented by a suite of Ecological Indicators developed specifically for Marillana Creek. This approach expands on indicators collected through the riparian index for the IDC to more broadly evaluate ecological functionality.

The monitoring programme proposed will enable a whole-of-reach condition assessment to be undertaken on a regular basis where any specific issues can be identified and addressed as appropriate.

The monitoring programme proposed will enable a whole-of-reach condition assessment to be undertaken on a regular basis where any specific issues can be identified and addressed as appropriate.

A summary of key elements of the Diversion Management Plan, as defined in Environmental Assessment Guideline 17 (EPA 2015), is provided in **Table E-1** below.

Table E-1: Key elements of the Diversion Management Plan

Title of Proposal	Marillana Creek (Yandi) life-of-mine proposal
Proponent Name	BHP Billiton Iron Ore Pty Ltd
Ministerial Statement Number	1039
Purpose of this Condition Environmental Management Plan	Diverted sections of Marillana Creek function as a fluvial system in a similar manner to the existing creek system.
Management Targets	To achieve a total IDC score in diversion reaches that is comparable (>70%) with the total IDC score for the upstream control reach during the *Establishment Phase* of diversion morphological development.
	To achieve 8 out of 10 Key Ecological Indicators during, or prior to, the *Equilibrium Phase* of diversion morphological development.
Signature of Duly Authorised Proponent Representative	P.P. [signature] On behalf of Alejandro Vasquez

1 Introduction

1.1 Background

The Marillana Creek (Yandi) operation, herein referred to as "Yandi", is located approximately 100km northwest of Newman, in the Pilbara region of Western Australia (**Figure 1-1**). The Yandi operation is situated within Mining Leases ML270SA, M47/292, ML47/69, ML47/70 and ML47/71. BHP Billiton Iron Ore is the manager for the Mt Goldsworthy Mining Associates Joint Venture, who owns the Yandi operation. The Joint Venture partners for Yandi are:

- BHP Billiton Minerals Pty Ltd - 85%;
- Itochu Minerals and Energy of Australia Pty Ltd - 8%; and
- Mitsui Iron Ore Corporation Pty Ltd - 7%.

Mining at Yandi is conducted through the use of conventional open-cut mining methods, including drill and blast, load and haul and processing through Ore Handling Plants. Ore is blended into stockpiles and railed to BHP Billiton Iron Ore's shipping facilities at Port Hedland for export.

The Yandi orebody is a near-surface channel iron deposit (CID) which, for mining purposes, has been sub-divided into a series of mine pit areas. Yandi mining operations commenced in 1991 and, to date, have concentrated on pit areas divided by Marillana Creek where the contemporary creek alignment crosses the CID (**Figure 1-2**).

A *"Life of Mine Proposal"* for the Yandi (Marillana Creek) Mining Operations was submitted to the Environmental Protection Authority (EPA) in 2005. Key characteristics of the proposal included diversion of sections of Marillana Creek in order to maximise resource use in the W5 mine area and the E1 to E6 mine area. This Proposal was approved under Ministerial Statement 679 (MS 679) granted under Part IV of the *Environmental Protection Act, 1986* (*EP Act*). Amended conditions of approval related to Marillana Creek diversion were approved in Ministerial Statement 1039 (MS 1039) on 4th October 2016.

Diversion of Marillana Creek provides the most feasible option to access creek constrained ore. Condition 7-1 of MS 1039 stipulates that prior to construction of a diversion of Marillana Creek, BHP Billiton Iron Ore shall prepare a Marillana Creek Diversion Management Plan. This document has been prepared to satisfy this requirement.

1.2 Purpose of Document and Structure

The aim of this Diversion Management Plan is to provide environmental management measures so that *diverted sections of Marillana Creek function as a fluvial system in a similar manner to the existing creek system*.

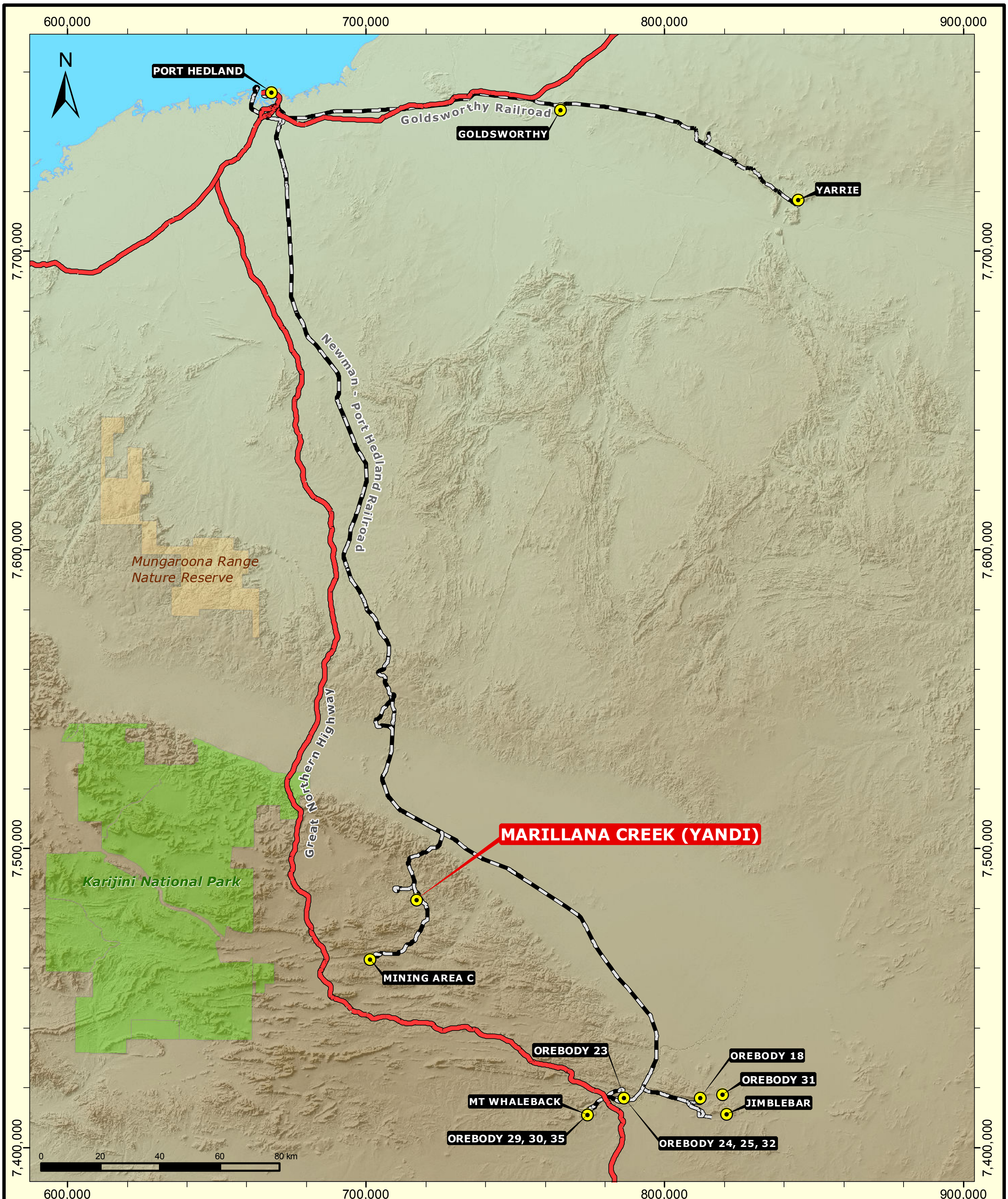
The key environmental factor and associated objective, as defined in Environmental Assessment Guideline (EAG) 8, addressed by this document is as follows:

EPA Environmental Factor	EPA Environmental Objective
Inland Waters Environmental Quality	To maintain the quality of groundwater and surface water, sediment and biota so that the environmental values, both ecological and social, are protected.

The content of this Diversion Management Plan meets the requirements specified in Condition 7-1 of MS 1039 and is structured as follows:

- **Section 2** outlines BHP Billiton Iron Ore's environmental management framework and identifies the function of this management plan within the context of the framework.
- **Section 3** provides background detail on the diversion of Marillana Creek and existing environmental approvals.
- **Section 4** summarises the existing environment as an important context for diversion design.
- **Section 5** provides results of hydrological, hydraulic and sediment transport modelling of Marillana Creek that has been used to support the basis of design.

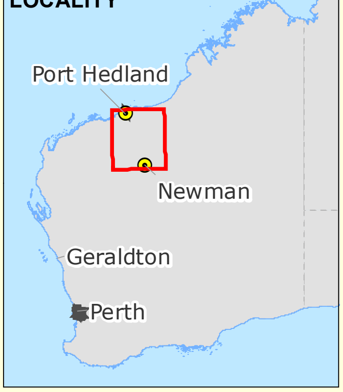
- **Section 6** details management actions through the channel design itself, the construction programme and revegetation strategies.
- **Section 7** assesses design performance based on results of hydraulic and sediment transport modelling and outcomes of an independent design review before outlining areas of focus for subsequent Definition Phase engineering.
- **Section 8** establishes management targets against which the efficacy of management actions in achieving the environmental objective can be assessed and documents monitoring and reporting requirements.
- **Section 9** outlines the audit and review process.



LEGEND

- BHP Billiton Operation
- National Highway
- Rail

LOCALITY



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Environment Approvals
BHP BILLITON IRON ORE

REGIONAL OVERVIEW

Not to scale	Prepared: P. Gant	Project No: A793/001
Date: 23/06/2016	Checked: C. Warman	1
Datum: GDA 94, Projection: MGA Zone 50	Revision: Final	

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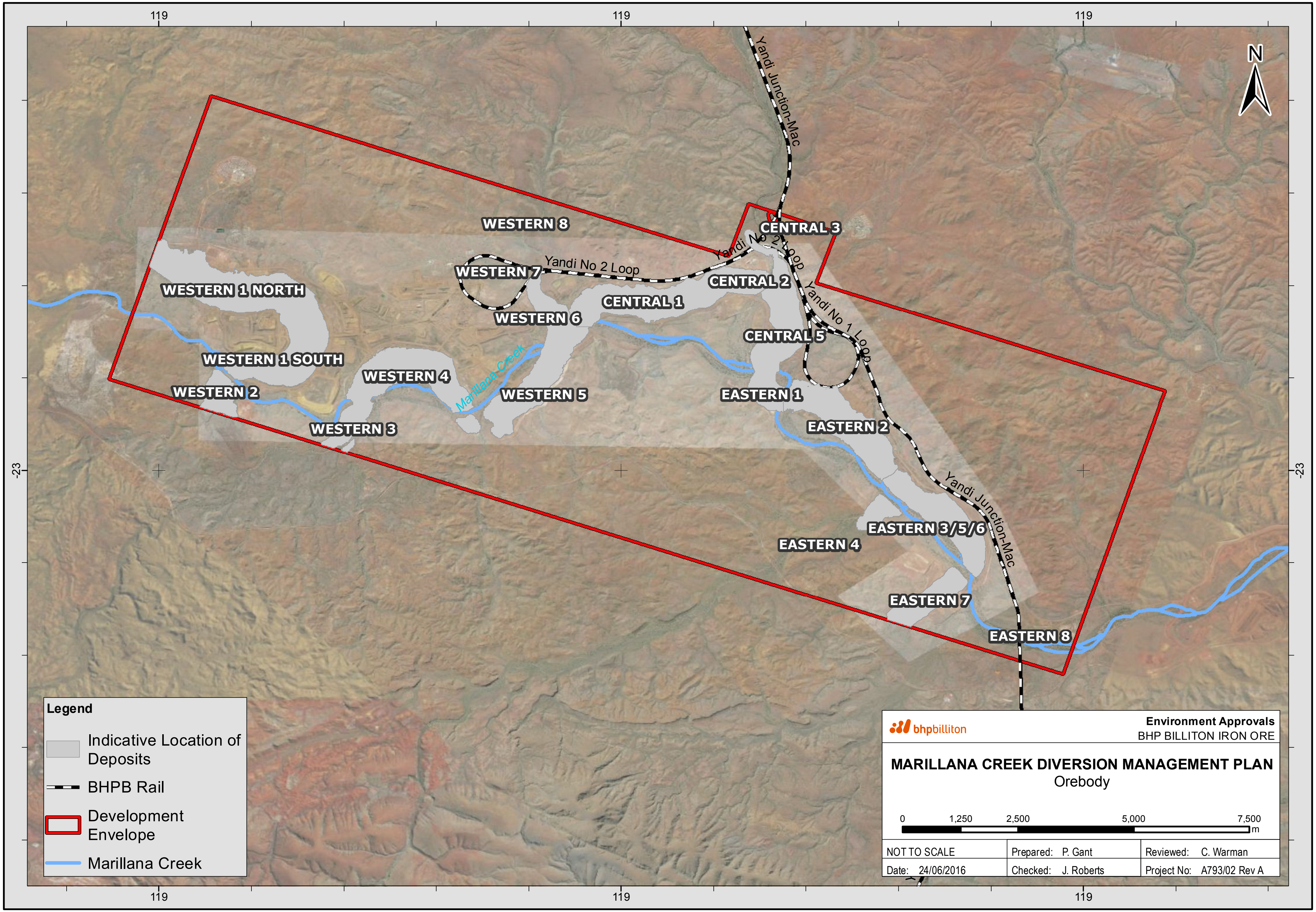

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2 Environmental Management Framework

2.1 BHP Billiton HSE Management System

The BHP Billiton Iron Ore Health, Safety and Environment (HSE) Management System is hierarchical, as illustrated in **Figure 2-1**. This management plan sits at the *Operation* level of the management system, and aligns with Asset-level Strategies and the requirements of the BHP Billiton Charter and Group Level Documents (GLD's): *Our Requirements* as described below.

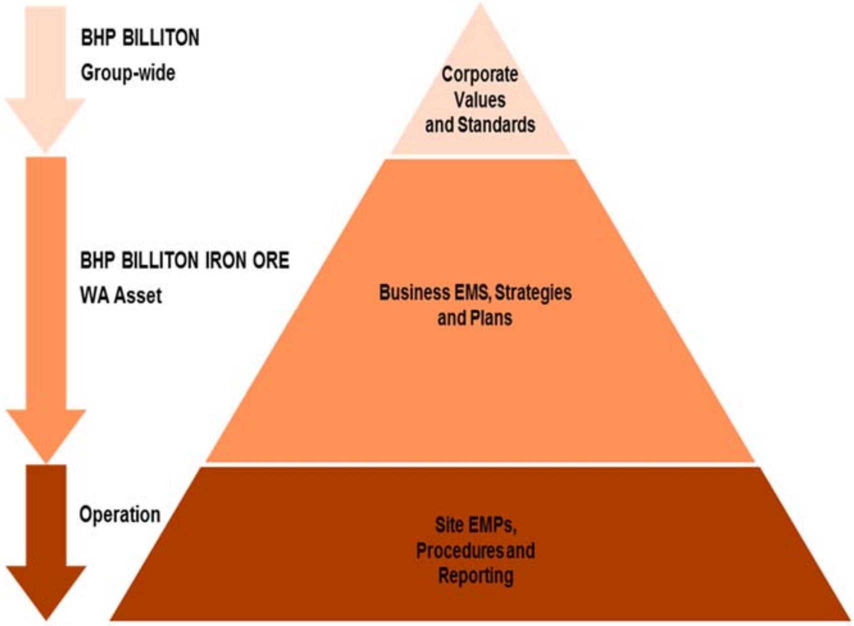


Figure 2-1: BHP Billiton Iron Ore's Health Safety & Environment Management System
This Diversion Management Plan sits at the *Operation* level of the management system but is guided by Regional management plans, Iron Ore policies and Group-wide values and standards.

2.2 BHP Billiton Charter

The BHP Billiton Charter explains BHP Billiton's purpose and core values which are applied Group-wide. It is the single most important means by which we communicate who we are, what we do, and what we stand for as an organisation, and is the basis for our decision-making.

Development of this Plan has taken into account our core values of:

- **Sustainability:** Putting health and safety first, being environmentally responsible and supporting our communities.
- **Integrity:** Doing what is right and doing what we say we will do.
- **Respect:** Embracing openness, trust, teamwork, diversity and relationships that are mutually beneficial.
- **Performance:** Achieving superior business results by stretching our capabilities.
- **Simplicity:** Focusing our efforts on the things that matter most.
- **Accountability:** Defining and accepting responsibility and delivering on our commitments.

2.3 BHP Billiton Iron Ore Policy and Standards

The BHP Billiton Iron Ore Policy and Standards explained in BHP Billiton's GLD's outline the company's environmental commitments. The GLD "*Environment and Climate Change Our Requirements*" specifies that, in line with our BHP Billiton Charter, we all have a role in demonstrating our environmental responsibility by minimising impacts and contributing to enduring environmental benefits. *Our Requirements* relevant to the diversion and management of Marillana Creek are to:

- Define the area of influence.
- Set the baseline or reference conditions.
- Identify and record the type and extent of actual and reasonably foreseeable environmental impacts associated with our activities.
- Assess and record the risks of our activities with actual and reasonably foreseeable environmental impacts.
- Get approval for target environmental outcomes for land, biodiversity, water resources and air consistent with the assessed risks and impacts.
- Implement controls by applying the mitigation hierarchy (avoid, minimise and rehabilitate environmental impacts, before applying compensatory actions) to achieve target environmental outcomes.
- Monitor and verify the effectiveness of implemented controls.

2.4 Regional Management Strategies and Plans

This document is guided by relevant regional management strategies and plans. A regional approach to management provides the benefits of standardisation and consistency in management across all BHP Billiton Western Australian Iron Ore (WAIO) sites.

2.5 Other Environmental Management Plans and Programmes at Yandi

2.5.1 Yandi Environmental Management Plan

The *Marillana Creek (Yandi Mine) Environmental Management Plan* (EMP) has been prepared to identify, manage and monitor environmental aspects and risks at BHP Billiton Iron Ore's Yandi Mine operations. The EMP covers all significant aspects of environmental management for current mining operations, proposed mining developments and closure operations. The EMP has been reviewed and revised periodically over the life of the mine according to mine development plans, with Revision 4 of the EMP developed in 2011.

A description of the environmental management procedures used to minimise and mitigate risks of key environmental aspects is provided in the EMP. For each aspect, the overall management objective, potential risks, management measures and monitoring programs to track performance are described.

2.5.2 Other Management Plans and Programmes required by Ministerial Statements 679 and 1039

Conditions of approval in MS 679 and MS 1039 include the preparation and implementation of a number of specific Environmental Management Plans and Programmes in addition to this one. A summary of the current status of these Plans / Programmes is provided in **Table 2-1**. While the content of these plans will not be duplicated here, where relevant, aspects of each have informed the development of appropriate management measures.

Table 2-1: Other Management Plans / Programmes required under Ministerial Statements 679 and 1039.

Ministerial Condition	Environmental Management Plan / Programme	Current Status
5	Closure Plan (previously titled Decommissioning and Final Rehabilitation Plan)	Revision 4 submitted to the OEPA in 2016
6	Progressive Rehabilitation Management Plan	Revision 2 submitted to the OEPA in 2011
8	Surface Water and Groundwater Management Plan	Revision 3 submitted to the OEPA in 2014
10	Stygofauna Investigation Plan	Revision 1 submitted to the OEPA in 2006
11	Significant Species Management Programme	Revision 2 submitted to the OEPA in 2011
12	Weed Management Plan	Revision 2 submitted to the OEPA in 2011

2.6 Project Environmental Aboriginal Heritage Review (PEAHR)

BHP Billiton Iron Ore has a Project Environmental Aboriginal Heritage Review (PEAHR) process to manage the implementation of its environmental, Aboriginal heritage, land tenure and legal obligations prior to and during land disturbance activities. A PEAHR approval is required prior to any land clearing activity.

The objectives of the PEAHR process are to:

- Identify the significant environmental, Aboriginal heritage and legal aspects of proposed activities;
- Ensure that, through appropriate environmental Aboriginal heritage and land access planning and management, BHP Billiton Iron Ore activities comply with all legal and other obligations;
- Avoid, minimise and mitigate the number and nature of environmental, Aboriginal heritage and land tenure events and ensure the environmental performance of BHP Billiton Iron Ore operations; and
- Provide a mechanism for continuous improvement.

BHP Billiton Iron Ore project managers wishing to undertake land clearing activities must first lodge a PEAHR application via the web based PEHAR application system. Each application is assessed by Environment and Heritage Advisors responsible for the area in which the clearing is to be conducted. Assessors of each PEAHR check that the required approvals and licenses are in place and that the appropriate management measures and conditions are being applied. Assessors will also apply the management hierarchy and recommend conditions and limitations where appropriate and reasonable. The PEAHR application and the recommendations of the assessing advisor are then reviewed by a Team Lead or Superintendent and a PEAHR permit is authorised. The ALARP (As Low As Reasonably Practicable) principle is applied when reviewing and approving PEHAR applications and applying management measures.

2.7 Adaptive Management

WAIO applies an adaptive management framework to implementing management measures identified in this plan. Adaptive management is a structured, iterative process to decision making. The framework embeds a cycle of monitoring, reporting and implementing change where required. It allows an evaluation of the management controls so that they are progressively improved and refined, or alternative solutions adopted, so that the defined objectives are achieved.

The audit and review process for this plan is described in **Section 9**.

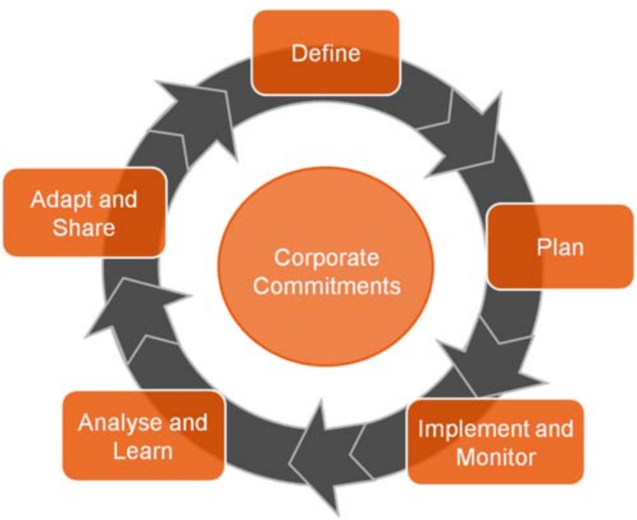


Figure 2-2: Adaptive management framework. The framework embeds a cycle of monitoring, reporting and implementing change where required.

3 Project Background

3.1 Project Description

The Yandi orebody is a Tertiary aged, near-surface deposit typically 80m to 90m thick. Mining at Yandi to date has occurred in a series of pits separated by the existing Marillana Creek channel. Through the Yandi lease area, Marillana Creek is characterised as a bedrock-constrained channel that has incised into the underlying geology over time. The contemporary creek crosses the paleo-meanders of the CID, passing successively through different lithologies: CID, Banded Iron Formation (BIF) and dolerite.

Diversion of Marillana Creek (the "Project") provides the most feasible option to access creek constrained ore in order to maximise resource use in the W5 mine area and the E1 to E6 mine area. Three separate diversion channels are proposed to allow for staged development and to minimise the total length of diversion required. The design of diversions has taken into account their operation during both the ongoing operation of the Yandi mine and following mine closure.

Diversions will consist of:

- a channel designed to produce hydraulic behaviour consistent with ranges seen in Marillana Creek;
- cut-off levees to redirect flow from the existing creek into the diversion channel and back again;
- flood levees to attenuate flows and provide operational flood protection; and
- a series of high flow by-pass spillways to direct excess floodwater into pit voids at closure to protect the ongoing integrity of the diversion.

A Selection Phase Study (SPS) has been completed to optimise the configuration and scope of the conceptual diversion design. *Advisian* was engaged by BHP Billiton to provide engineering services during the SPS and were supported by sub-consultants including *AQ2* and *Hydrobiology*. Key outputs from the SPS are presented in this document.

While refinement of the detailed design will continue through a Definition Phase Study (DPS) and into the Execution Phase, the current design is considered sufficient to demonstrate conformance with the Conditional Environmental Objective that diverted sections of Marillana Creek function as a fluvial system in a similar manner to the existing creek system.

3.2 Existing Environmental Approvals

Mining at Yandi from the E2 pit, with an initial installed capacity of 5 mtpa, was first approved by the Minister for the Environment in May 1988. Mining commenced under this approval in 1991, with the first ore railed in January 1992.

Subsequent incremental expansions of installed capacity and development of additional orebodies proceeded through a series of discrete approvals prior to BHP Billiton Iron Ore submitting a proposal for the conceptual *Life of Mine* for the Marillana Creek (Yandi) operation in April 2005. A key characteristic of the proposal was *"permanent diversion of Marillana Creek to maximise resource use in the W5 mine area and the E1 to E6 mine area"*.

The Environmental Protection Authority's (EPA) assessment and recommendations were issued in Bulletin 1166 in April 2005. Approval by the Minister for Environment was granted on 6 July 2005 under MS 679. The conditions of this statement superseded those of previous statements relevant to Yandi. MS 679 requires the preparation of a Marillana Creek Diversion Management Plan prior to diversion of any section of Marillana Creek.

Since being granted, the proposal has undergone six amendments under Section 45C of the *EP Act* addressing, for example, increased production rates and disturbance areas with MS 679 updated accordingly. The latest amendment included an increase in the "total area disturbed" element for vegetation clearing at Yandi from 4,050 to 4,558 ha – including adjustment of clearing associated with diversion of Marillana Creek to 393 ha.

Most recently, amendments to conditions of approval specified in MS 679 were also made under Section 46 of the *EP Act*. These amendments included:

- replacement of Condition 5 *Rehabilitation and Decommissioning* with more contemporary conditions consistent with those recently applied to similar proposals;

- minor amendment to Condition 7 *Marillana Creek Diversion* including adjustment of the submission timeframe to at least six months prior to diversion construction; and
- addition of Condition 13 *Offsets* to address residual impacts and risks as a result of implementation of the proposal.

These amendments were approved in Ministerial Statement 1039 on the 4th October 2016.

Condition 7 of MS 1039 defines the required content of this Diversion Management Plan. Content specified in Condition 7-1 is detailed in **Table 3-1** below, with references to relevant sections within this document provided.

Table 3-1: Document cross-references for requirements specified under Condition 7-1 of MS 1039.

Condition 7-1, items:		Document Reference
1.	Design details and specifications of the planned diversions and associated diversion cut-off levee(s) and high flow by-pass spill-out channel(s).	**Section 6.2**
2.	Design details for creating appropriate transitional gradients to minimise the potential for scouring at the confluence of tributaries and the creek diversion.	**Section 6.2.7**
3.	Design options for the section of Marillana Creek to be diverted. Independent technical peer review will be required: • to compare the various design options; • to ensure that the option selected is the most suitable and practicable, consistent with current best practice; and • to ensure that at each diversion there is continuous improvement, based on adaptive management and benchmarking against similar projects in Australia and Internationally.	**Section 6.1** and **Section 7.3**
4.	The construction programme for the creek diversion, including how the work is to be staged and progressively integrated with the mining operations and mine void overburden infill programme.	**Section 6.3**
5.	Baseline information on water flow, water quality, geomorphology, fauna, vegetation and flora on the section of Marillana Creek to be diverted.	**Section 4**
6.	Revegetation for the diversion channel using suitable riparian species and alluvial sediment sourced from the diverted section of Marillana Creek.	**Section 6.4**
7.	Management of Aboriginal heritage matters within the planned disturbance area and vicinity of the planned diversion.	**Section 0**
8.	Weed management within the planned disturbance area and vicinity of the planned diversion.	**Section 6.4.4**
9.	Performance criteria for water flow, water quality, ecology and geomorphology for the creek diversion.	**Section 8.2**
10.	Monitoring of water flow, water quality, vegetation, flora, fauna and ecological and geomorphologic integrity of the creek diversion and downstream of the creek diversion during operations and post-closure.	**Section 8.2**
11.	Inspection and maintenance of the creek diversion and revegetation works during operations and until the objective is met.	**Section 8.3**
12.	Findings of hydrological and hydraulic modelling, groundwater modelling, research programmes, and monitoring results to show whether the planned diversion satisfies the objectives of the Mine Closure Plan.	**Section 7**
13.	Water quality management of Marillana Creek which is consistent with the State Water Quality Management Strategy, 2000 or the approved equivalent.	**Section 4.3** and **Section 8.2**
14.	Reporting procedures and schedule.	**Section 8.5**

4 Existing Environment

4.1 Climate

Climate is of primary significance to fluvial system behaviour as it provides energy for system processes as well as directly influencing basin hydrology and rates of erosion (Knighton, 2014). The climate of the Pilbara is semi-arid to arid, characterised by irregular rainfall and hot summers.

Tropical lows and cyclones dominate the Pilbara's climate in the summer wet season. Cyclonic systems deliver widespread rain across the region, with rainfall occurring mostly between December and March. During the spring to autumn months, however, a semi-permanent low pressure system influences the formation of convective thunderstorms of varying size and intensity, producing heavy localised rainfall over short periods (Charles *et al.,* 2013).

Average annual rainfall within the Marillana Creek catchment ranges from 450 mm in the west of the catchment to just over 300 mm near the confluence with Weeli Wolli Creek in the east. The long-term average annual rainfall recorded at the Marillana rainfall station (BOM ID 5009), opened in 1936 and located approximately 32 km away from Yandi, is 327 mm. The long-term average rainfall at the Flat Rocks stream gauging station (DoW ID 708001), located approximately 300 m upstream of the Yandi lease boundary and operational since 1967, is 383 mm. Annual rainfall in the region is, however, highly variable due to the influence of cyclonic events and thunderstorms, with large rainfall events contributing several hundred millimetres of rain at one time.

Mean daily temperatures in the summer months from November to February exceed 32°C and maximum temperatures above 42°C are common. Mean daily maximum and minimum temperatures in winter are about 28°C and 13°C, respectively (MWH, 2016).

Annual average evaporation potential is far in excess of the annual average rainfall, as are evaporation potentials in all individual months. The average annual pan evaporation rate at Yandi is in excess of 3,200 mm, which is an order of magnitude higher than the average annual rainfall (MWH, 2015). As a result, there is commonly a large moisture deficit in the environment.

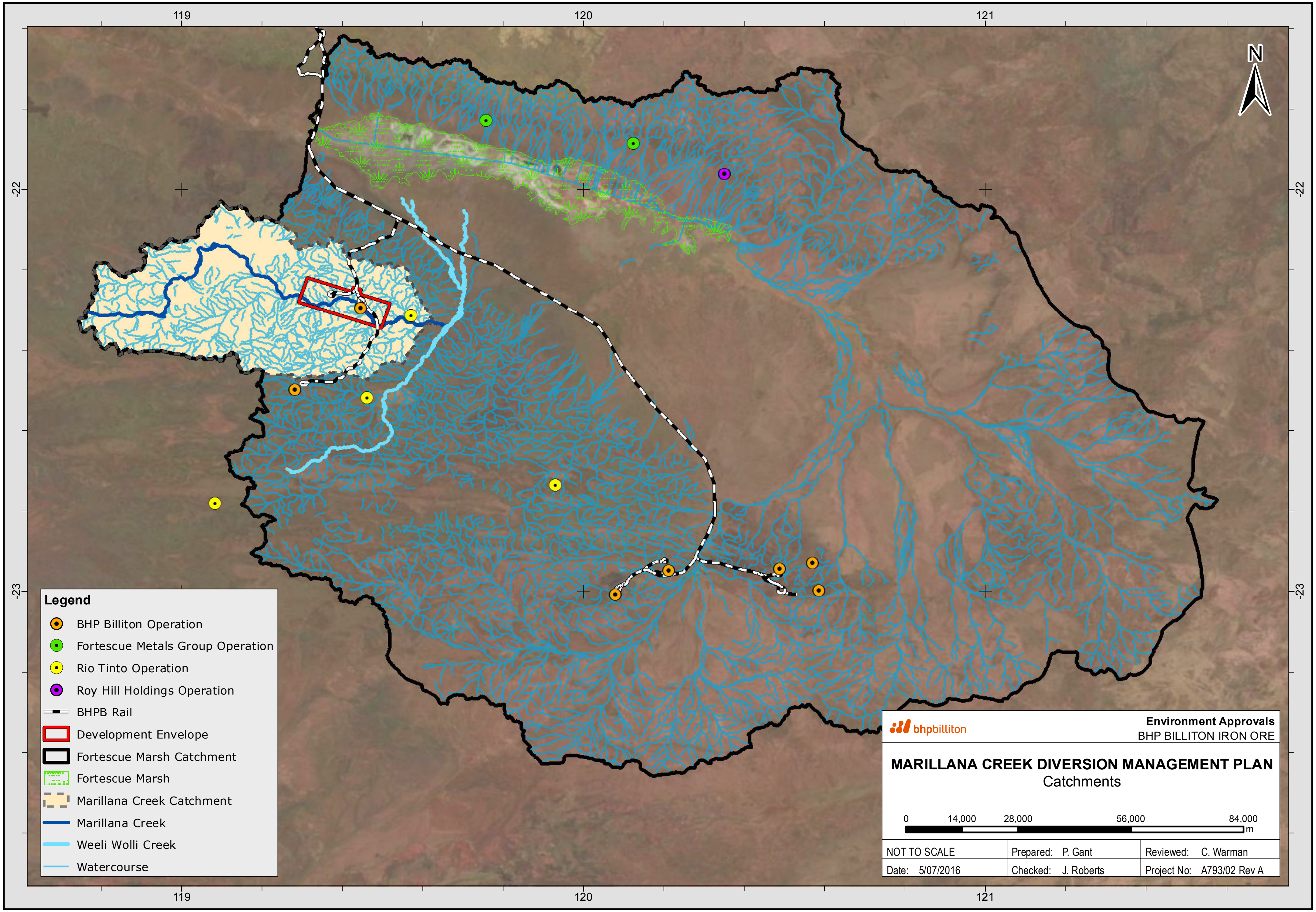
4.2 Hydrology

Marillana Creek is a tributary of Weeli Wolli Creek, within the Fortescue River catchment. The 2,050 km^2 Marillana Creek catchment is located in the north-west of the 30,279 km^2 Fortescue River catchment for which Fortescue Marsh is the drainage terminus (**Figure 4-1**).

The headwaters of Marillana Creek comprise a broad alluvial plain, known as Munjina Flats, flanked by high-relief areas with elevations up to 1200 m AHD. The broad, gently sloping Munjina Flats provide considerable water storage capacity, which attenuates some surface water flows and stores sediment upstream of Yandi. The lower part of the catchment comprises extensive outcropping bedrock of moderate relief, into which Marillana Creek is incised. Marillana Creek flows in an easterly direction through the Yandi lease area, where a number of tributaries, including Herbert's Creek and Iowa Creek, enter.

Streamflow in Marillana Creek is ephemeral, due to the irregular nature of rainfall and high evaporation rates described above. Large stream flows are typically associated with rain-bearing depressions of high intensity rainfall. Analysis of gauging station data at Flat Rocks (DoW ID 708001) between 1967 and 2014 indicates a historical average of four flow events per year with a range of 0 to13 occurring in a given year. Flow events in Marillana Creek tend to be "flashy" with steep rises in the flood hydrograph followed by a relatively quick recession. Variability in the discharge record is highlighted by the mean hourly discharge rates presented in **Figure 4-2**. The largest discharge in the gauging record, with a peak hourly discharge of 1,322 m^3/s, was as a result of heavy rainfall associated with tropical cyclone Joan which passed the catchment on 9 December 1975.

Downstream of Yandi, Marillana Creek passes through Rio Tinto's lease where Phil's Creek and Yandicoogina Creek enter Marillana Creek prior to its confluence with Weeli Wolli Creek. Weeli Wolli Creek flows in a northerly direction for approximately 40km before discharging into the Fortescue Marsh. The Fortescue Marsh is a brackish to saline, endorheic wetland, extending for about 100 km along the Fortescue Valley with a width of between 3 and 10 km.



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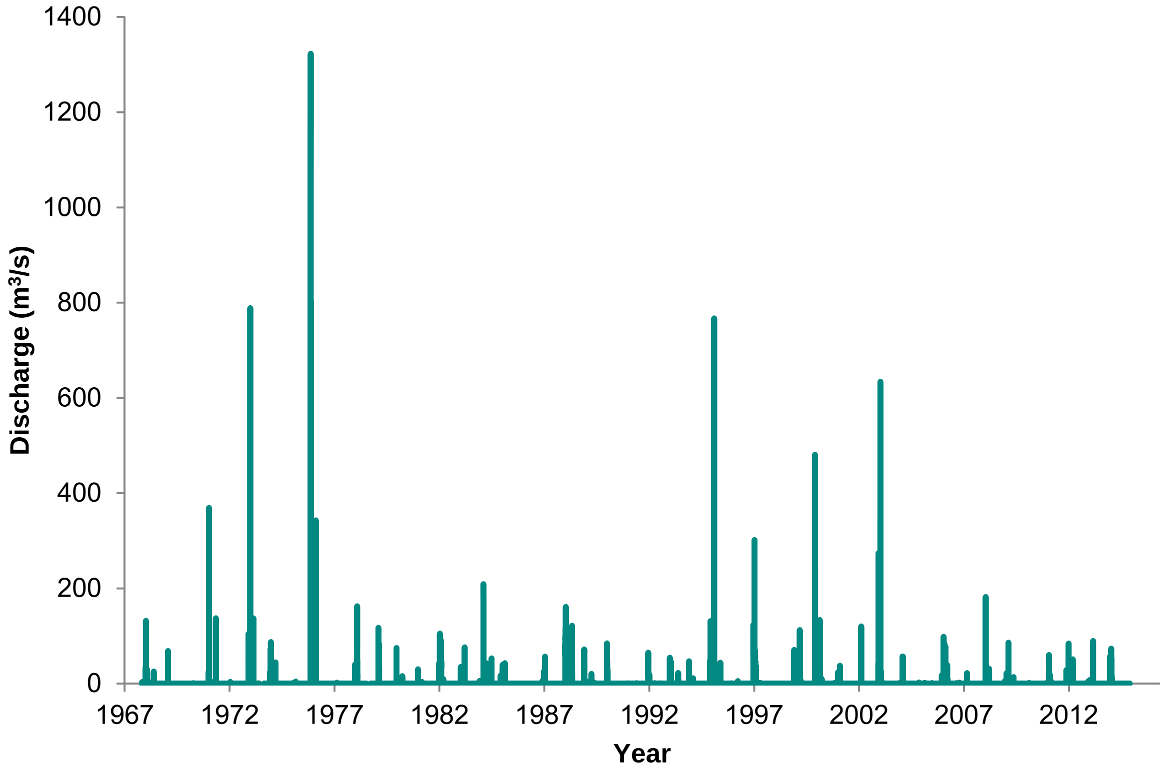


Figure 4-2: Mean hourly stream discharge recorded at the Flat Rocks gauging station. There is significant inter-annual variability in stream flow, with extended periods of no or low flow interspersed with large discharge events.

The Fortescue Marsh water balance is dominated by surface water inputs. The largest source of surface water inflow to Fortescue Marsh is the Fortescue River. Weeli Wolli Creek contributes approximately 18% of mean annual inflow to Fortescue Marsh (MWH, 2016). Flooding of Fortescue Marsh is generally associated with cyclonic rainfall and runoff in the summer months, with large-scale inundation events estimated to occur every five to seven years on average, during which more than 20% of the Marsh is inundated. Floodwaters may persist for several months providing breeding and foraging habitat for waterbirds and other biota before evaporating - leading to salt accumulation. Beneath the Marsh, the groundwater is hypersaline (BHP Billiton, 2016).

4.3 Surface Water Quality

Baseline information on surface water quality for Marillana Creek prior to mine dewatering (i.e. pre-1991) is available from the Flat Rocks gauging station. Based on this information, surface water in Marillana Creek can be classified as fresh to brackish (with electrical conductivity ranging between 136 and 1,805 µS/cm) with a neutral to slightly alkaline pH (recorded pH between 6.10 and 8.70) (BHP Billiton, 2014).

Surface water monitoring is currently undertaken at monitoring points MCSW002 and MCSW005 in accordance with the *Marillana Creek (Yandi) Mine Surface Water and Groundwater Management Plan Revision 3* (BHP Billiton, 2014) and the Yandi environmental licence L6168/1991/11 (**Table 4-1**). Sporadic monitoring has been ongoing at these locations since 2002.

Water quality sampling events were also conducted at a number of pools within the Yandi mining lease as well as at reference sites upstream and in an adjacent catchment in April 2014 (late wet) and September 2014 (late dry) as part of an aquatic fauna survey commissioned to establish the current condition of Marillana Creek (WRM, 2015). Water quality variables were recorded in situ using portable field meters, including pH, electrical conductivity (µS/cm), dissolved oxygen (% and mg/L), and water temperature (°C). Water samples were also taken for analysis of ionic composition, nutrients and dissolved metals.

Three rising stage samplers with water quality sondes were also installed within Marillana Creek in February 2014 to take water samples during flow events (**Table 4-1**). To date data captured at these sampling points has been limited, with few flow events occurring since their installation.

Table 4-1: Surface water monitoring locations and parameters tested.

Reference Number	Co-ordinates (GDA 94 MGA Zone 50)	Analytes	Frequency
YNSWPC002	702190E 7486341N	pH Electrical Conductivity Total Dissolved Solids (TDS) Total Suspended Solids (TSS) Total Recoverable Hydrocarbons (TRH) Sodium (Na) Potassium (K) Calcium (Ca) Magnesium (Mg) Chloride (Cl) Carbonate (CO_3) Bicarbonate (HCO_3) Sulfate (SO_4) Nitrate (NO_3) Aluminium (Al) Boron (B) Iron (Fe) Copper (Cu) Zinc (Zn) Silver (Ag) Arsenic (As) Chromium (Cr) Cadmium (Cd) Mercury (Hg) Nickel (Ni) Selenium (Se) Manganese (Mn)	Spot sample following rain events
YNSWPC001	720629E 7478491N		
YNSWPC003 (RSS1)	704857E 7484392N	Same as above suite except: • Selenium not measured; and • Tin (Sn), Lead (Pb) and turbidity (NTU) measured	During flow events: • Sonde 15-minute Interval: Turbidity (NTU), Conductivity, TDS, Temperature, Depth, Salinity; and • Bottle samples: All other analytes
YNSWPC004 (RSS2)	719615E 7479883N		
YNSWPC005 (RSS3)	719461E 7479783N		

The current surface water quality data for Marillana Creek is scattered over a wide range making it difficult to establish statistical relationships on expected surface water quality. This scatter in the data is likely to have resulted from the sporadic nature of the sampling, variability in the flow regime of the creek and changes in sample analysis methods. The compiled FY15 and FY16 data from the rising stage samplers show relatively little correlation between the water quality of samples when sorted by level, by year, or by location. Despite this, the collected data is useful in establishing a baseline and an understanding of the range in surface water quality parameters that can be expected within Marillana Creek. For example, the TSS data from the rising stage samplers (**Figure 4-3**) shows a large fluctuation in TSS at each location independent of the flow rate but does provide a range of TSS values that might be expected.

Table 4-2: TSS Records for RSS1, RSS2 and RSS3.

Surface Water Monitoring Location	Minimum TSS (mg/L)	Maximum TSS (mg/L)	Average TSS (mg/L)
RSS1	50	2,580	640
RSS2	111	4,600	1,124
RSS3	22	1,500	620

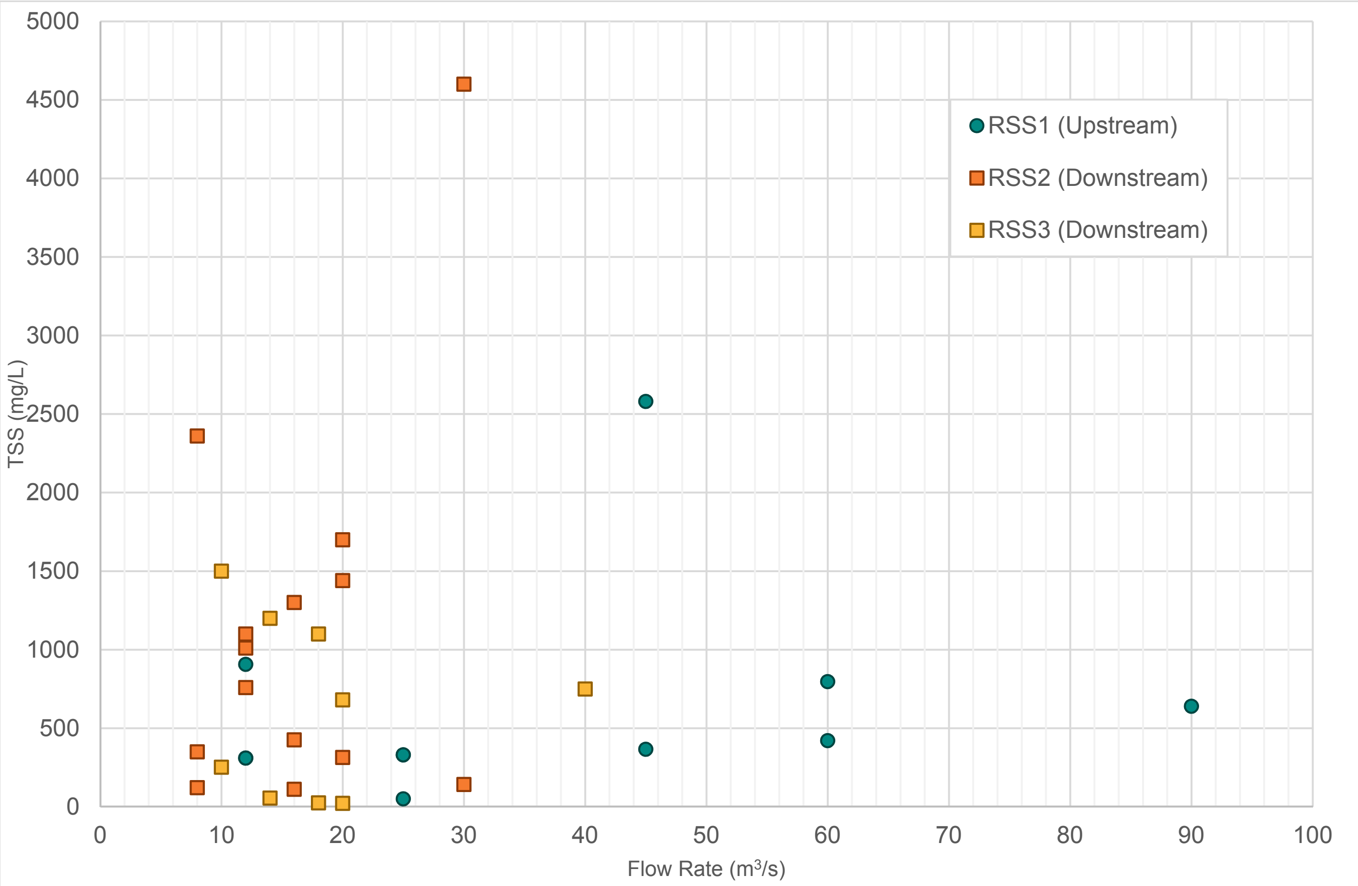


Figure 4-3: Rising stage samplers Total Suspended Sediment vs flow rate (2015-2016)

The results of pool water sampling from 2014 are presented in **Table 4-3**. Based on these results, the surface water quality of pools in Marillana Creek within the Yandi lease area is generally good. Sites were characterised by fresh to slightly brackish waters, with adequate dissolved oxygen levels, circum-neutral to basic pH, generally low dissolved metal levels, high alkalinity (thus buffering capacity) and relatively high nutrient levels, i.e. inorganic nitrogen oxides (N_NOx), total nitrogen and total phosphorus. At sites both within the Yandi lease area and at reference locations, a number of water quality parameters exceed ANZECC/ARMCANZ (2000) guidelines for the protection of aquatic systems in tropical northern Australia. Overall, the water quality of sites at Yandi was statistically similar to reference sites with these results providing a more appropriate reference than the ANZECC/ARMCANZ (2000) guidelines (WRM, 2015).

Ongoing sampling at the existing monitoring locations, supplemented by the three rising stage samplers, will assist with the refinement of the surface water modelling and continue to provide a greater understanding of the range of surface water conditions seen in Marillana Creek.

Table 4-3: In-situ water quality data recorded from pools during the Wet and Dry seasons of 2014.

	Marillana Creek (Within Lease Area)												Marillana Creek Reference				Weeli Wolli Reference					
	MC1		MC2		MC4		MC5		MC6		MC7		FR		FRDS		WMU		MW		UWWCS	
Parameter	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Temp (°C)	21.1	–	23.7	–	20.1	DRY	27.1	DRY	30.8	DRY	NOT SAMPLED	30.9	27.2	24.5	NOT SAMPLED	26.2	19.9	18.9	22.8	15.6	25.3	NOT SAMPLED
pH	8.62	9.34	8.62	8.67	7.48		7.82		7.89			7.08	8.68	8.86		8.42	8.67	7.87	7.8	7.94	7.66	
EC (µS/cm)	1120	1280	1470	5030	1320		1310		1070			977	1300	2020		1220	255	872	3260	23000	954	
DO (%)	87.1	–	98.4	–	48.4		143.3		143.8			78.1	116.4	91.2		95.4	93.6	51.7	75.3	28.1	98.4	
Max depth (m)	2	1.4	1.4	0.7	0.4		1.2		0.4			2.5	0.8	0.4		4	1.1	0.4	0.85	0.4	1.1	
Ca (mg/L)	18.5	7.3	27.2	16.3	57.7		59.1		54.4			40.9	23.9	30		27.1	21.7	61.7	158	749	68.1	
Mg (mg/L)	59.7	88.6	73.9	331	57.2		62.2		55.1			39.1	73.9	114		70.1	12.2	45.6	165	1640	59.4	
Na (mg/L)	99	124	130	566	104		99.9		81.7			66.1	122	206		115	7.1	35.2	308	3390	23.7	
K (mg/L)	10.4	10.6	12.6	41.2	9.4		10.9		10.9			6.3	14.4	20.1		13.6	4.1	19.8	9.1	42	3.5	
HCO_3 (mg/L)	273	180	221	432	416		426		346			348	249	347		279	118	451	517	158	496	
Cl (mg/L)	187	234	298	1150	172		159		131			49	235	404		205	15	61	485	4740	57	
SO_4 (mg/L)	48.8	38.6	91.8	359	90		86.3		60.8			56.9	63.9	92		46.9	7.2	8.8	774	8640	36.6	
CO_3 (mg/L)	15	89	19	122	<1		<1		<1			<1	27	46		22	3	<1	<1	<1	<1	
Hardness	290	380	370	1400	380		400		360			260	360	540		360	100	340	1100	8600	410	
Alkalinity	249	297	213	558	342		350		284			286	250	361		265	102	370	425	130	407	
NH_3 (mg/L)	<0.01	<0.01	<0.01	<0.01	0.09		<0.01		<0.01			<0.01	<0.01	<0.01		<0.01	<0.01	2.6	<0.01	0.1	<0.01	
Nitrate (mg/L)	0.07	0.38	0.07	0.29	3.8		0.21		0.15			2.5	1.5	0.16		0.14	0.15	0.01	0.1	<0.01	0.11	
Total N (mg/L)	0.36	0.8	0.42	1.3	4.2		0.27		0.24			2.6	2.2	0.91		0.54	0.39	5.8	0.28	2.5	0.17	
Total P (mg/L)	<0.010	0.015	<0.010	<0.010	<0.010		<0.010		<0.010			0.021	<0.010	<0.010		<0.010	<0.010	0.14	<0.010	0.02	<0.010	
Al (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005		<0.005		<0.005			<0.005	<0.005	0.007		0.014	0.01	<0.005	<0.005	<0.005	<0.005	
As (mg/L)	<0.001	<0.001	<0.001	<0.002	<0.001		<0.001		<0.001			<0.001	<0.001	<0.001		<0.001	<0.001	0.002	<0.001	<0.005	<0.001	
B (mg/L)	0.39	0.36	0.38	1.1	0.42		0.47		0.41			0.35	0.46	0.68		0.39	0.06	0.09	0.22	0.39	0.13	
Ba (mg/L)	0.028	0.011	0.049	0.028	0.11		0.066		0.058			0.038	0.033	0.046		0.048	0.005	0.15	0.12	0.092	0.03	
Cd (mg/L)	<0.0001	<0.0001	<0.0001	<0.0002	<0.0001		<0.0001		<0.0001			<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	
Co (mg/L)	0.0001	0.0001	0.0001	0.0003	0.0001		<0.0001		<0.0001			<0.0001	0.0001	0.0003		<0.0001	0.0001	0.0014	0.001	0.011	0.0002	
Cr (mg/L)	<0.0005	<0.0005	<0.0005	<0.0010	<0.0005		<0.0005		<0.0005			<0.0005	<0.0005	<0.0005		<0.0005	<0.0005	<0.0005	<0.0005	<0.0025	<0.0005	
Cu (mg/L)	0.0002	0.0002	0.0007	0.0007	0.0001		<0.0001		<0.0001			<0.0001	0.0008	0.0014		0.0005	0.0017	0.0007	0.0005	0.0017	<0.0001	
Fe (mg/L)	0.035	0.012	0.006	0.01	0.021		0.032		0.02			<0.005	0.008	0.016		0.01	0.028	0.78	0.04	0.12	0.04	
Mn (mg/L)	0.004	0.023	0.004	0.014	0.042		0.008		0.019			<0.001	0.004	0.02		0.002	0.009	0.34	0.33	5.3	0.097	
Mo (mg/L)	<0.001	<0.001	<0.001	<0.002	<0.001		<0.001		<0.001			<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.005	<0.001	
Ni (mg/L)	<0.001	<0.001	<0.001	<0.002	<0.001		<0.001		<0.001			<0.001	<0.001	<0.001		<0.001	<0.001	0.002	0.001	0.006	<0.001	
Pb (mg/L)	<0.0001	<0.0001	<0.0001	<0.0002	<0.0001		<0.0001		<0.0001			<0.0001	<0.0001	<0.0001		<0.0001	<0.0001	<0.0001	<0.0001	<0.0005	<0.0001	
S (mg/L)	16	15	31	130	30		29		23			19	25	35		17	2.4	3.2	260	1900	12	
Se (mg/L)	<0.001	<0.001	<0.001	<0.002	0.001		<0.001		0.001			0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.005	<0.001	
U (mg/L)	0.001	0.001	0.001	0.002	0.002		0.002		0.002			0.001	0.001	0.001		0.001	<0.001	0.001	0.003	0.001	0.001	
V (mg/L)	0.0027	0.001	0.0036	0.004	0.0065		0.0073		0.012			0.001	0.0048	0.002		0.001	0.0033	0.004	0.0017	0.001	0.0007	
Zn (mg/L)	0.001	0.002	0.001	0.008	0.001		0.001		0.001			0.003	0.001	0.006		0.002	0.003	0.006	0.002	0.008	0.002	

Note: Grey shading indicates values outside the ANZECC/ARMCANZ (2000) guidelines.

4.4 Geology

The geology within a river catchment not only has an effect on the nature of sediment available within the system but, in some cases, directly influences stream channel behaviour itself. The geology at Yandi is part of a broader geological region known as the Hamersley Basin, a Precambrian basin which occurs over the southern part of the Pilbara Craton. The main geological features of the Yandi area (**Figure 4-4**) have been described by Tyler et al. (1991) and are summarised below.

The Proterozoic basement rock of the Weeli Wolli Formation is typically composed of a jaspilitic banded iron-formation (BIF), together with shale and chert. The BIF and shales of the Weeli Wolli Formation are overlain by a thin, red brown colluvial soil, containing angular gravel fragments. The shales and BIF are generally closely bedded or laminated and tend to break into flaky or tabular fragments on excavation. Natural exposures in creek banks indicate a moderately to highly weathered material of low to moderate strength.

The Weeli Wolli Formation has been intruded by several dolerite dykes and sills, giving a distinctive, broadly striped appearance to the outcrops. The upper zone of the dolerite is variably weathered to form a reddish brown, closely jointed and blocky material. Below this, the dolerite remains a fresh, grey, very high strength rock, with characteristic columnar jointing. One of the most prominent dolerite sills exposed at Marillana Creek forms the Flat Rocks site immediately upstream from Yandi.

The younger Cainozoic Robe Pisolite, also referred to as the CID, is associated with the presence of a meandering band of mesas within the Marillana Creek paleochannel which has incised into the Weeli Wolli Formation. This formation constitutes the main iron-ore deposits at Yandi and is composed of pisolitic limonite with fossil wood fragments. Where the present Marillana Creek crosses the CID, the CID forms sheer cliff faces 15 to 20 m high adjacent to the channel.

4.5 Geomorphology

The 25 km reach of Marillana Creek running through the Yandi lease area is characterised by a low sinuosity, bedrock controlled, anabranching channel. All geomorphic measures along the creek are highly variable, but the average dimensions and ranges are as follows:

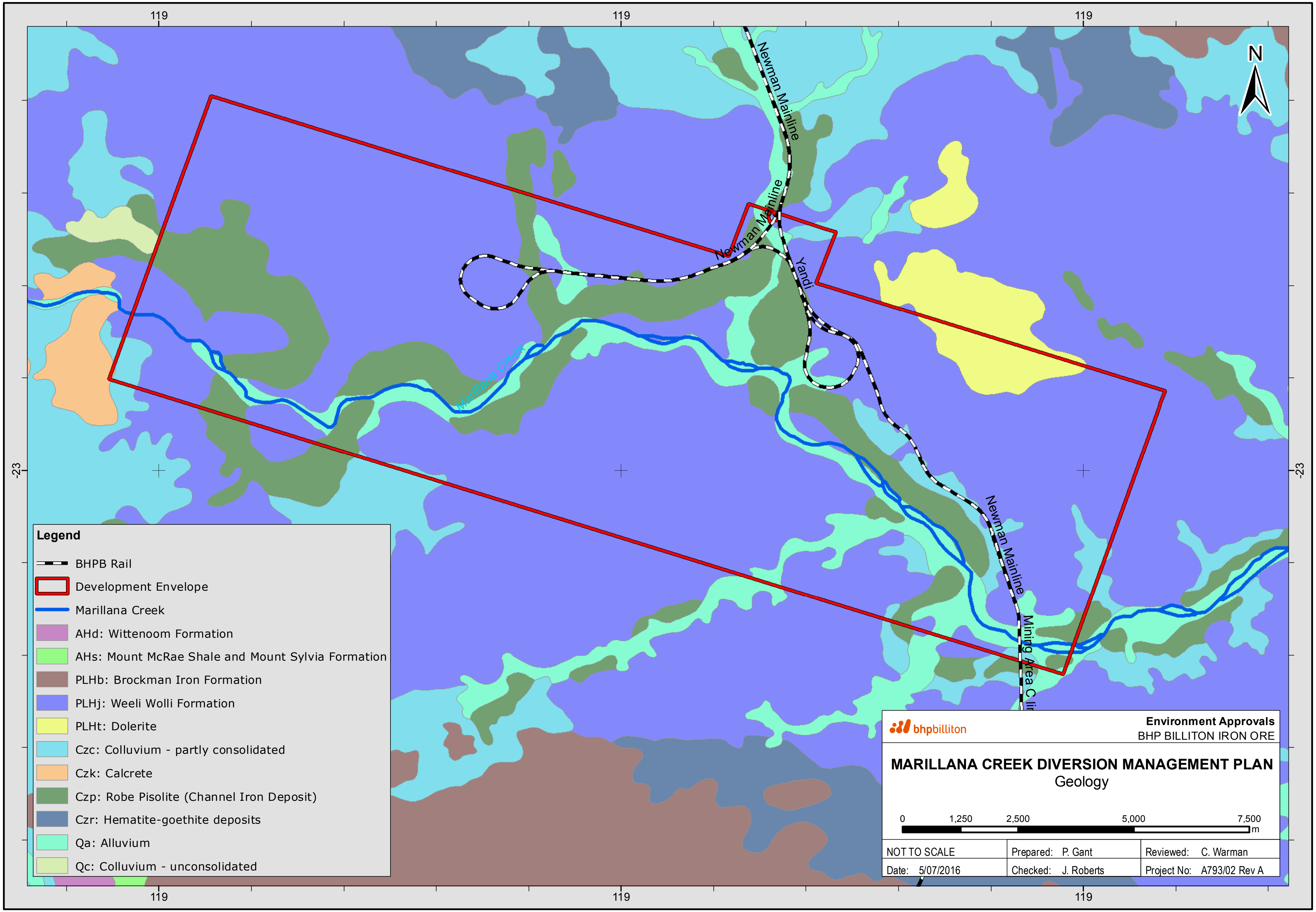
- channel width varies from 30 to 340 m, with an average of 153 m
- channel depth ranges from 1.2 to 3.4 m, with an average of 2.1 m
- slope varies between 0.002 and 0.003 m/m
- sinuosity ranges between almost straight (1.05 - 1.07) to winding (1.16).

While geomorphic characteristics in Marillana Creek are highly variable, the morphology at Yandi can be principally divided into two reach types, as described by Gilbert and Associates (2004), GHD (2007) and Entura (2014):

- unconfined to semi-confined anabranching reaches (approximately 60% of the channel length); and
- incised reaches with a planar channel bed (approximately 40% of the channel length)

The location of these reach types at Yandi is presented in **Figure 4-5**. A third reach type, characterised by exposed bedrock, is located directly upstream of Yandi at Flat Rocks.

Descriptions of the geomorphology of Marillana Creek presented below are principally drawn from Entura (2014).



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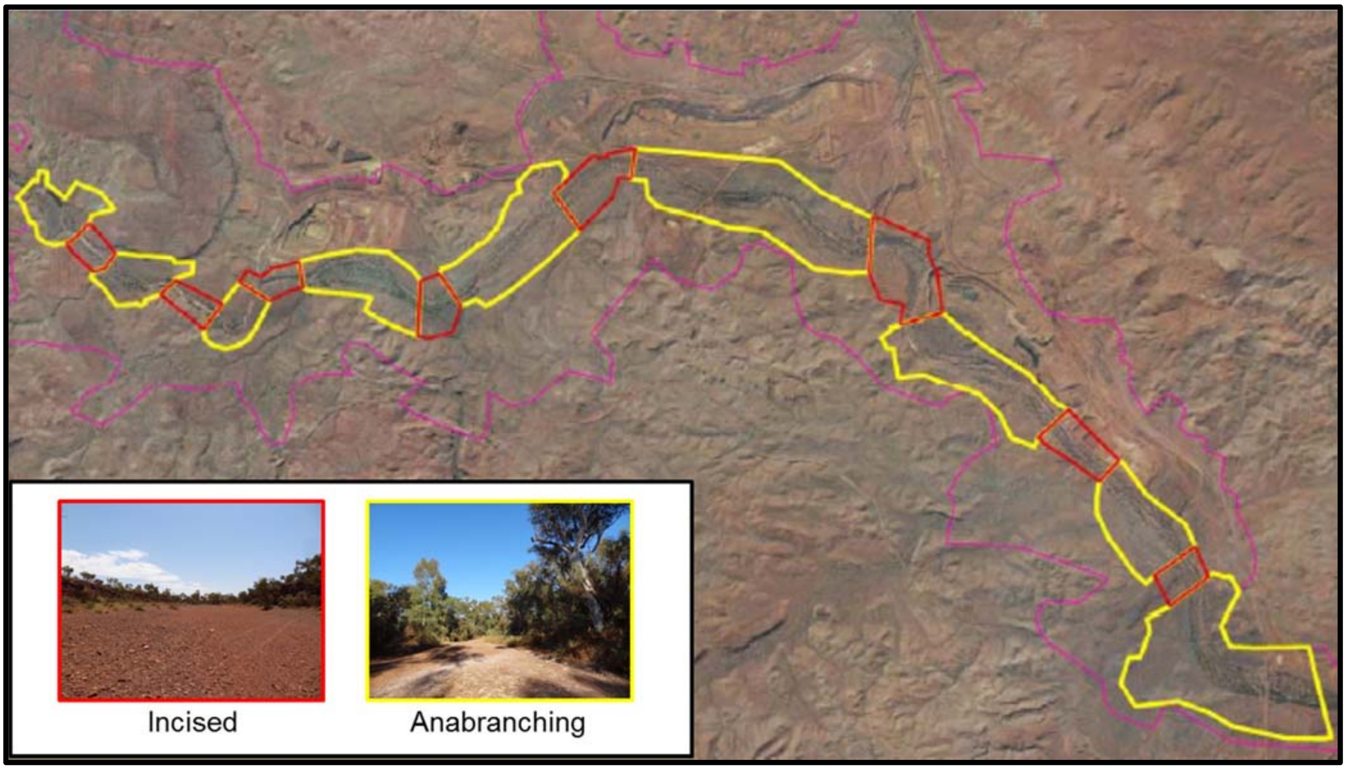


Figure 4-5: Reach types present in Marillana Creek at Yandi.
While geomorphic characteristics in Marillana Creek are highly variable, the morphology can be divided into two reach types; unconfined to semi-confined anabranching reaches and incised reaches with a planar channel bed.

4.5.1 Anabranching Reaches

Rivers with multiple channels characterised by vegetated or otherwise relatively stable, elongated alluvial bars that divide flows at discharges up to bankfull are classified as *anabranching* (Tooth and Nanson, 1999; Nanson, 2013). A conceptual cross section of an anabranching reach is presented in **Figure 4-6**. The crest of bars (herein referred to as "anabranch ridges") are characterised by silt, sand and fine gravels, while the base of the anabranch ridge is typically gravel. Anabranch ridges are an evolving channel-form that are progressively deposited and destroyed over time. As a result, ridge crests are seen at different elevations throughout Marillana Creek but can reach up to 2m high. Channels between anabranch ridges vary in width and depth, with deeper channels functioning as more active secondary flow channels.

The primary channel in anabranching reaches is relatively narrow, typically ranging between 30m and 50m wide. The median bed sediment size is fine gravel, but there is a wide range of bed-material sizes up to large boulders with clasts dominated by the local geology: CID, BIF and dolerite. The bounds of the primary channel are defined by the presence of anabranch ridges and/or a marginal bench.

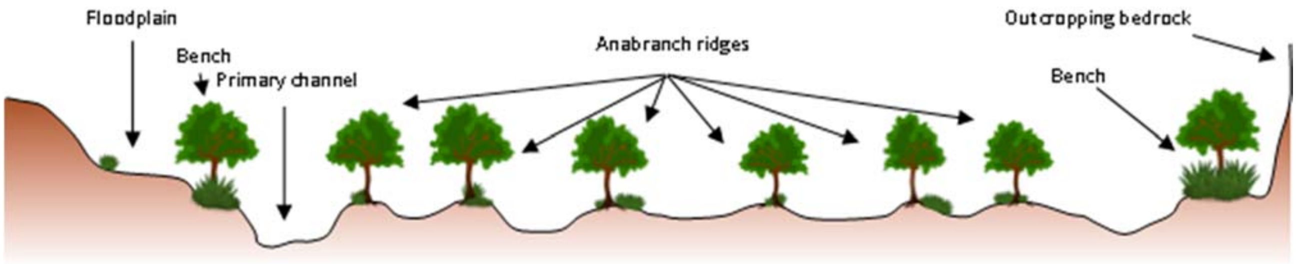


Figure 4-6: Conceptual cross-section of an anabranching channel reach in Marillana Creek.

A four stage process by which anabranch ridges evolve in Marillana Creek, is proposed by Entura (2014) as follows:

1. *Initiation phase*: A keystone tree establishes itself in the channel and becomes large enough to withstand flood events and influence flow. This increased roughness in the channel creates an area of lower velocity on the downstream side of the tree which promotes aggradation. This process is accentuated by “pier scour” around the trunk of the tree.
2. *Extension phase*: Further development of the anabranch ridge occurs as additional vegetation colonises the bar of sediment behind the keystone tree. This prompts a positive feedback loop of sediment accumulation and stabilisation by vegetation. The influence of the keystone tree is also accentuated by woody debris trapped by the tree.
3. *Interaction phase*: The further development of anabranch ridges is regulated by those forming adjacent to it. As ridges grow in size the width/depth ratio of the channel between them decreases and velocities increase. The sides of the ridges begin to erode and steepen as ridges continue to grow in height with deposition of suspended sediment.
4. *Destruction phase*: Keystone trees become susceptible to removal during large flood events either by death or undermining by ongoing “pier scour”. Eventual loss of the keystone tree leads to destruction of anabranch ridges. Anabranch ridges can also be broken by lateral flows cutting across them between successive large trees. This may occur as a result of the secondary tree gaining greater influence on local hydraulics.

Examples of anabranch ridge development are presented in **Figure 4-7**.

The general elevation of the crest of the anabranch ridges at Yandi is almost always coincident with the elevation of benches at the channel margin. Marginal benches are formed along most of the length of Marillana Creek, although not always on both sides of the channel. Similar to the formation of anabranch ridges, marginal benches are formed where surface water recirculation moves suspended sediment into slower velocity areas where it is deposited. Bench widths are typically 10 to 20 m wide, consist of fine-grained silt to sand, and are characteristically well vegetated. The stream-ward edges of the benches are usually close to vertical where it is undercut by lower flows. There are occasionally small secondary flood channels at the rear of the bench adjacent to outcropping bedrock or at the floodplain margin.

There is a well-defined, discontinuous floodplain along Marillana Creek that is typically 2 to 6 m higher in elevation than the active channel bed level. The surface of the floodplain has small channels and ridges of less than 0.5 m amplitude, and is typically covered by hummock grass. The floodplain is longitudinally discontinuous, and tends to occur on the inside of a channel bends.

Figure 4-7: Development of anabranch ridges in Marillana Creek.
Left: Sediment accumulates behind a keystone tree established in the channel. Right: Keystone trees become susceptible due to death and "pier scour".

A feature of Marillana Creek also evident throughout the anabranching reaches is the development of intermittent pools. Scour in the primary channel leads to the formation and maintenance of permeable pools following discharge events. This can occur either as a result of localised scour around trees forming small (sometimes quite deep) pools or scour along the channel margin resulting in elongated pools. The persistence of pools following discharge events varies, however some appear to remain for several months. While the prevalence of pools is sporadic it is likely that they play an important role in the ecological function of Marillana Creek through the provision of refugia for aquatic fauna.

Figure 4-8: Permeable pools in Marillana Creek.
Left: Localised scour around a large tree forming a small pool. Right: A large elongated pool at the channel margin.

4.5.2 Incised Reaches

Incised channel reaches are characterised by vertical cliffs of outcropping bedrock up to 20 m high through which Marillana Creek passes. A conceptual cross section of an incised reach is presented in **Figure 4-9**.The channel is characteristically broad (more than 100 m wide) and single-threaded. The channel bed is comprised of sand and gravels ranging in size from pebbles to cobbles. The channel bed profile is characterised as "featureless", with only slight changes in bed elevation noted between the thalweg and the remainder of the channel.

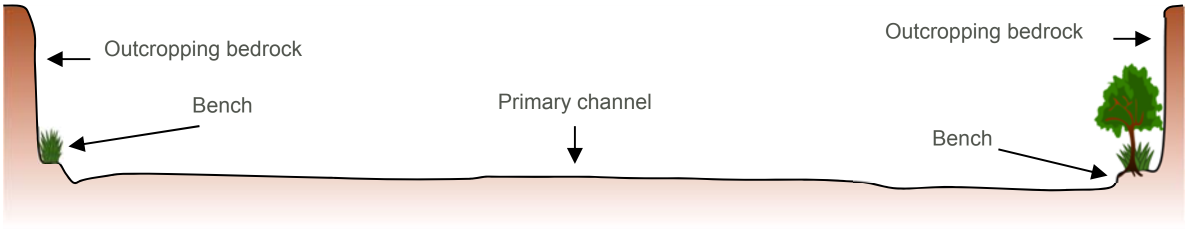


Figure 4-9: Conceptual cross-section of an incised channel reach in Marillana Creek.

The bounds of the channel are defined by the presence of marginal benches comprised of fine-grained silt to sand. Bench widths range in size from several metres up to 20 m wide. In contrast to the channel, which has very little vegetation, marginal benches are typically well vegetated. Benches are confined by the outcropping bedrock characteristic of this reach type. A small secondary flow channel is occasionally seen at the back of the bench running along the toe of the outcropping bedrock. Valley floor width, defined by the separation distance of outcropping bedrock, appears to be a key control on the formation of either incised or anabranching channel forms. For example, where valley widths increase to approximately 200 m or greater anabranching occurs despite the presence of CID cliffs on either side of Marillana Creek.

Outcropping bedrock at the margins of incised reaches confines flow during large discharge events, thereby increasing stage heights and shear stresses relative to those seen in anabranching reaches. As a result, vegetation is scoured from the channel reach and bedload sediments are readily mobilised. The more competent flow in the incised channel reaches transports sediment to anabranching reaches where it is deposited on ridges, benches and in the case of larger events, the floodplain. It is important to note, however, that incised reaches of Marillana Creek have a lower slope than anabranching reaches. This indicates that sediment behaviour through incised reaches is not simply limited to erosion and conveyance (which would result in relatively steeper slopes) but a phase of aggradation also occurs. It is likely that this occurs at a point on the waning limb of the flood hydrograph where the unit stream power in anabranching reaches exceeds that in incised reaches. This occurs when low flow volumes are confined to a relatively small primary channel in anabranching reaches whereas they are dissipated across a broad channel in planar reaches.

4.5.3 Bedrock Reaches

While not within the Yandi lease itself, the Flat Rocks reach of Marillana Creek represents another significant channel type in the area. Flat Rocks, located approximately 300 m upstream of Yandi, is a dolerite bedrock gorge approximately 2 km in length. A conceptual cross section of a bedrock reach is presented in **Figure 4-10**. The channel bed and banks are composed of exposed dolerite with very little alluvium present.

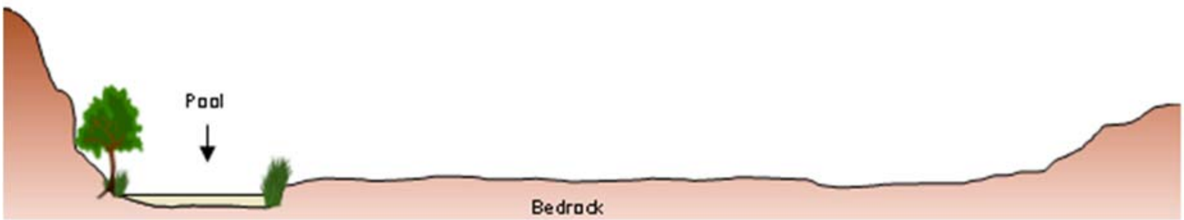


Figure 4-10: Conceptual cross-section of a bedrock reach in Marillana Creek.

The channel is characterised by a steeper average slope (0.0078) than seen further downstream but with significant variability in profile throughout the reach due to the jointed structure of the dolerite. As a result, non-permeable pools have formed in flatter sections of the channel reach. These pools persist for the majority of the year and support aquatic vegetation (freshwater algae, aquatic macrophytes and reeds) and fauna as discussed further in **Section 4.7.3**.

The absence of sediment through the bedrock reach is a result of a number of factors. Firstly, the retention capacity of the Munjina Flats located further upstream limits the supply of sediment to the reach. Secondly, the steeper channel slope results in highly competent flows that are readily able to entrain and transport sediment through the reach. Finally, despite the high competence and conveyance capacity of the flow, the resistance of the exposed dolerite to erosion provides little in-situ supply of sediment to the system.

4.6 Flora and Vegetation

Yandi is located in the Hamersley Botanical District, within the Pilbara IBRA region of the Eremaean Province (Beard 1990). The vegetation and flora at Yandi has been comprehensively studied over a number of years, with a total of 32 flora and vegetation surveys having been completed within or in close proximity to the Yandi lease area since mining commenced in 1991. The most recent flora and vegetation survey commissioned by BHP Billiton Iron Ore was conducted by Onshore Environmental in June 2015 to provide a detailed assessment of the riparian flora and vegetation of Marillana Creek through the Yandi lease.

Potential impacts to significant flora species were assessed under the original *Marillana Creek (Yandi) Life of Mine Proposal* and subsequent amendments under Section 45C of the *EP Act*, and it was concluded that the proposal would not have a detrimental impact to the survival of surveyed taxa as they are known from records from several localities (or more) which were not under imminent threat. In addition, the original proposal found that the riparian vegetation communities identified within the Yandi disturbance boundary were widespread, and there would be no regional loss of these communities as a result of the proposal.

No plant taxon gazetted as Threatened Flora (T) pursuant to subsection (2) of Section 23F of the *Wildlife Conservation Act* (*1950)* or listed under the *Environment Protection and Biodiversity Conservation Act (1999)* have been recorded from the Yandi lease area.

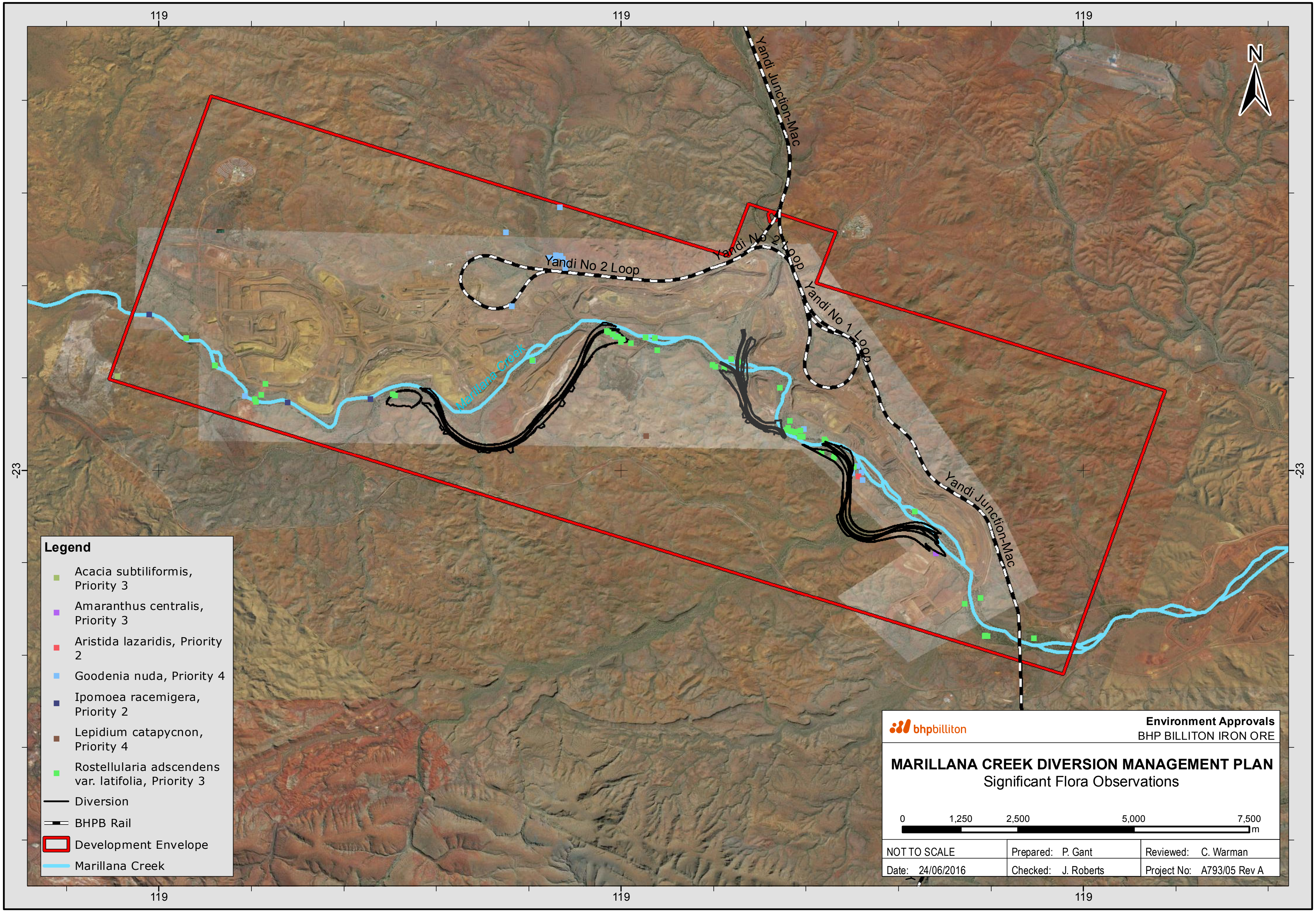
Seven Priority flora taxa as defined by the Western Australian Department of Parks and Wildlife are known to occur within the Yandi lease area (**Figure 4-11**):

- *Amaranthus centralis* (Priority 3);
- *Acacia subtiliformis* (Priority 3);
- *Aristida lazaridis* (Priority 2);
- *Goodenia nuda* (Priority 4);
- *Ipomoea racemigera* (Priority 2);
- *Lepidium catapycnon* (Priority 4); and
- *Rostellularia adscendens* var. *latifolia* (Priority 3).

The Priority flora species recorded at Yandi are all known from the surrounding area and have records from within conservation estate land (i.e. Karijini National Park or Millstream Chichester National Park).

Amaranthus centralis was recorded as scattered plants providing less than one percent cover from one location in the eastern sector of the Yandi lease area. Plants were growing to 0.4 m in height on brown clay loam on seasonally wet flood plains fringing Marillana Creek. This habitat extends beyond Yandi and throughout the central Pilbara region. *Amaranthus centralis* has been recorded from this habitat type within Karijini National Park, and is also known from another location within the Pilbara region. This species is widespread and commonly recorded in southern Northern Territory through to northern South Australia.

Acacia subtiliformis was recorded from one location in the far south-west corner of Yandi lease area. This species has been recorded from undulating low hills with prominent calcrete outcropping evident at the surface. This habitat is located immediately adjacent to the Yandi lease and extends northwest beyond the Yandi area. *Acacia subtiliformis* has also been recorded from this habitat and is known from 21 records between Newman and Karijini National Park, with one of these records occurring within Karijini National Park (NatureMap, 2015).



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Aristida lazaridis was recorded from two locations within the Yandi lease and is also known to occur on the floodplain adjacent to Marillana Creek beyond the eastern boundary of the lease. Scattered plants were recorded at each location. This species prefers sand or loam soils and occurs in the Pilbara and Kimberly Regions of Western Australia and in the Northern Territory and Queensland (Onshore Environmental, 2015a). There are recent records of this species from throughout the central Pilbara (BHP Billiton Iron Ore database). Regionally this species has been recorded from Karijini National Park (NatureMap, 2015) and the Coondewanna Flats area (Onshore Environmental, 2015a).

Goodenia nuda was recorded from 25 spot locations throughout the Yandi lease associated with floodplains and banks in the central part of Marillana Creek and its northern tributaries. The number of plants recorded at each location ranged from 1 to 25 plants. *Goodenia nuda* is commonly recorded throughout the Pilbara, including from within the Karijini National Park, associated with drainage levees, flood plains and sand plains. These habitat types are widespread outside of Yandi. *Goodenia nuda* has previously been collected from nearby tenements associated with similar habitat, including Camp Hill to the west and Jinidi to the south-east (Onshore Environmental, 2013b).

Ipomoea racemigera was recorded in the Yandi lease area as scattered creeping plants from five spot locations situated on raised banks within and fringing Marillana Creek. This species has been recorded from Newman through to Millstream Chichester National Park in the Pilbara region (NatureMap, 2015) and also from Kununurra in the Kimberley region (Onshore Environmental, 2015a). *Ipomoea racemigera* has recently been recorded from two sites west of Jimblebar Iron Ore Mine in the eastern Pilbara, occurring as approximately 40 plants from the major drainage channel of Shovellana Creek (Onshore Environmental, 2015b).

Lepidium catapycnon was recorded as four plants from a single location in the central southern section of the Yandi lease, associated with undulating low hill slopes. This landform that is well represented locally and regionally and large populations of *Lepidium catapycnon* have been recorded from localities nearby Yandi including Mount Robinson (Onshore Environmental, 2013b) and eight populations confirmed from Karijini National Park (Onshore Environmental, 2013a).

Rostellularia adscendens var. *latifolia* was recorded from multiple locations throughout the Yandi lease where it was recorded mostly from the banks and floodplains adjacent to Marillana Creek. This species is known to occur from numerous locations along Marillana Creek beyond the lease boundary and has been recorded nearby to Yandi at Weeli Wolli Creek and Jinidi (Onshore Environmental, 2013b). Regionally, *Rostellularia adscendens* var. *latifolia* is known from 29 locations between Warrawagine and Tom Price within the Pilbara region (NatureMap, 2015); including five records from within Karijini National Park (Onshore Environmental, 2013b).

One additional Priority flora taxa has been recorded within Marillana Creek from locations beyond the boundary of the Yandi lease area, *Goodenia* sp. East Pilbara (A.A. Mitchell PRP 727) (Priority 3). It was recorded from 11 locations on calcrete plains and hills surrounding Marillana Creek.

There were 21 introduced (weed) species recorded from the Yandi lease area. None of these species are listed as a Declared Plant under the *Biosecurity and Agriculture Management Act 2007*. One of the weeds of relevance to diversions is Buffel Grass (*Cenchrus ciliaris) which can completely dominate some creeklines and is readily spread by wind and herbivores. Other weeds of concern include Ruby Dock (*Acetosa vesicaria), Kapok Bush (*Aerva javanica), Feathertop Rhodes Grass (*Chloris virgata), Couch (*Cynodon dactylon) and Mimosa Bush (*Vachellia farnesiana) which has the propensity to form dense thickets.

A total of 24 vegetation associations from 12 broad floristic formations were described and mapped from the Yandi lease (this includes a non-vegetated unit mapped in association with the ephemeral pools located throughout Marillana Creek). None of the vegetation associations had any affiliation with Federal or State listed Threatened Ecological Communities (TECs), or State listed Priority Ecological Communities (PECs). Vegetation condition within the Yandi lease ranged from excellent to degraded.

Detailed riparian vegetation mapping of Marillana Creek was completed by Onshore Environmental (2015). A total of 22 vegetation associations were described for the creek system and adjacent plains (**Table 4-4**). The dominant species and description of the vegetation based on the main landform types of the creek system are summarised below:

Stream Bed of Major Channels

Open forest to open woodland of tall riverine eucalyptus (*Eucalyptus victrix, E. camaldulensis* subsp. *refulgens*) and cajeput (*Melaleuca argentea*) over variable understorey of small trees or tall shrubs (*Acacia citrinoviridis, Acacia coriacea* subsp. *pendens, Melaleuca glomerata* and *Melaleuca bracteata*) over open low shrubs or heath

(*Corchorus crozophorifolius, Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186)) and perennial tussock grasses (*Eriachne* species).

Stream Banks

Open woodland of riverine eucalyptus (*Eucalyptus victrix, E. camaldulensis* subsp. *refulgens*) over low woodland (*Acacia coriacea* subsp. *pendens, Atalaya hemiglauca, Acacia citrinoviridis, Acacia pruinocarpa, Corymbia hamersleyana*) with low shrubs (*Corchorus crozophorifolius, Acacia pyrifolia*) over hummock grasses (*Triodia* species) and tussock grasses (*Eriachne tenuiculmis* and *Enneapogon lindleyanus*).

Floodplains

Grassland of hummock grasses (*Triodia* species) and/or tussock grasses (*Themeda triandra*, *Eulalia aurea*) with open woodland (*Eucalyptus victrix*, *Corymbia hamersleyana*, *C. aspera*, *Hakea lorea* subsp. *lorea* and *Acacia* species) and high open shrubs (mostly *Acacia* species and *Gossypium robinsonii*).

Slopes and Uplands (Terrestrial Vegetation)

Hummock grassland (*Triodia* species, mostly *T. wiseana*) with low woodland (*Eucalyptus species, Acacia pruinocarpa*) and open shrubs (*Acacia* species and *Senna* species).

Table 4-4: Detailed vegetation associations for Marillana Creek by landform.

Landform	Vegetation Association
Stream Bed of Major Channels	Open Forest of *Eucalyptus camaldulensis, Melaleuca argentea* and *Eucalyptus victrix* over Low Open Forest of *Acacia coriacea* subsp. *pendens, Atalaya hemiglauca* and *Melaleuca argentea* over Sedgeland of *Typha domingensis, Cyperus vaginata* and *Schoenoplectus subulatus* on major drainage line with pools with brown light clay or sandy loam
	Open Forest of *Eucalyptus victrix* and *Eucalyptus camaldulensis* over Open Scrub of *Melaleuca bracteata* and *Melaleuca glomerata* with Low Open Woodland of *Acacia ampliceps* and *Atalaya hemiglauca* on major drainage line with brown light clay
	Woodland of *Eucalyptus camaldulensis* and *Eucalyptus victrix* over Low Woodland of *Acacia coriacea* subsp. *pendens, Eucalyptus victrix* and *Eucalyptus camaldulensis* over Low Open Shrubland of *Corchorus crozophorifolius* and *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) on major drainage line with brown clayey sand
	Open Woodland of *Eucalyptus camaldulensis, Melaleuca argentea* and *Eucalyptus victrix* over High Open Shrubland of *Melaleuca glomerata* and *Myoporum montanum* over Very Open Herbs of *Pluchea rubelliflora* and *Stemodia grossa* on open gravel beds of major drainage line with brown sand/clay loam
	Low Open Heath of *Corchorus crozophorifolius* and *Tephrosia rosea* var. Fortescue creeks (M.I.H. Brooker 2186) with Scattered Trees of *Eucalyptus camaldulensis* and *Eucalyptus victrix* and Scattered Tussock Grasses of *Eriachne tenuiculmis, *Cenchrus ciliaris* and *Eriachne pulchella* subsp. *dominii* on creekbed of major drainage line with brown clay loam
	Open Herbs of *Potamogeton tricarinatus* with Open Woodland of *Eucalyptus camaldulensis* and Very Open Sedges of *Typha domingensis, Schoenoplectus subulatus* and *Cyperus vaginatus* on dolerite platforms of major drainage line with brown light clay
Stream Banks	Woodland - Open Woodland of *Eucalyptus camaldulensis* and *Eucalyptus victrix* over Low Woodland of *Acacia coriacea* subsp. *pendens, Atalaya hemiglauca* and *Eucalyptus victrix* over Open Hummock Grassland of *Triodia pungens* and *Triodia longiceps* on levees and channel islands of major drainage lines with brown sandy loam
	Low Woodland of *Acacia citrinoviridis, Acacia coriacea* subsp. *pendens* and *Atalaya hemiglauca* with Open Hummock Grassland of *Triodia pungens* and Open Tussock Grassland of *Eriachne tenuiculmis* and *Enneapogon lindleyanus* on raised levee banks of major drainage line with brown loam
	Hummock Grassland of *Triodia pungens* and *Triodia wiseana* with Low Woodland of *Acacia pruinocarpa, Corymbia hamersleyana* and *Acacia coriacea* subsp. *pendens* and Low Shrubland of *Corchorus crozophorifolius* and *Acacia pyrifolia* on levee banks of major drainage line with brown sandy loam
	Tussock Grassland of *Sorghum plumosum, Eriachne tenuiculmis* and *Themeda triandra* with Low Open Woodland of *Eucalyptus victrix, Eucalyptus camaldulensis* and *Acacia coriacea*

	subsp. *pendens* and High Open Shrubland of *Grevillea pyramidalis* subsp. *leucadendron, Gossypium robinsonii* and *Acacia pyrifolia* on levee banks of major drainage line with brown silty loam
Floodplains	Hummock Grassland of *Triodia wiseana* and *Triodia longiceps* with Low Open Woodland of *Corymbia hamersleyana, Acacia aptaneura* and *Hakea lorea* subsp. *lorea* and Open Shrubland of *Acacia arida, Acacia ancistrocarpa* and *Acacia bivenosa* on plains with brown silty loam
	Hummock Grassland of *Triodia pungens, Triodia longiceps* and *Triodia wiseana* with Low Open Woodland of *Hakea lorea* subsp. *lorea, Acacia pruinocarpa* and *Corymbia aspera* and High Open Shrubland of *Acacia dictyophleba, Acacia pachyacra* and *Gossypium robinsonii* on floodplains with brown sandy loam or clay loam
	Tussock Grassland of **Cenchrus ciliaris, Themeda triandra* and *Bothriochloa ewartiana* with Open Woodland of *Eucalyptus victrix* and *Eucalyptus camaldulensis* and Very Open Hummock Grassland of *Triodia pungens* on floodplains and levee banks of major drainage line with brown sandy loam
	Tussock Grassland of *Eulalia aurea, Themeda triandra* and *Eriachne tenuiculmis* with High Shrubland of *Acacia tumida* var. *pilbarensis* and *Gossypium robinsonii* and Open Woodland of *Eucalyptus victrix* on floodplains with brown sandy loam
	Tussock Grassland of *Themeda triandra, Eulalia aurea* and *Aristida inaequiglumis* with Open Woodland of *Eucalyptus victrix* and *Corymbia aspera* and High Open Shrubland of *Gossypium robinsonii, Eremophila longifolia* and *Atalaya hemiglauca* on plains with brown sandy loam
Slopes and Uplands	Hummock Grassland of *Triodia wiseana* and *Triodia pungens* with Low Woodland of *Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia pruinocarpa* and Open Shrubland of *Corchorus lasiocarpus* subsp. *lasiocarpus, Senna glutinosa* subsp. *glutinosa* and *Senna glutinosa* subsp. x *luerssenii* on hillcrests and upper slopes of ironstone ranges with brown sandy loam
	Hummock Grassland of *Triodia wiseana* with Open Shrubland of *Eremophila fraseri, Senna glutinosa* subsp. *glutinosa* and *Senna artemisioides* subsp. *oligophylla* on dolerite hills with brown sandy loam
	Hummock Grassland of *Triodia wiseana* and *Triodia pungens* with High Open Shrubland of *Acacia inaequilatera* and *Acacia bivenosa* (wispy form) and Scattered Low Trees of *Corymbia hamersleyana* and *Acacia pruinocarpa* on hillslopes with brown sandy loam
	Hummock Grassland of *Triodia angusta* and *Triodia wiseana* with Open Mallee of *Eucalyptus socialis* subsp. *eucentrica* and *Eucalyptus xerothermica* and High Open Shrubland of *Acacia bivenosa* (wispy form) and *Petalostylis labicheoides* on undulating calcrete plains and hills with brown silty clay loam
	Hummock Grassland of *Triodia pungens* and *Triodia wiseana* with Low Open Woodland of *Eucalyptus leucophloia* subsp. *leucophloia* and *Acacia pruinocarpa* and High Open Shrubland of *Grevillea wickhamii* and *Acacia monticola* on hillslopes and hillcrests with brown sandy loam
	Hummock Grassland of *Triodia wiseana, Trioida longiceps* and *Triodia angusta* with Low Open Woodland of *Eucalyptus xerothermica, Corymbia hamersleyana* and *Hakea lorea* subsp. *lorea* and High Open Shrubland of *Acacia bivenosa* (wispy form), *Acacia inaequilatera* and *Acacia ancistrocarpa* on undulating calcrete plains and slopes with brown loam
	Hummock Grassland of *Triodia schinzii* over Open Tussock Grassland of *Paraneurachne muelleri, Eragrostis eriopoda* and *Eulalia aurea* with Low Open Woodland of *Hakea lorea* subsp. *lorea, Corymbia aspera* and *Corymbia hamersleyana* on stony sandplains with red sand

(Onshore Environmental, 2015)

4.7 Fauna

The fauna at Yandi has been comprehensively studied over a number of years, with numerous vertebrate fauna, short-range endemic (SRE) invertebrate fauna, and aquatic fauna surveys having been completed within or in close proximity to the Yandi lease area since the commencement of mining.

Potential impacts to fauna species were assessed under the original *Marillana Creek (Yandi) Life of Mine Proposal* and subsequent amendments under Section 45C of the *EP Act*. It was concluded that the proposal would not have a detrimental impact to the survival of surveyed taxa as they are known from beyond the Yandi lease area and generally throughout the wider region.

4.7.1 Vertebrate Fauna

Seven fauna habitats have been mapped at Yandi (Biologic, 2014). Of these habitats, the *Major Drainage Line* habitat type associated with Marillana Creek is considered to be of highest importance to fauna as it provides foraging and dispersal opportunities for a number of species (Biologic, 2011). This habitat extends beyond the Yandi lease area and, like other habitat types at Yandi, is reasonably widespread in the local area and occurs throughout the Pilbara region (Biologic, 2014).

Field assessments have identified eight conservation significant vertebrate fauna species within the Yandi lease area (**Figure 4-12**[1]):

- Northern Quoll, *Dasyurus hallucatus* (EPBC Act Endangered, WC Act Schedule 2);
- Pilbara Olive Python, *Liasis olivaceus* subsp. *barroni* (EPBC Act Vulnerable, WC Act Schedule 3);
- Western Pebble-mound Mouse, *Pseudomys chapmani* (DPaW Priority 4);
- Common Sandpiper, *Tringahypoleucos* (EPBC Act Migratory, WC Act Schedule 5);
- Eastern Great Egret, *Ardea modesta* (EPBC Act Migratory, WC Act Schedule 5);
- Fork-tailed Swift, *Apus pacificus* (EPBC Act Migratory, WC Act Schedule 5);
- Peregrine Falcon, *Falco peregrinus* (WC Act Schedule 7); and
- Rainbow Bee-eater, *Merops ornatus* (EPBC Act Migratory, WC Act Schedule 5).

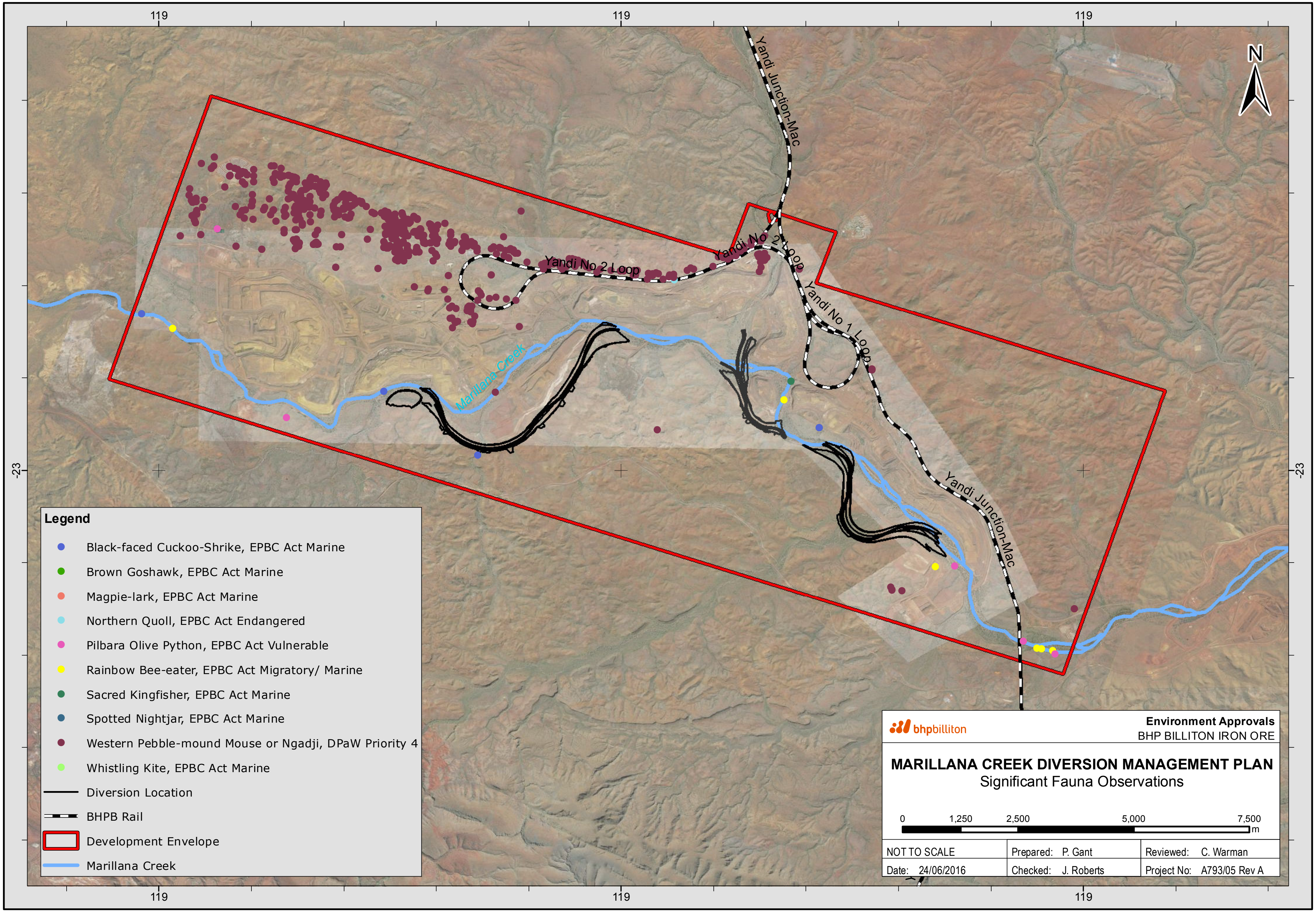
The Northern Quoll was recorded from a single road-killed individual within the Yandi lease area in 2010 (Biologic, 2011). Northern Quolls are known to den in rocky areas and outcrops which are largely absent from Yandi. The major drainage lines at Yandi, however, offer dispersal and foraging opportunities for this species. In the surrounding area there are records of the Northern Quoll from Karijini National Park, Hope Downs and Koodaideri, and three single scat records at South Flank, Camp Hill and Marillana (Biologic, 2013a). The records, combined with the large amount of survey effort undertaken throughout the region, suggest that this species does not reside in the area but occurs transiently and in low numbers. The presence of Northern Quolls at Yandi was assessed as unlikely based on the species' distribution and its habitat preferences (Ecologia Environment, 2008).

The presence of the Pilbara Olive Python was recorded from Marillana Creek within the Yandi lease (Biologic, 2011). There has also been a siting from early 2013 of this species from the evaporation pond south of Spinifex Camp. This species prefers to inhabit areas of deep gorges and waterholes in rocky ranges (Pearson, 2003). At Yandi the major drainage line habitat containing ephemeral pools (i.e. Marillana Creek) would provide suitable foraging habitat for this species. This habitat extends beyond Yandi and suitable habitat for this species is present within the surrounding region, with nearby records for this species at Mining Area C, Marillana, Jinidi, South Flank and Tandanya (Biologic 2011; BHP Billiton Iron Ore database). This species is considered to be common and widespread in the Hamersley region.

There are numerous records of Western Pebble-mound Mouse mounds at Yandi. This species is endemic to the Pilbara region and inhabits the gentler slopes of rocky ranges with stony mantle ground cover and vegetated by hard spinifex (van Dyck and Strahan, 2008). A large portion (approximately 70%) of Yandi is mapped as suitable crest/ slope habitat for this species (Biologic, 2011). Suitable habitat for this species also occurs beyond Yandi and is widespread throughout the Pilbara region with over 192,700 ha of this habitat type mapped from BHP Billiton Iron Ore tenure (Biologic, 2014).

The Common Sandpiper is a migratory species that winters in Australia, and prefers to inhabit edges of sheltered waters salt or fresh (Johnstone and Storr, 1998). This species has been recorded on one occasion from Yandi (Maunsell, 2003).

[1] Note not all bird species are shown on Figure 4-12 as coordinates for the records were not provided in the historical survey reports.



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The Eastern Great Egret is described as dispersive and migratory in parts of its range (DEWHA, 2010d), with some regular seasonal movements. The preferred breeding habitat of this species includes river pools with Eucalyptus and Melaleuca tree species (Johnstone and Storr, 1998), similar to the habitat associated with Marillana Creek. This species has been recorded once at Yandi (Maunsell, 2003)

The Fork-tailed Swift is largely an aerial species and does not utilise terrestrial habitats. It has a broad distribution across much of Western Australia and is viewed as a nomadic species. Fork-tailed Swifts have been seen flying over Marillana Camp, is on the eastern boundary of the Yandi lease (Biologic 2011).

The Peregrine Falcon is uncommon but wide ranging across Australia. They occur mainly along coastal cliffs, rivers and ranges as well as wooded watercourses and lakes. The Peregrine Falcon nests primarily on cliffs, granite outcrops and quarries, and feed mostly on birds (Johnstone and Storr 1998). Individuals have been recorded from the Yandi lease area on two occasions (Biologic 2011).

The Rainbow Bee-eater is a common and widespread species in Western Australia, except in the drier interior of the State and the far south-west. It occurs in lightly wooded, often sandy country, preferring areas near water. This species is common within the Yandi area having been recorded predominantly in association with Marillana Creek (Biologic 2011).

4.7.2 Short-range Endemic Invertebrate Fauna

Five Potential Short-range endemic (SRE) invertebrate fauna species are known to occur at Yandi (**Figure 4-13**):

- one spider: *Karaops* ‘ARA001-DNA’;
- one snail: *Succinea* ‘sp. indet.’; and
- three pseudoscorpions: *Xenolpium* ‘sp. indet.’/ *Xenolpium* ‘cf. PSE033’, *Troglochernes* ‘sp. indet.’ and *Sundochernes* ‘PSE090’.

Twenty-seven specimens of *Karaops* ‘ARA001-DNA’ have been recorded at Yandi and one additional specimen outside of, but adjacent to, Yandi (Biologic, 2013b; 2015). This species has been categorised under Western Australian Museum (WAM) category ‘D’ molecular evidence and has been designated as a Potential SRE. This species is currently only known from Yandi and immediately adjacent areas. It was recorded from a wide range of rocky habitats throughout the Yandi lease area (Biologic 2015), habitat that occur extensively throughout the wider local area surrounding Yandi.

The Potential SRE species *Xenolpium* ‘sp. indet.’ was recorded from 25 locations at Yandi. The collections of this species at Yandi were juvenile, and as such were categorised under WAM category ‘A’ data deficient due to the inability to identify juvenile *Xenolpium* specimens (Biologic, 2015). DNA analysis on one of the specimens (labelled *Xenolpium* ‘cf. PSE033’) found it to be genetically comparable to a species found approximately 75km to the west of Yandi, *Xenolpium* `PSE033` (Biologic, 2015). During surveys at Yandi, *Xenolpium* pseudoscorpions were frequently detected across almost all habitat types (Biologic, 2015).

The snail *Succinea* ‘sp. indet.’ was recorded as two specimens from a single location at Yandi, and the pseudoscorpions *Troglochernes* ‘sp. indet.’ and *Sundochernes* ‘PSE090’ each from a single specimen. All three species were found within dense vegetation-based habitats and complex detrital microhabitats which only occur in association with Marillana Creek and its floodplains (Biologic, 2015). Marillana Creek is likely to act as a dispersal habitat for these taxa, with similar habitat extending upstream and downstream of the Yandi lease, and due to the relatively continuous corridor of dense vegetation and the periodic influence of flooding (Biologic, 2015).

4.7.3 Aquatic Fauna

A number of regionally restricted (Pilbara endemic) surface water macroinvertebrates and potential SRE aquatic macroinvertebrate species from within the hyporheic zone[2] were recorded at Yandi (WRM 2015). These species were recorded from sites both upstream and downstream of the proposed diversions (see **Figure 4-13**). Species included:

[2] The hyporheic zone comprises subsurface interstitial spaces in coarse creek bed sediments that creates habitat and connectivity between surface and subsurface (groundwater) zones and is recognised as a critical component of many streams.

Regionally restricted surface water species recorded were:

- one damselfly: *Eurysticta coolawanyah*; and
- two dragonflies: *Hemicordulia koomina* and *Nannophlebia injibandi*.

Eurysticta coolawanyah (Pilbara Pin Damselfly) is listed as Near Threatened on the IUCN Redlist. It is a Pilbara endemic, encountered in riverine pool habitats with a range in frequency of inundation and degree of persistence, including permanent/semi-permanent pools, permanent springs, ephemeral pools and sites permanently inundated and flowing due to mine dewatering discharge operations. *E. coolawanyah* is known from over 40 locations across the Pilbara (WRM, 2015).

Hemicordulia koomina (Pilbara Emerald dragonfly) is listed as Near Threatened on the IUCN Redlist. *H. koomina* was not recorded at Yandi but rather at a reference site upstream at Flat Rocks. *H. koomina* appears to prefer wide, relatively deep permanent pools but is also found at large ephemeral riverine pools. This species is a Pilbara endemic known to occur at Millstream station, Koomina Pools (Tanberry Creek), Palm Pool (50 km south of Karratha), Fortescue Crossing and Millstream Spring (Hawking 2009), as well as Kalgan Creek, Nyeetbury Spring (Robe River), Red Hill Creek, Bamboo Springs (DeGrey River), the Ashburton River system, Cane River, Sherlock River, and the Shaw River (Pinder *et al.* 2010). Despite its seemingly widespread distribution across the Pilbara, *H. koomina* is infrequently collected, and often in low numbers (WRM, 2015).

Although not listed as being of conservation significance, the Pilbara archtail dragonfly *Nannophlebia injibandi* is restricted to the Pilbara region, and is relatively infrequently collected. *N. injibandi* is typically encountered at warm, shallow, ephemeral creekline pools, such as those along the lower reaches of Marillana Creek at Yandi. It appears this species has fast larval development to ensure rapid maturation to adult stage in such habitats (WRM, 2016). In addition to Marillana Creek, *N. injibandi* is known from Millstream Delta and Gregory Gorge in the Fortescue River catchment (Pinder *et al.* 2010), Weeli Wolli Creek and the DeGrey River (DPaW 2015, WRM 2016).

Potential SRE hyporheic fauna recorded were:

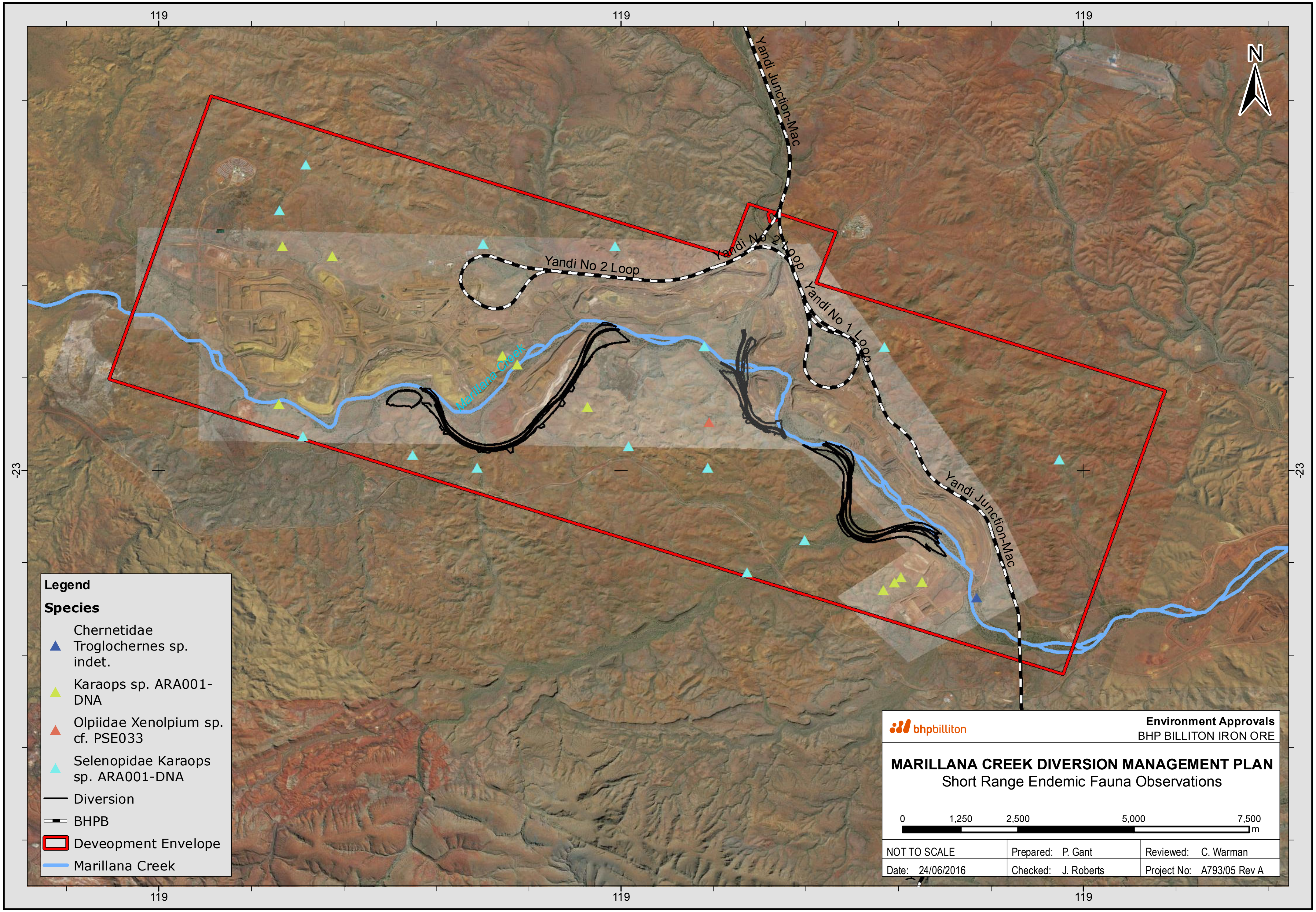
- one ostracod: *Gomphodella* n. sp. (BOS334); and
- three amphipods: *Chydaekata* sp., *Paramelitidae* sp. B and *Paramelitidae* sp. D.

In general, sampling of the hyporheic zone suggests that hyporheic fauna are more diverse and abundant at sampling locations with coarse pebbles, gravel and/or sand substrates, which are conducive to hyporheic flows, allowing movement of fauna through interstitial spaces. The low hydraulic conductivity of clay is not conducive to hyporheic flows or the provision of interstitial spaces to allow movement of fauna. Bedrock substrates also inhibit hyporheic flows and therefore limit the presence of fauna. Therefore, the presence of SRE species in the hyporheic zone is reliant on coarse sediments with low compaction (WRM, 2016).

Gomphodella n. sp. (BOS334) is likely to be locally or regionally endemic. Several *Gomphodella* species are known only from one locality and are commonly found in springs. *Gomphodella* n. sp. (BOS334) has previously been recorded from bores in the Yandi area as well as from hyporheic zones on Weeli Wolli Creek (WRM 2015). *Gomphodella* n. sp. (BOS334) was recorded at the upstream extent of the Yandi lease area as well as at one location reach between the proposed diversions.

Chydaekata sp. is currently undescribed, and is known only from Weeli Wolli Creek, Marillana Creek, Coondiner Creek and Mindy Mindy Creek (WRM 2015, Bennelongia 2011). This would suggest it is an SRE with high conservation value. *Chydaekata* sp. was collected from the hyporheic zone in the channel reach between the proposed diversions.

The stygobitic amphipods *Paramelitidae* sp. B and *Paramelitidae* sp. D are also currently undescribed species. Both species appear to be restricted to Weeli Wolli Creek, Marillana Creek (WRM 2015) and the Coondewanna Flats catchment (Bennelongia 2011). Again, these species appear to be SRE taxa and of high conservation value. Both species were collected from the hyporheic zone in the channel reach between the proposed diversions.



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4.8 Aboriginal Heritage

4.8.1 Current Heritage Knowledge - Pilbara

Archaeological research in the Pilbara region has focused strongly on the timing, nature and continuity of human occupation of the region. Recent archaeological excavations have demonstrated occupation sequences from 40,000BP with two models, a biogeographic and a desert transformation model, proposed for how people subsisted through inland Australia and hence the central Pilbara. The biogeographic model proposes that settlement was effected by changes in climate that in turn affected areas suitable for people to live (Veth, 1993). While some areas became refuges during periods of increased aridity others became barriers. The desert transformation model develops the biogeographic model further through a series of hypotheses built around adaptive strategies and technological changes (Hiscock and Wallis, 2005). Unfortunately at this time there is not enough data in Australia to effectively assess these models for the initial settlement period.

Recent excavations undertaken in the Pilbara indicate significant changes in both the intensity of occupation and mobility of people depending on environmental conditions. The adaptations of people are particularly evident during the Last Glacial maximum (LGM) which occurred approximately 25,000 – 17,000BP where increased aridity prevailed. Archaeological sequences from this period have been interpreted to represent increased residential mobility as a response to increased aridity during the LGM with decreased mobility after the LGM as aridity decreased.

4.8.2 BHP Billiton Iron Ore – Cultural Heritage Management Principals

Cultural Heritage Management at BHP Billiton Iron Ore is driven by the Sustainable Heritage Strategy. The strategy is underpinned by three elements – legal compliance, scientific research and legacy building – with three key objectives:

- Comply with the WA *Aboriginal Heritage Act 1972* (*AH Act*) and other relevant legislation;
- Guide the heritage approvals process by addressing key gaps in the knowledge base; and
- Create a positive heritage legacy for future generations.

The strategy enables the effective facilitation of meaningful and effective partnerships which centre on common concerns and improve the ongoing management of the heritage landscape in the Pilbara.

BHP Billiton Iron Ore conducts its operations in accordance with a standard set of heritage principles. These principles are based on international conventions, regulatory processes, community expectations and industry standards:

1) BHP Billiton Iron Ore conducts its operations in accordance with all State, Federal and international heritage legislation.
2) BHP Billiton Iron Ore recognises that Australian Aboriginal people have an intrinsic link to land, culture, and heritage.
3) BHP Billiton Iron Ore works cooperatively with Aboriginal communities to jointly identify, record and manage heritage sites.
4) BHP Billiton Iron Ore conducts archaeological and ethnographic surveys to identify and record significant heritage sites prior to undertaking land disturbance activities.
5) BHP Billiton Iron Ore keeps an active register of all significant heritage sites situated on tenure.
6) BHP Billiton Iron Ore integrates its heritage management processes into standard business planning and project cycles and native title agreements where applicable.
7) BHP Billiton Iron Ore has an internal land management procedure to ensure compliance with legal and community commitments.
8) BHP Billiton Iron Ore is committed to minimising impacts to significant heritage sites through consultation/planning.
9) BHP Billiton manages cultural objects in accordance with protocols outlined in a Cultural Materials Management Plan.

10) BHP Billiton Iron Ore actively promotes Aboriginal Culture through community-based heritage projects and academic research.

4.8.3 Management of Cultural Landscapes

Cultural landscapes are an important element of the Indigenous cultural heritage of the Pilbara. Indigenous cultural values which represent past and present connection to country are not always represented physically in the landscape and can be imbued to a physical place or location through story, song, dance, language, kinship, custom, ceremony or ritual. Through these traditions cultural heritage values may give shape, form and meaning to a particular landscape with or without an archaeological or physical component. This is termed a ‘cultural landscape’ and needs to be considered when assessing significance of heritage places. The identification, mapping and management of cultural landscapes while meeting regulatory requirements, taking into account stakeholder expectations and potential impacts to cultural significance are a management requirement within BHP Billiton’s GLD’s: *Our Requirements*.

4.8.4 BHP Billiton Iron Ore – Native Title Agreements

BHP Billiton Iron Ore has entered into a claim-wide agreement with the Banjima Native Title Group that provides certainty around future tenure requirements beyond the existing lease and mining operations in the area. As part of this agreement BHP Billiton Iron Ore and the Banjima Native Title Group have agreed to specific cultural heritage commitments in relation to the management of heritage sites including the recognition, mapping and capture of places of ethnographic importance (i.e. exclusion zones).

4.8.5 BHP Billiton Iron Ore – Management, Compliance and Sustainability

BHP Billiton Iron Ore conducts archaeological and ethnographic surveys with the relevant Traditional Owners to identify any significant heritage sites situated within its areas of interest. Based on BHP Billiton’s Iron Ore Life of Asset (LOA) data, approximately 55 % of the LOA area has been archaeologically surveyed with all identified heritage sites (archaeological and ethnographic) managed by BHP Billiton Iron Ore’s Heritage and GIS team.

The Yandi lease has been subject to detailed Archaeological and Ethnographic surveys and BHP Billiton has consulted with the Banjima on the Creek diversion project. All potential Heritage sites have been identified. One Ethnographic site has been identified within the lease. In addition, one significant site, the Barimuya / Three Sisters site, sits outside of the lease. None of these places will be impacted by the Project.

BHP Billiton Iron Ore manages and protects Aboriginal heritage in compliance with the *AH Act*. Heritage sites are managed by the Heritage and GIS team in accordance with strict internal processes and procedures. Within surveyed areas, BHP Billiton Iron Ore is aware of the spatial location of each heritage place and, where practical, adopts engineering solutions to avoid them. If any heritage site cannot practically be avoided, BHPBIO seeks to consult with the relevant Native Title Group and apply for approval from the Minister for Aboriginal Affairs under Section 18 of the *AH Act* before the site is disturbed. Requirements around the management and minimising impacts to significant heritage places and values are a performance requirement of BHP Billiton.

As described in **Section 2.6**, BHP Billiton Iron Ore has developed the Project, Environmental, Aboriginal, Heritage, Review (PEAHR) procedure to internally manage and enforce conditions associated with all ground disturbing activities and ensure compliance to environmental, Aboriginal heritage, land tenure , legal and regulatory requirements. The PEAHR procedure provides a mechanism for the heritage specialists within the Heritage and GIS team to provide technical and professional advice regarding cultural heritage management of sites including protection requirements to ensure compliance with the *AH Act* and the relevant Native Title Agreements.

5 Hydrological, Hydraulic and Sediment Transport Modelling

It is a balance between the discharge regime and sediment regime of a fluvial system that ultimately influences stream channel form and behaviour. Changes in channel form are therefore a product of the calibre and quantity of sediment delivered from upstream as well as the pattern of competence and capacity to transport sediment within the reach itself. Modelling the discharge and sediment regime of Marillana Creek provides insight into system behaviour and establishes a foundation for testing design performance.

5.1 Hydrological Modelling

5.1.1 Evaluation of the Flat Rocks rating curve

Stream gauging stations typically record the stage (height) of flows. In order to translate this into stream discharge, suitable as a basis for modelling and analysis, the data is converted using a stage-discharge rating curve. As is the case with most gauging stations, the stage-discharge rating curve for the Flat Rocks gauging station operated by the Department of Water has been developed largely on analysis and modelling, with few manual stage discharge measurements made at the site and measurement of high flows being rare. While scatter of data around a rating curve is normal, there can be considerable uncertainty in rating curves at high flow levels.

Due to uncertainties in the existing rating curve for Flat Rocks, BHP Billiton Iron Ore engaged GHD to review the rating curve in light of increased data availability (GHD 2012; 2014). A detailed two dimensional model of a stretch of Marillana Creek at Flat Rocks was developed to assist with analysis of the rating curve. The model was developed using *Mike Couple* based on newly available LiDAR ground surface data and aerial imagery. Surveyed peak water level data from an event in February 1995 was provided by the Department of Water and used to calibrate a peak flow for the event and to test the model's predictions.

A stage-discharge relationship was derived from the model and compared with the Department of Water rating curve. The revised rating curve indicates that newly modelled flows are, on average, 13% greater than those previously derived from the Department of Water rating curve. A linear relationship was fitted to the data and this relationship was used to adjust flow data. This relationship, as fitted, is valid for Department of Water flows between 40 and 1,400 m^3/s.

A revised flood frequency analysis was then undertaken using flows adjusted with the revised rating curve. The results of this analysis are presented in **Table 5-1**.The flow adjustment has most effect on the flood frequency results previously derived for low and high flows. Flows with a two-year Average Recurrence Interval (ARI) increase by almost 70% and 500-year ARI flows by 40%. 100-year ARI flows increase by 15%.

Table 5-1: Flood frequency table for Flat Rocks gauging station

Average Recurrence Interval (ARI) (years)	Annual Exceedance Probability (AEP) (%)[1]	Revised peak discharge (m^3/s)
2	39	152
5	18	333
10	10	536
20	5	825
50	2	1,394
100	1	2,027

Note: 1) AEP is the probability of an event occurring or being exceeded within a year.
The relationship between ARI and AEP is: $AEP = 1 – e^{(-1/ARI)}$

5.1.2 Yandi hydrological model

Various flood models have been developed and maintained for the Yandi site over time as modelling techniques have advanced and additional data have become available. In conjunction with the rating curve review described above, BHP Billiton Iron Ore engaged GHD to develop an integrated hydrological model covering Marilllana Creek and tributaries. In 2014 this model was updated using new LiDAR, imagery and up-to-date gauging station data.

The hydrological model for Yandi consists of an integrated rain on grid representation of overland flow (using *Mike SHE*) and a network of connected streams in *Mike 11*. *Mike 11* was linked to the overland flow component using explicit links. These links allow water to move to and from the stream and the overland surface. Broad areas of ponding and overland flow were represented using the overland flow module in *Mike SHE*. The model was used to generate water level and flow predictions through the Yandi lease for a range of design events.

The rainfall station located at Flat Rocks was used for design event simulations. Design rainfall and rainfall hyetographs were derived using methods given in Australian Rainfall and Runoff (Pilgrim 2001) with intensity-frequency-duration information from the Bureau of Meteorology.

The process adopted for model calibration and verification was:

- evaluation of the model's representation of ponding in the Munjina claypan upstream from Yandi compared with site observations;
- calibration of roughness to the Flat Rocks reach, using the *MIKE 21* model and observed hydrographs and peak water level data for the 1995 event;
- calibration of loss rates to peaks recorded at Flat Rocks and in the mine area;
- calibration of loss rates to the flood frequency data calculated for Flat Rocks;
- verification by comparison of the model predictions with other studies; and
- sensitivity analysis.

Flows, levels and flood extent were modelled at key points along Marillana Creek for 5, 10, 20, 50 and 100-year ARI events. Flood hydrographs extracted from the MikeSHE model near Flat Rocks are provided in **Figure 5-1**.

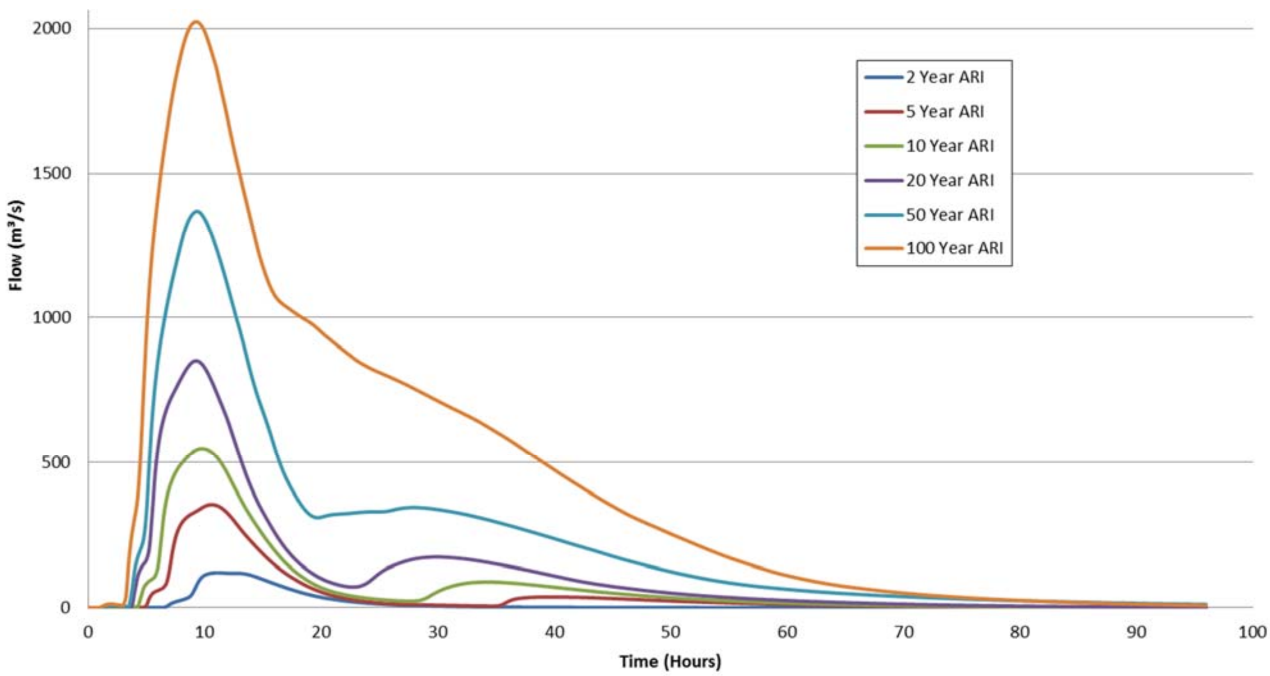


Figure 5-1: Flood hydrographs extracted from the MikeSHE model near Flat Rocks.
Flows were modelled for 5, 10, 20, 50 and 100-year ARI events

5.2 Hydraulic Modelling

5.2.1 2D TUFLOW Modelling

To characterise the existing hydraulic behaviour in Marillana Creek, a 2D hydraulic model was developed by *Advisian* using *TUFLOW* modelling software. A 5m grid size was adopted in the model domain with the Digital Elevation Model (DEM) built from LiDAR data. The LiDAR data has a vertical accuracy of 0.1 m and a horizontal accuracy of <0.20 m although the definition of the ground surface underneath trees and other vegetation may be less accurate.

Inflow hydrographs from the existing *MikeSHE* hydrological model (**Figure 5-1**) were used as inflow boundaries for the *TUFLOW* model. Additionally, the 10,000 year ARI and Probable Maximum Precipitation (PMP) rainfall events were run through the hydrological model to provide the flows for the 10,000 year ARI and Probable Maximum Flood (PMF) events. Other inflows were applied to the model domain to account for other tributaries based on the flows when they enter Marillana Creek.

Manning's Equation is an empirical formula commonly used to estimate the average velocity of open channel flow. A key variable in this equation is the amount of hydraulic roughness in a channel, expressed as "Manning's n". Lower values of Manning's n are attributed to "cleaner" channels with few obstructions to flow. Manning's n values were evaluated using land unit classifications, published reports/papers and analysis of aerial and site photographs to develop a set of values that are considered representative of Marillana Creek at Yandi for use in the *TUFLOW* model. The resulting Manning's roughness values adopted for the modelling are listed in **Table 5-2**. Analysis of aerial photography for the model area was used to delineate zones and assign Manning's n roughness values based on observed vegetation type and density.

Table 5-2: Manning's n values adopted for the existing conditions hydraulic model

Roughness category	Manning's n
Marillana, Herbert's and Iowa Creeks:	
- *Main channels, smooth and uniform with sand and gravels*	0.035
- *Floodplain areas with vegetation and trees*	0.05 - 0.065
Minor creeks:	
- *Uniform cross section*	0.04
All other areas:	0.055

The *TUFLOW* model was used to characterise the existing hydraulic behaviour in Marillana Creek with the following information extracted from the model using *waterRIDE* software for the 2, 5, 10, 20, 50 and 100 year ARI events:

- flow hydrographs showing the peak flow, duration of flow and total flow volume;
- peak velocities;
- peak bed shear stresses; and
- peak unit stream power.

Peak velocity, bed shear and unit stream power surfaces were mapped and the frequency distributions (S-curves) from model grid cells were then plotted for each ARI and evaluated to characterise the complete range of hydraulic behaviour of the existing Marillana Creek system. The statistics were plotted for the:

- entire length of Marillana Creek from immediately upstream of W1W2 to the railway waterway crossing downstream of E7 (22km);
- incised sections of creek only; and
- anabranching sections of creek only.

An additional set of frequency distributions were generated for upstream incised reaches where the channel bed is featureless and vegetation is characteristically limited to the channel margins. This provides an opportunity to compare the hydraulic behaviour of diversions along the spectrum of incised reaches, which can then be used to gain an indication of what vegetation density may potentially re-establish.

Typical plots showing the cumulative frequency distributions for velocity in Marillana Creek under existing conditions for a variety of discharges are provided in **Figure 5-2**.

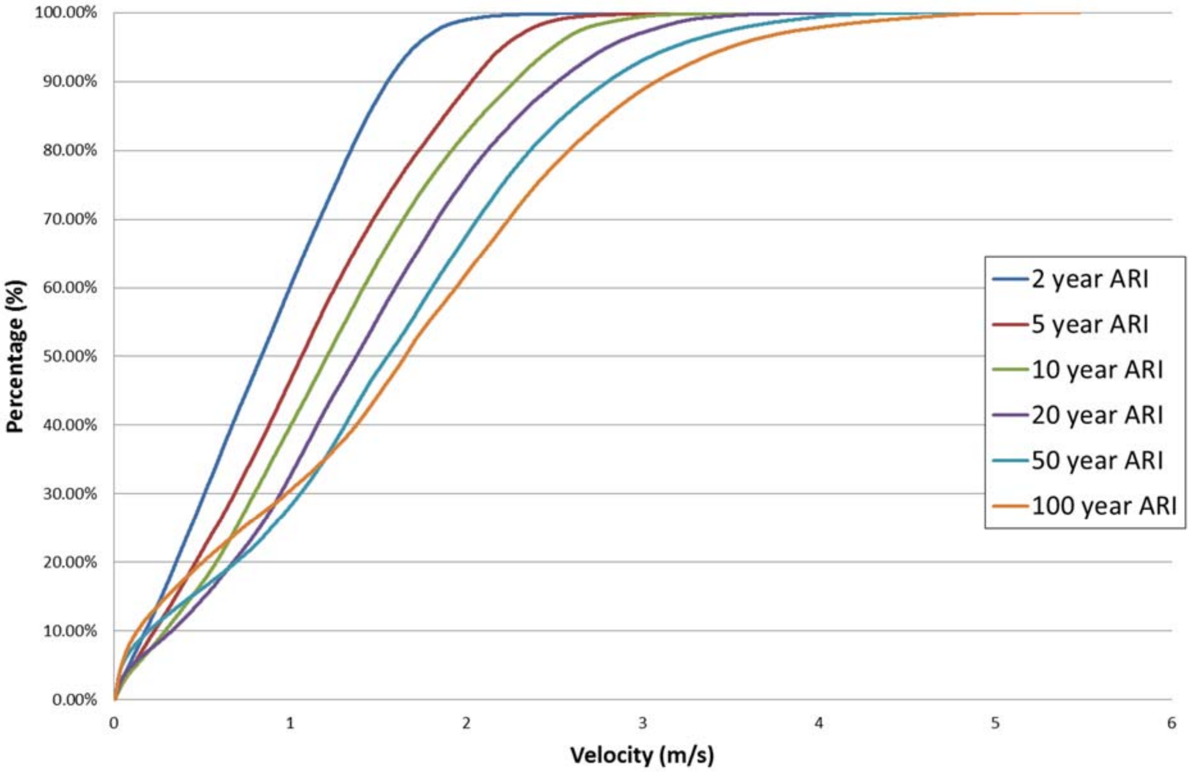


Figure 5-2: Typical set of cumulative frequency distributions for velocity under existing conditions. The percentage shown (%) represents the cumulative percentage of modelled cells with a peak velocity value equal to or less than the corresponding value on the x-axis, considering all "wet cells" within the model domain.

5.2.2 1D HEC-RAS Modelling

A 1D hydraulic model was also developed for Marillana Creek using *HEC-RAS* modelling software. *HEC-RAS* was used to model the 2, 5, 10, 20, 50 and 100 year ARI events under steady state conditions using the peak flows extracted from the 2D hydraulic model. The main inputs into *HEC-RAS* are the topography of the landscape, roughness coefficients, boundary conditions and flow conditions.

A simplified Manning's n allocation was completed for use in the *HEC-RAS* model. Two Manning's n classifications were used for the creek bed (0.035) and riparian vegetation (0.06) respectively. The allocation of Manning's n was guided by the analysis undertaken for the 2D *TUFLOW* modelling.

Peak velocity, shear stress and stream power results were extracted from the model to represent the natural range of variability for Marillana Creek. Both average and absolute minimum and maximum values were calculated, where:

- the average minimum and maximum values were based on taking the average of the maximum and minimum values within each of the anabranching and incised reaches in Marillana Creek; and
- the absolute minimum and maximum values were based on taking the maximum and minimum values across all of the anabranching and incised reaches in Marillana Creek.

Values were calculated for the main channel as well as across the entire channel cross-section. A summary of results for the entire cross-section is provided in **Figure 5-3**.

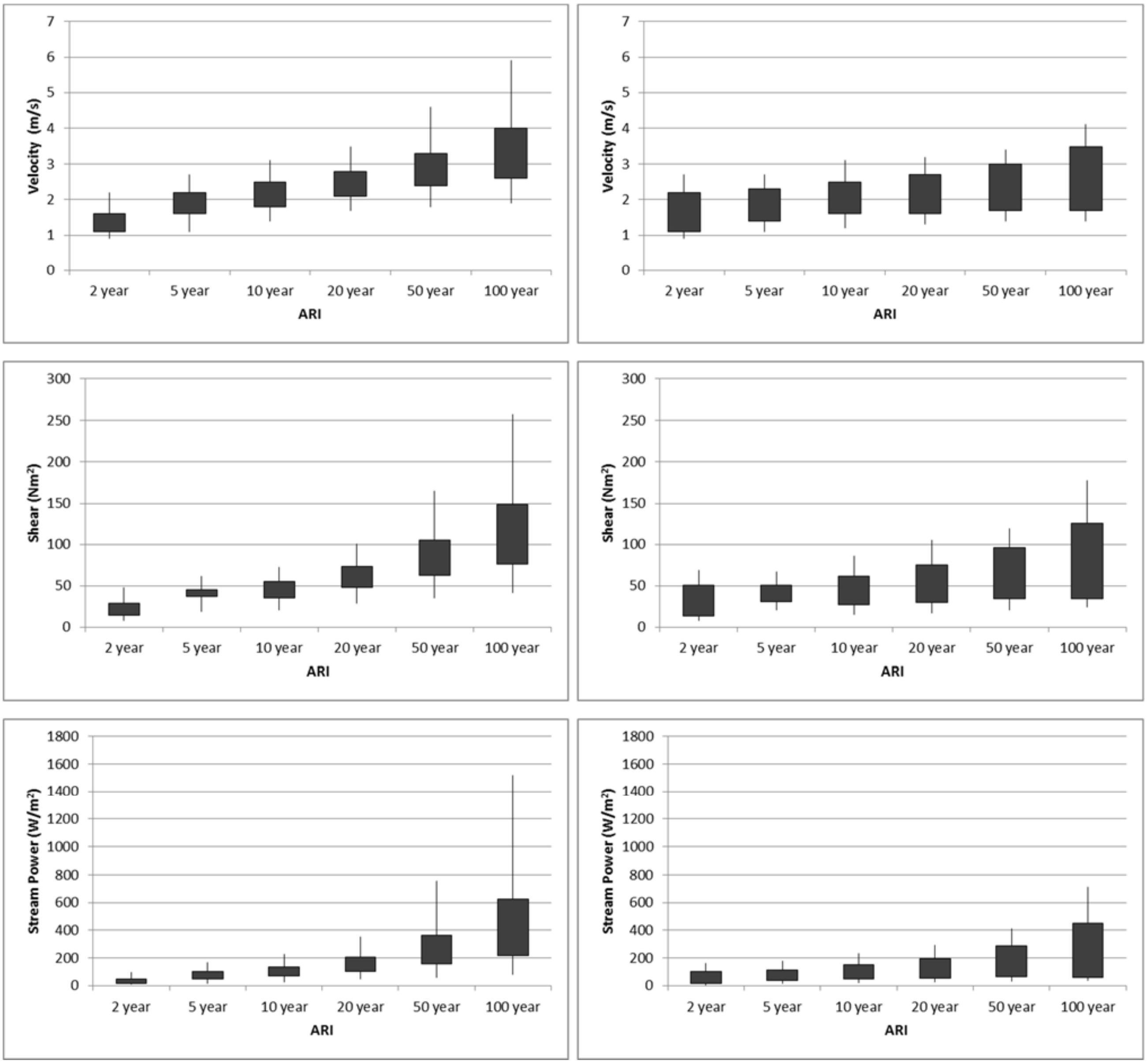


Figure 5-3: Peak velocity, shear stress and stream power for the entire cross-section of Marillana Creek for incised (left) and anabranching reaches (right).

The bars represent average maximum and minimum values while the range lines represent absolute values.

5.3 Sediment Transport Modelling

5.3.1 1D and 2D Modelling

1D and 2D sediment transport modelling, using *HEC-RAS* and *MIKE 21* respectively, was conducted by *Advisian* to provide a high level understanding of sediment transport conditions. *HEC-RAS* produces average changes in bed level across each cross section (uniform change in bed level) while *MIKE 21* computes bed elevation changes at each cell in the model domain. Therefore, *HEC-RAS* was used to assess average scour and erosion rates while *MIKE 21* was used to identify and assess localised areas of scour and erosion. It should be noted, however, that due to the complexity of sediment transport models, limitations on their applicability in some physical contexts and their reliance on high quality sediment datasets for reliable predictions, the model results in this instance were utilised as a basis for relative comparison to diversion designs rather than to be relied upon to determine absolute changes.

The *HEC-RAS* hydraulic model was used for sediment transport modelling as it has the capability to model mobile layer sediment transport. Changes in bed elevation are calculated by performing a sediment mass balance for a series of control volumes, defined between cross-sections. To determine whether there is erosion or deposition within a control volume, sediment transport capacity is calculated at each cross-section and compared to the sediment load entering the control volume. If capacity exceeds supply there is erosion within the control volume and if supply exceeds capacity there is deposition. The change in sediment volume is distributed evenly over the wetted width of the cross-section to determine the magnitude of the bed elevation change.

A simplified Manning's n allocation was adopted in the *HEC-RAS* model based on two classifications; 0.035 for the main channel of the creek and 0.06 for all other overbank areas containing riparian vegetation. The 100 year ARI flow hydrograph was extracted from the 2D *TUFLOW* hydraulic model and applied to the HECRAS model at the upstream boundary.

The *MIKE 21* Flow Model FM is a dynamic 2D modelling system based on a flexible mesh approach. The model consists of a number of modules, including a hydrodynamic module and a sediment transport module. The hydrodynamic module simulates water level variations and flows in response to a variety of forcing functions, such as water levels. The sediment transport module calculates the resulting transport of non-cohesive materials based on the flow conditions found in the hydraulic model. The changes in bed level as a result of sediment transport are calculated and reported at individual cells in the model domain.

5.3.2 Transport Functions

A key consideration when setting up a sediment transport model is the selection of an appropriate sediment transport function (the mathematical equation used to calculate transport). A variety of sediment transport functions have been developed and reported in the literature and a number are available for use within modelling software. Sediment transport results are highly sensitive to the selected transport function (i.e. under identical hydraulic conditions, the sediment transport results may vary widely). Sediment transport functions have been developed under certain experimental and field conditions and their use is typically driven by consideration of the conditions the method was developed under compared to the actual field conditions to be modelled.

The assumptions, hydraulic conditions and grain sizes for which a number of available functions were developed were compared to the conditions at Marillana Creek to determine which of the functions were most applicable. Velocities and sediment particle sizes at Marillana Creek were greater than the conditions under which all of the transport functions available in *HEC-RAS* and MIKE 21 were developed. Therefore, the transport functions considered most appropriate for Marillana Creek were those tested under the highest velocities and with the largest grain sizes, amongst other criteria. The two transport functions considered most appropriate for Marillana Creek are:

- Meyer-Peter and Müller; and
- Engelund and Hansen

The Meyer-Peter and Müller function is a bedload transport equation and is one of the most widely used equations for determining sediment transport potential. The use of the Meyer-Peter and Müller function is recommended for rivers with relatively coarse sediment. It is most successfully applied over the gravel range and tends to under predict the transport of finer materials (USACE, 2010). The specific gravity of sediments at Marillana Creek were within the range for which this method was developed, however velocities are greater than the range of 0.4 to 2.9 m/s for which the method was developed.

The Engelund and Hansen function is a total load transport equation. The use of the Engelund and Hansen function is expected to produce reasonable results for sandy rivers with substantial suspended loads (USACE, 2010). Although it is expected that sediment transport in Marillana Creek will be bed load dominant, high velocities modelled suggest that a mixed load formula could also be appropriate. The method was developed on particle diameters between 0.19 and 0.93 mm and for velocities between 0.2 to 1.8 m/s which are lower than what is expected at Marillana Creek.

Both the Meyer-Peter and Müller function and the Engelund and Hansen function are available in both MIKE 21 and *HEC-RAS* which allows a comparison of results for the 1D and 2D modelling approaches.

5.3.3 Sediment Transport Results

Model results were interpreted in a qualitative manner with results generated under the two transport functions compared against each other to see if they predicted similar patterns of change in bed elevations. The focus of the event-based sediment transport modelling was the 100 year ARI event as this extreme event has a greater ability to mobilise sediment than more frequent, lower magnitude events. Model results, for the existing Marillana Creek system, depicted as a bed elevation change map, are presented in **Figure 5-4**.

Sediment transport modelling results for the 100 year ARI event indicate that the existing system is generally in equilibrium (i.e. the bed level variations balance out between erosion and deposition). This is demonstrated by symmetrical bell curves of model output being centred on a zero change in bed elevation. This is also evident through visual assessment of bed elevation change mapping.

Maximum bed elevation changes when using the Engelund and Hansen function ranged between +/- 5 m, however 99.7% of cells had bed elevation changes of less than 3 m. Maximum bed elevation changes when using the Meyer Peter and Müller function ranged between +/- 4 m, with 99.9% of the cells having bed elevation changes of less than 3 m. While not intended to be relied upon to determine absolute changes, both models indicate limited change beyond a 3 m magnitude.

When comparing the 1D and 2D modelling results it should be noted that the 2D *MIKE 21* modelling estimates changes in bed level at individual cells in the model domain. As a result, the magnitude and range of bed elevation changes is greater than in the 1D *HEC-RAS* model, which only produces average bed elevation changes. The *HECRAS* model, however, is useful when looking at general patterns of scour and deposition throughout long sections.

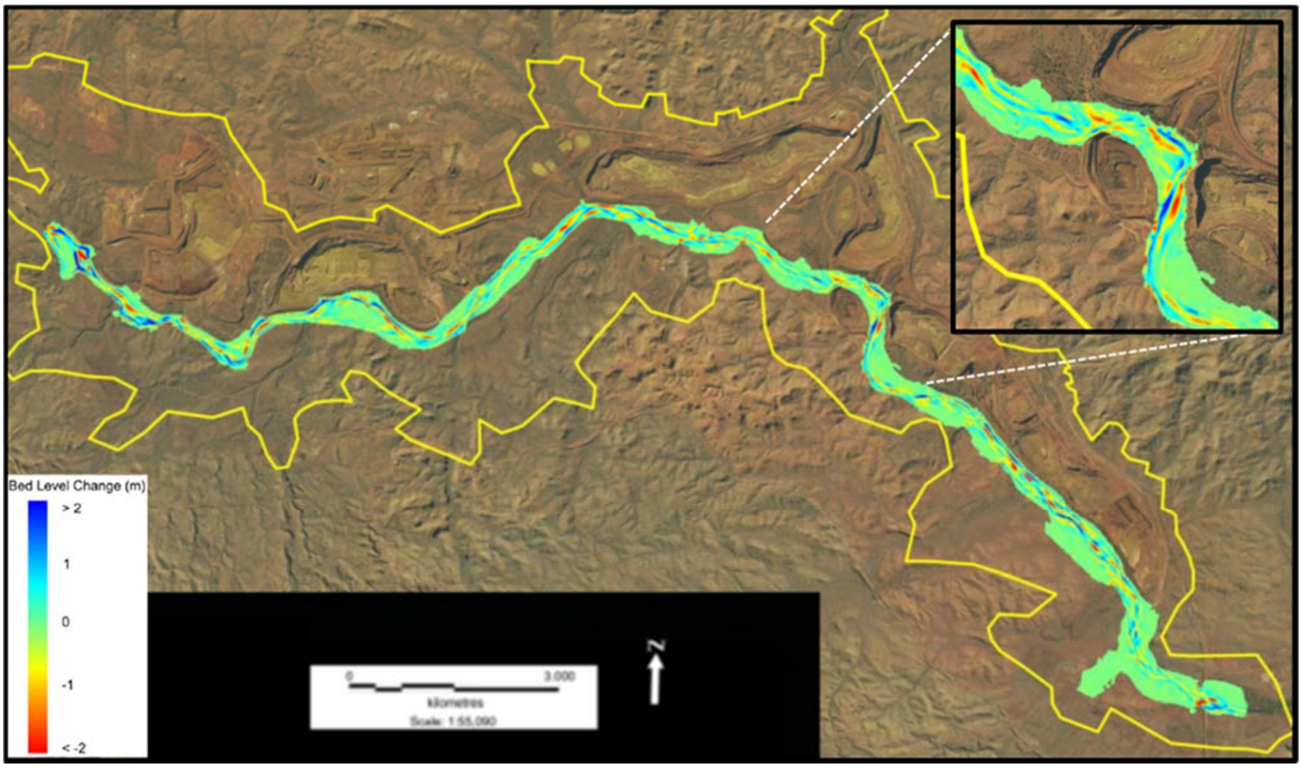


Figure 5-4: Modelled bed-level change following a 1:100 year ARI flood event.
Results indicate that the existing system is generally in equilibrium with bed level variations balancing out between erosion and deposition.

6 Management Actions

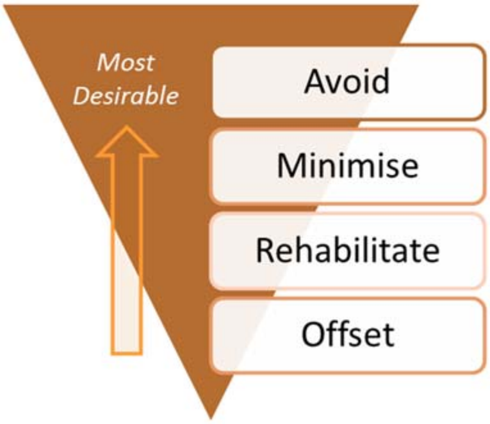


Figure 6-1: Mitigation hierarchy

As defined in BHP Billiton Iron Ore's GLD *Environment and Climate Change Our Requirements* and consistent with Environmental Assessment Guideline 17 (EPA, 2015), management actions should follow the mitigation hierarchy (**Figure 7-1**), demonstrating avoidance and minimisation as far as practicable. For diversion of Marillana Creek, the greatest opportunity to avoid or minimise impact is achieved through design. The approach taken in design to achieve this outcome commenced with a high-level consideration of options, followed by development of design features based on natural analogues and finally testing and optimising designs in an iterative process. This section provides a brief summary of the design process before providing detail on the proposed design itself. The construction programme and subsequent revegetation program are then outlined.

6.1 Design Approach

6.1.1 Concept Evaluation

While diversion of Marillana Creek is a key characteristic of the *Marillana Creek (Yandi) Life of Mine Proposal* approved under MS 679 and MS 1039, an Identification Phase Study (IPS) commenced with a process to test the validity of this approach as the preferred option to access creek constrained ore. Each target ore body was reviewed and potential engineering concepts that could be applied were identified. Options were developed on the basis of:

- releasing multiple constrained ore targets where possible;
- performing over a range of discharge events; and
- minimising off-lease impacts.

Multi-criteria analysis of engineering options was then undertaken based on a series of technical, commercial, environmental and social criteria, including:

- construction conflict with operations;
- geotechnical settlement / stability;
- off-lease interfaces;
- alignment with existing approval concepts;
- area of natural creek bypassed; and
- impact to the ethnographic landscape.

After filtering options through the multi-criteria analysis, additional engineering investigations were undertaken and supporting models were developed. This information provided a basis for the development of more detailed capital and operating cost estimates for evaluation.

Evaluation of alternative options showed a large range of capital intensity, closure liabilities and risks, however diversion of Marillana Creek remained the preferred approach for accessing creek ore. Diversion of Marillana Creek is capable of meeting necessary environmental objectives while offering the lowest capital intensity and presenting the lowest operational risk to access the creek ore. The IPS did, however, identify opportunities to refine the engineering design in subsequent phases, particularly regarding the conveyance capacity of diversion channels.

6.1.2 Design Objectives

Creek diversions are required to provide access to currently constrained ore while providing appropriate levels of flood protection for safe mining operations. As specified by the Condition Environmental Objective, diverted sections of Marillana Creek shall be designed to function *as a fluvial system in a similar manner to the existing creek system*. Diversion design has therefore focused on achieving the following objectives:

- *Hydrology* – Surface water flow volumes are maintained within acceptable ranges to minimise downstream ecological impacts.
- *Water quality* – Diversions do not have an adverse impact on water quality.
- *Hydraulics* – Velocity, shear stress and stream power throughout diversions are within ranges seen through existing channel reaches.
- *Sediment regime* – The volume of sediment exiting diversions is similar to that entering.
- *Geomorphology* – The channel incorporates, and has the capacity to develop, geomorphic features that are similar to those seen through existing channel reaches.
- *Ecology* – A diversity of habitats is established that supports representative flora and fauna species and provides ecological function and connectivity through the system.
- *Cost* – The design should be practicable such that the capital investment required should achieve an acceptable return on investment.

6.1.3 Design Method

The overarching design approach has been to reference the form and function of Marillana Creek in the diversions as far as practicable. Key attributes specified as a basis of design included planform type, width, depth, slope, sediment depth and roughness. While not attempting to exactly replicate the existing creek, by designing within ranges seen in the natural system, the hydraulic and sediment-transport characteristics of the diversion channels should be similar to those of the natural creek. Establishing a comparable physical environment, based on understanding the discharge and sediment regime, provides the foundation for meeting the Condition Environmental Objective.

Development and testing of engineering design considered both operational and closure scenarios at Yandi. During the operational phase, diversions and associated levees will provide appropriate levels of flood protection for safe mining operations. During the closure phase, the diversions will provide a stable, functioning landform. This includes the partial direction of surface water flow over a given level into mine voids via spillways as a means of maintaining the integrity of the diversions during extreme events. It is also recognised that channel roughness, largely attributable to vegetation, will evolve over time thereby having a variable influence on hydraulic performance from early commissioning of diversions through to their ongoing operation.

Key steps in the design process undertaken during the SPS are outlined in **Figure 6-2** and summarised below. Refinement of the engineering design commenced with adjustment of the diversion route alignment to optimise diversion length and minimise depth of cut through terrain where possible. Following selection of alignments, channel dimensions were then investigated. However, rather than design the diversion channels to arbitrarily convey a specific discharge, the approach adopted was to test design objectives (as identified above) across a range of discharge scenarios with differing annual exceedance probabilities.

A screening assessment of channel designs was conducted using a variety of uniform trapezoidal channels with default widths ranging from 25 to 300 m and a range of spillway heights adopted. Hydraulic performance was then assessed using the *TUFLOW* flood modelling software and compared with existing conditions modelling results across a range of ARIs under both operational and closure conditions.

Although a small proportion of high velocities occur naturally and therefore should be considered in the design, the distribution of modelled velocities and shear stress was referenced against guideline values for evaluation. Inspection of the frequency distribution ‘S’ curves (an example of which is provided in **Section 5.2.1)** indicated that higher values typically included the upper 5-10% of the velocity and subsequent shear stress distributions (corresponding to the top part of the ‘S’ curve beyond the inflection point of the curve). An upper guide was therefore set at the 95th percentile value of the frequency distributions for comparison.

A lower guide of velocity/shear stress for the modelled diversion was also considered to be appropriate in order to avoid an oversized diversion channel (resulting in excessive construction costs) and the risks of excessive sediment accumulation. It was considered that the median (50th percentile) value from the velocity and shear stress frequency distributions would be a reasonable guideline value. Although it is acknowledged that there remains some subjectivity in the choice of these upper and lower values, the method presented a practicable screening-level assessment for the basis of design. The outcome of the screening assessment was to identify a nominal channel width as a preliminary basis for design that could then be adjusted to achieve the design objectives.

Following the screening assessment, the first design iteration commenced with the addition of a primary (low-flow) channel throughout the diversions. This "channel-in-channel" feature is designed to convey more frequent low-flow events and was sized based on dimensions of the primary channel seen in existing reaches of Marillana Creek.

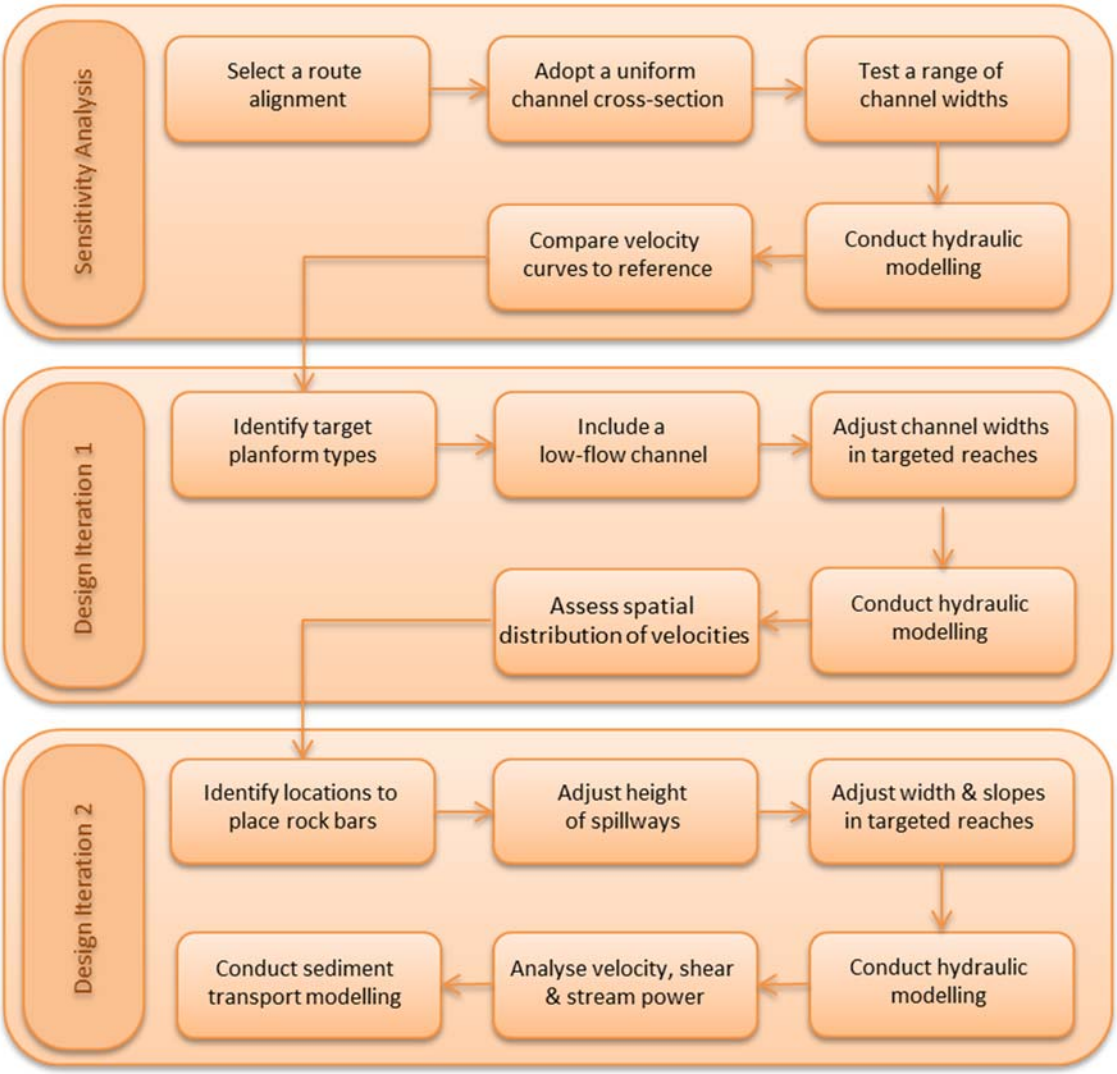


Figure 6-2: Key steps in the design process undertaken during the Selection Phase Study

Targeted planform types (incised and anabranching) were then identified along the length of diversions with the aim of achieving proportions across the diversions within target ranges derived from the natural analogue as follows:

- **Incised channel:** 40% nominal with a target range between 30 – 50%; and
- **Anabranching channel**: 60% nominal with a target range between 50 – 70%.

Channel widths were then adjusted to fall within ranges identified for each respective planform type (typically by widening the channel for anabranch reach types).

For Design Iteration 1, flood protection bunds included a 2 m freeboard from the 100 year ARI flood level. Concept spillway designs were adopted and set to the 100 year ARI flood level.

Hydraulic modelling was undertaken to assess the performance of the diversions against the natural analogue under both operational and closure conditions. This included review of the spatial distribution of peak velocities based on 2D modelling. Reaches where hydraulic performance was not achieved were identified and targeted for refinement during Design Iteration 2.

Design Iteration 2 commenced with adjustment of the primary channel to incorporate sinuosity within the broader channel and better “tie in” to the thalweg of the existing creek both upstream and downstream of diversions. Channel widths and gradients were then adjusted in targeted reaches. Rock bars were also included in the design and adjusted as required to address areas of higher velocity, that were either at the upper limit or slightly outside the natural range of variability, thereby mitigating potential scour in these areas. While operational flood protection bunds remained set at the 100 year ARI flood level plus 2 m freeboard, closure spillway heights were lowered to reduce peak velocities in diversions during extreme flood events.

1D and 2D hydraulic modelling was then used to assess the hydraulic performance of the revised diversion designs. While refinement of the detailed design will continue prior to construction of the diversions, the design process described above was considered sufficient to progress diversion designs to a point where likely conformance with the Conditional Environmental Objective can be demonstrated. The proposed design features adopted in diversions are described below and are drawn from design input provided by *Advisian*, *AQ2* and *Hydrobiology*.

6.2 Proposed Design

6.2.1 Channel alignment and planform

Diversion alignments were selected to reduce the amount of cut volumes by favouring flatter terrain and managing changes in grade by minimising channel lengths to as close to those being replaced as possible. Minimum curvatures of diversion channel bends were based on analysis of bend radii in the existing creek. Setbacks from mine voids were also specified to provide a buffer between pits and diversions.

The eastern diversion was progressed as two smaller channel lengths, resulting in three diversions in total:

- W3W5 diversion
- E1 diversion
- E4 diversion

Reaches within diversions were nominally identified as either anabranching or incised and design geometries then applied based on their respective natural analogues. The location of incised and anabranching reaches in the diversion design was based on prevailing geology and topography, with the objective of minimising cut volumes where possible. The length of ‘anabranching’ and ‘incised’ reaches were selected to achieve similar proportions observed in the existing Marillana Creek system. Transitions between anabranching and incised reaches were based on natural rates of change in channel width between planform types, identifying bank angles and transition lengths for guidance.

Three anabranching reaches and two incised reaches were targeted in the W3W5 diversion. Two anabranching reaches and one incised reach were targeted in E1 while a single anabranching reach was targeted for E4. The percentages of reach lengths targeted as anabranching or incised respectively are summarised in **Table 6-1**.

Table 6-1: Percentages of anabranching and incised reaches included in the design

Diversion	Incised	Anabranching
W3W5	60%	40%
E1	41%	59%
E4	0%	100%
Combined	**36%**	**64%**

Diversion alignments and the location of nominal incised and anabranching reaches is depicted in **Figure 6-3**.

6.2.2 Cross-sectional channel form

It is important to note that the response of diversion channels to discharge events will be complex and will evolve over time. Diversions have been designed so that the channel incorporates and has the capacity to develop geomorphic features that are similar to those seen through existing channel reaches. As a result, the cross-sectional form of diversions is expected to develop over time to reflect the existing system as far as is practicable.

The diversion channel geometry adopted for design includes a main channel with one low flow primary channel to provide the basis on which the observed natural geomorphological characteristics of Marillana Creek can develop over time. The diversion channel geometry is summarised as follows:

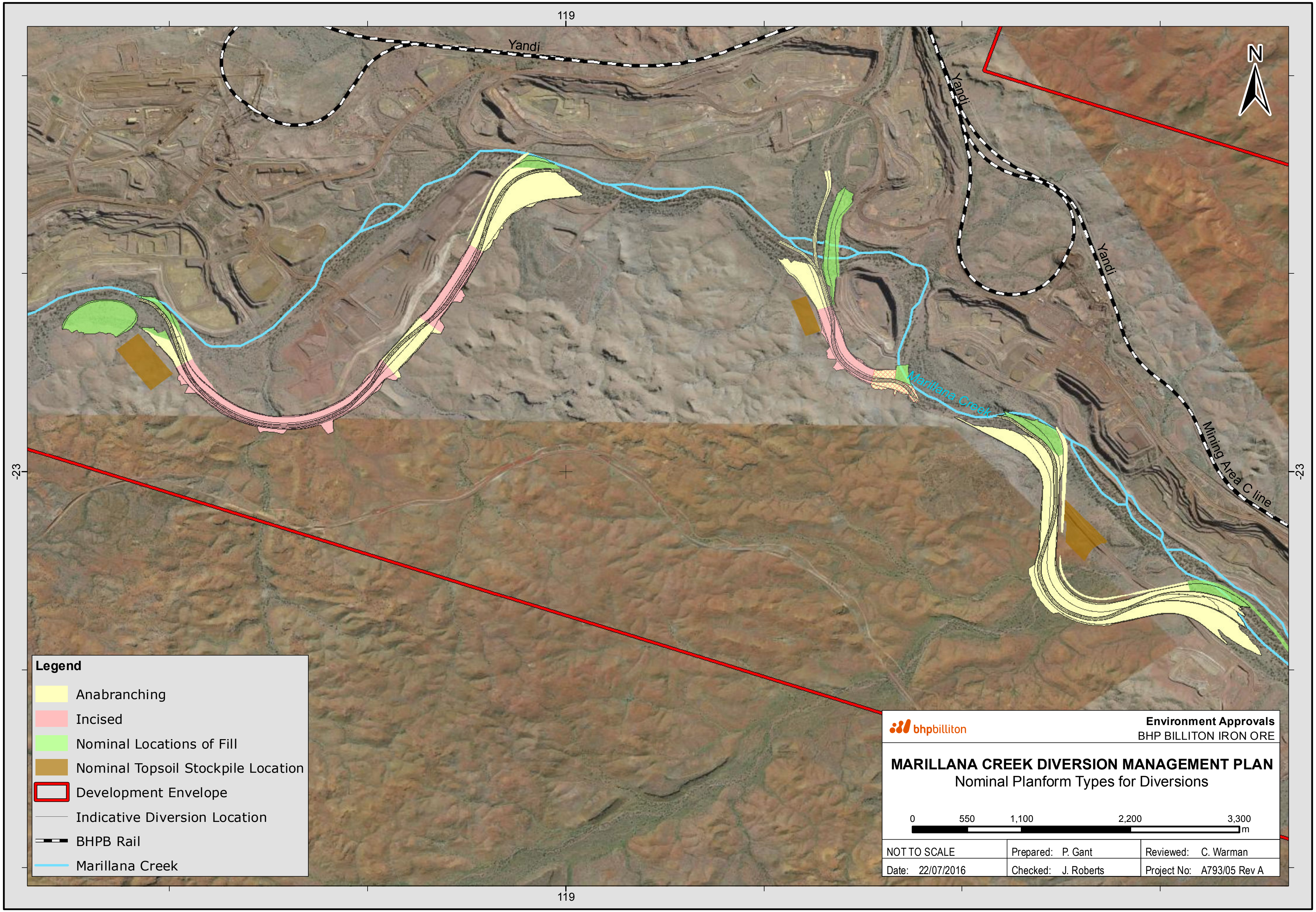
- Incised reaches:
  - Widths of between 120 m and 140 m (excluding transitions);
  - Lengths of between 900 m and 2,300 m (excluding transitions); and
  - Bed slopes of between 0.10% (0.001) and 0.27% (0.0027).
- Anabranching reaches:
  - Widths of between 150 m and 350 m (including transitions);
  - Lengths of between 500 m and 3,880 m (including transitions); and
  - Bed slopes of between 0.05% (0.0005) and 0.47% (0.0047).

The design low flow channel width and depth was set to 25m and 2m respectively which is consistent with the average low flow channel parameters observed in Marillana Creek. The low flow channel has batter slopes set at 1V:2.5H. Further refinement of the low flow channel may occur during Definition Phase engineering, including increasing the width:depth ratio through incised reaches.

Channel geometries and bed gradients adopted in the design generally fall within the natural range of variability for the existing system and are consistent with the natural pattern of changes in bed gradients, widths and lengths in the system. Exceptions to this are as follows:

- The longest incised reach (2,300 m in W3W5) was longer than the maximum observed incised reach length through the Yandi lease area (1,985 m);
- The longest anabranching reach (3,880 m in E4) was longer than the maximum observed anabranching reach length through the Yandi lease area (2,279 m); and
- The minimum anabranching bed gradient was 0.0005, which is lower than the observed minimum of 0.0016 through the Yandi lease area.

These exceptions do not adversely impact design performance and are therefore considered acceptable. All other reaches fall within the natural range of variability observed in Marillana Creek.



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6.2.3 Hydraulic roughness

The design work undertaken for diversions has considered how they will transition over time from a low Manning's n associated with a freshly excavated channel to higher Manning's n values typical of the existing creek system. This will be achieved by designing channel geometries that achieve velocities, shear and stream power within natural ranges to allow revegetation of channels and by fostering geomorphological variability through the introduction of induced roughness measures. The Manning's n roughness values presented in **Table 6-2** and schematically depicted in **Figure 6-4**, were adopted for diversion design.

Table 6-2: Manning's roughness values for diversions

Scenario	Low Flow Channel/s *	Floodplain, anabranch ridges and overbank areas
Operations (commencement) – clean gravelly channel without vegetation.	0.025	0.025
Operations (commencement with induced roughness) – clean gravelly channel with induced roughness measures and some emergent vegetation.	0.035	0.035
Closure (mature vegetation) – clean gravelly channel with mature vegetation.	0.035	0.035 - 0.06**

Note:

* Defined as the generally clean section/s of creek with vegetation on banks of channel (in the incised reaches this clean section includes the entire planar bed, while in anabranching reaches this includes the low-flow (primary) channel).

** Manning's n values will be dependent on the density of trees and grass on floodplain areas, which is dependent on the depth of alluvium. Areas with limited alluvium will be assigned 0.035, while areas with deep alluvium will be assigned 0.06.

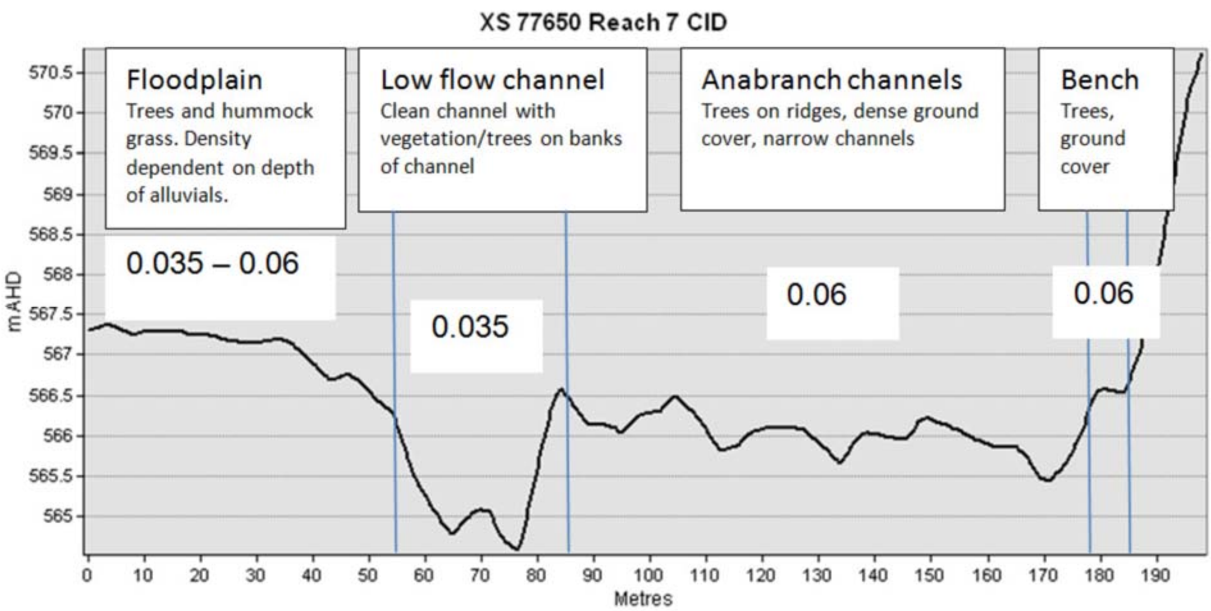


Figure 6-4: Characteristics and proposed roughness values for geomorphic features of Marillana Creek under a closure scenario (floodplain, low-flow channel, anabranch channels, and benches).

The introduction of roughness elements will be an important catalyst for the development of geomorphological variability in the diversion designs. There are a range of options that have been considered in the design to increase roughness from n = 0.025 to approximately n = 0.035 at the commencement of operation including:

- Placement of large logs with nominal diameter at breast height of >1.0m (length variable);
- Placement of relatively smaller logs with nominal diameter at breast height of between 0.5m and 1.0m (length variable);
- Placement of boulders with diameter nominally between 1.0m and 2.0m; and
- Specifying earthworks to not be finished as a smooth surface.

It should be noted that the placement of roughness measures is proposed outside of the primary low flow channel to be “activated” during higher discharge events. A nominal spacing of induced roughness measures was developed during the design process, however implementation will be subject to refinement of channel design and finalisation of the construction programme. For example, the option of targeted placement of jumbled sediment and logs from the bypassed channels into the diversions, rather than placement at uniform intervals, may represent a more logistically feasible option. This could allow diverted channels to develop a quasi- equilibrium morphology from the dumped arrangement over time while focussing on key areas in the short-term to achieving the target roughness.

6.2.4 Shallow aquifer design

The key fluxes in the shallow alluvial aquifer of Marillana Creek are vertical: recharge comprising infiltration during flood events; and discharge comprising evapotranspiration and seepage into the underlying geology. In the absence of major horizontal fluxes of water, the volume of water in storage is a key control on eco-hydrological behaviour. Important aspects of the design criteria are therefore: the dimensions of the engineered aquifer (i.e. the dimensions of the soil and groundwater store) and the material properties of the soil and groundwater store (i.e. its ability to store and release water). These key factors, summarised from design input by *AQ2*, are discussed below.

Dimensions of the alluvial aquifer

On average, natural groundwater levels in the shallow alluvial aquifer fluctuate between 0 mbgl (immediately after a flood/recharge event) and 3 mbgl (towards the end of the dry period). While Eucalyptus species (*Eucalyptus camaldulensis* subsp. *refulgens* and *E. victrix*) are likely to be able to rely on soil moisture most of the time, a permanent water level at around 3 mbgl is believed to be the optimum conditions for *Melaleuca argentea*. Therefore up to 2 m of aquifer thickness below the naturally fluctuating range has been adopted in the diversion design, resulting in a 5 m deep engineered aquifer below the base of the low-flow channel.

While this is at the lower end of the natural range of observed alluvial thicknesses in the natural system, there are some sections of creek in the western lease area where the alluvium is thinner. If additional geotechnical investigations reveal the prevalence of a thinner alluvial unit throughout a section of creek to be diverted then this thinner alluvial cover could be adopted for the diversion in this location.

Assuming a similar volume of water is available to the environment, tree density is likely to evolve towards that currently observed of between 4 and 30 mature trees per hectare (it should be noted this is an average figure developed with the inclusion of areas of channel that are devoid of trees due to scouring). Variations in the width of the alluvial aquifer effectively change the volume of water available per length of creek. A cumulative width of alluvial aquifer extending beyond the low flow channel of between 20 m and 40 m has been adopted in the design (resulting in a total width of between 45 m and 65 m).

The depth of alluvium over the remaining active channel width, defined as the minimum width of the diversion channel needed to allow for migration of the low flow channel similar to the existing creek system, was set to 4 m to allow for retention of at least 2 m of alluvium below the base of the low flow channel. The depth of alluvium over the remaining width of the diversion (floodplain) was set to 1 m. This is achieved in the design through benching of cut.

A schematic depicting the shallow aquifer design dimensions for incised and anabranching reaches is provided in **Figure 6-5**, where:

X_T = Aquifer width (m) = $X_1 + X_2$

W_T = Effective width of low flow channel

d = Low flow channel depth

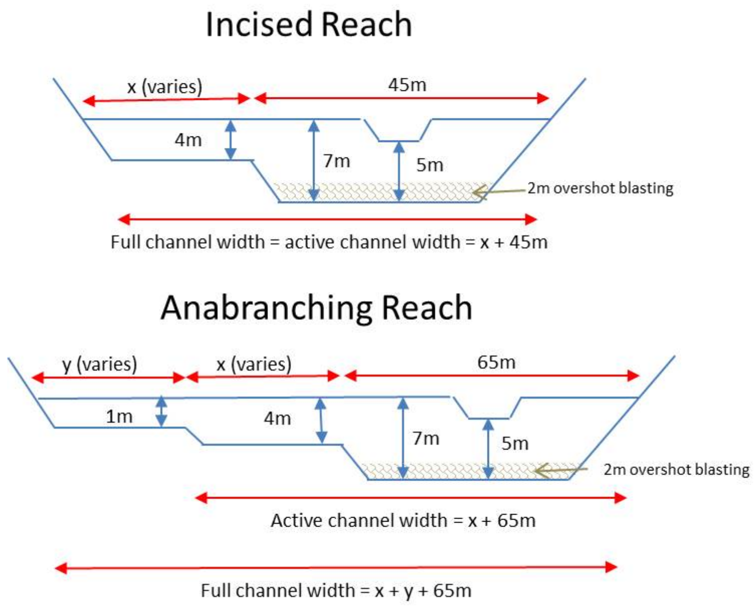


Figure 6-5: Schematic depicting the shallow aquifer design adopted for incised and anabranching reaches (not to scale)

Note the cross sectional profile is expected to develop heterogeneity over time.

Where the creek-diversion and associated engineered shallow aquifer crosses permeable geology (e.g. alluvium or colluvium of tributary creeks or residual CID), then groundwater will seep from the bottom of the engineered aquifer into this underlying material. This is particularly the case where this underlying permeable material is in connection with the mine-voids. Recharge will cause water levels to rise and multiple recharge events in succession will bring water levels to the surface. However, between recharge events, water levels will recede and no permanent shallow water table can be expected. These are referred to as “Type A” environments in the design and can be considered comparable with those areas of the current system that are affected by dewatering in the CID. Trees likely to establish in Type A environments are *E. victrix* and *E. camaldulensis* subsp. *refulgens*.

Where the creek diversion is excavated through low-permeability basement, no such losses will occur. These are referred to as “Type B” environments in the design and are comparable with those areas of the current creek that overlie the Weeli Wolli Formation and are not affected by dewatering. The aquifer will be subject to water level rise and fall between recharge events and provides both groundwater and vadose-zone water for the riparian system. As a shallow water table will be preserved at the base of the aquifer between recharge events, riparian tree species will likely comprise *E. victrix* and *E. camaldulensis* subsp. *refulgens* and potentially *M. argentea*.

To avoid hydrogeological connection along the entire length of the diversions (resulting in all areas becoming Type A environments), a series of rock bars have been added to the basement profile so that each Type B environment is isolated at each end. Rock bars are discussed in further detail in **Section 6.2.5**.

Material properties of the alluvial aquifer

The engineered aquifer can be considered in two zones, the upper zone (nominally 3m below the low flow channel) which is characterised by coarse alluvium through which water levels fluctuate; and the lower zone which will either host a permanent water table in Type B environments or become unsaturated between recharge events in Type A environments. Separate design objectives have been identified on the basis of this differing behaviour as specified in **Table 6-3**.

Where the aquifer will be unsaturated for times, important hydraulic properties include porosity, specific yield, plant-available water and soil-moisture-matric pressure relationships. The engineered fill comprising the unsaturated zone should resemble the existing alluvial material both in terms of particle size distribution (which will influence moisture retention properties) and stratification (which will influence sediment stability and the nature of a potential root-zone). However, given that scouring occurs to several metres depth during major flooding, stratification is likely to evolve naturally over time. In contrast, where the aquifer will always be saturated (i.e. in the lower zone of Type B environments), then only specific yield and porosity are of primary importance as unsaturated properties become less relevant.

Table 6-3: Design objectives for the engineered shallow aquifer.

<table>
<tr><th></th><th>Type A Shallow Aquifer</th><th>Type B Shallow Aquifer</th></tr>
<tr><td>Upper zone</td><td rowspan="2">Aquifer should closely match the existing alluvial material both in terms of porosity, specific yield, plant-available water and soil-moisture-matric pressure.</td><td></td></tr>
<tr><td>Lower zone</td><td>Aquifer should have a similar porosity and specific yield to the existing alluvial aquifer.</td></tr>
</table>

In order to meet the design objectives, the upper zone of the shallow aquifer and the lower zone in Type A environments has been designed to comprise a mix of gravels, sand, silt and clay – being an overall blend of material sourced from the alluvial aquifer in diverted channel reaches.

For the lower zone of Type B environments, the use of in-situ overblast material has been adopted in the diversion design. A sample of blasted waste rock was obtained from an existing creek diversion and subject to moisture retention testing to evaluate the suitability of this material to make-up part of the engineered aquifer. While data remain limited, the test results indicate that blasted rock has similar saturated hydraulic properties to alluvial materials characteristic of Marillana Creek. Should further testing of material indicate that broader design objectives specified in **Table 6-3** can be met by blasted rock, then its wider use may be adopted.

6.2.5 Rock bars

Rock bars have been included in the diversion design to serve two purposes:

1. To contain water in the shallow aquifer to promote re-establishment of groundwater dependent vegetation at targeted locations. These will be constructed using in-situ material (competent rock).
2. Provide grade control of the diversion bed levels by limiting scour and head cutting in areas where relatively higher velocities are expected. These will be constructed using in-situ material (competent rock) where available or imported rock (rock fill) where unsuitable materials are present.

The location of rock bars along the diversion alignments are presented in **Figure 6-6**.

The crest of rock bars created using imported rock fill is designed to be 20 m long. The crest of rock bars cut into in-situ material is designed to be 100 m long to minimise the risk of fracturing caused by blasting. Should the in-situ material at a proposed rock bar location intended to contain shallow groundwater be unsuitable, then the batter slopes will be lined with weathered dolerite or another low permeability material to achieve a desired water retention capability.

Batter slopes for the rock bars have been designed to minimise the risk of them becoming barriers to fish passage should pools form on their downstream edge. The selection of batter slopes was based on analysis of naturally occurring riffle structures observed in Marillana Creek. Analysis of bed slopes associated with these natural features suggests that a batter slope of 4% would be similar to the existing riffles and was therefore adopted for design.

Current designs are also based on the crest of rock bars being set at the invert level of the low flow channel. The potential to place some initial alluvial cover over rock bars will be reviewed during Definition Phase engineering.

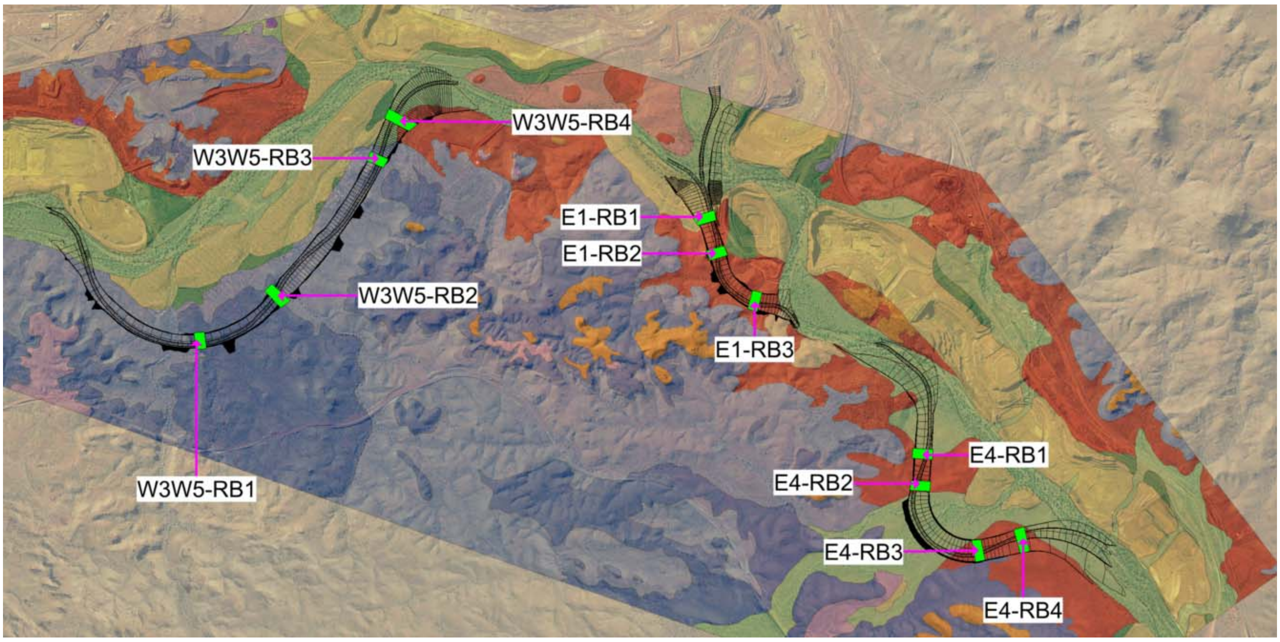


Figure 6-6: Proposed locations of rock bars.
Rock bars are designed to retain water in the shallow aquifer and provide grade control.

6.2.6 Interface with existing channels (transitions and levees)

Detailed 12D civil design modelling has been undertaken to connect the low flow channel and floodplains of the diversions with the low flow channel and floodplains of Marillana Creek, Iowa Creek and Herbert's Creek. The designs were developed to provide smooth transitions which are consistent with the geomorphic characteristics, gradients and minimum curvatures of the existing creek system.

Flood protection bund (levee) levels for operational mine pits were set using the results of flood modelling. A freeboard of 2 m from the 100 year ARI flood level during mining operations was adopted for design as this is consistent with the level of flood protection currently used on site at Yandi. The conceptual design for flood protection bunds is depicted in **Figure 6-7**.

The design for flood protection bunds includes a minimum crest width of 5 m and a maximum seepage cut-off depth of 5 m into the alluvium. The bund comprises compacted common material (Zone 1B) sourced from the diversion cuts. The embankment has both upstream and downstream slopes of 1.75H:1V and an upstream rock protection layer (rip-rap).

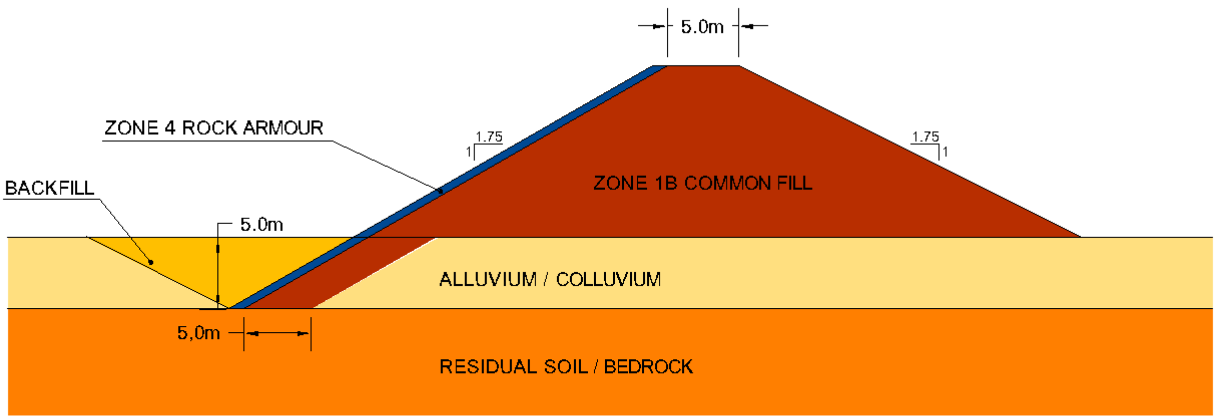


Figure 6-7: Conceptual design of a flood protection bund.

Rock riprap scour protection was included to control flow-induced erosion on flood protection bunds where scour may be expected and extends 3 m below the depth of the low flow channel (5 m below the floodplain level at the toe of the bund). Rock used for riprap shall be clean, hard, dense and durable and shall be free from laminations and fractures. Rock shall be angular in shape with width and thickness not less than a third of its length. The results of 2D flood modelling were used to assess velocity and shear adjacent to the flood bunds in order to size rock protection. Sediment transport modelling was also used to inform the placement of rock protection based on estimated scour depths for a variety of scenarios.

Additional BIF material sourced from drill and blast activities during construction of the diversions will be used to fill existing creek areas adjacent to the flood protection bunds. This is required to fill in depressions adjacent to the bund to create a continuous floodplain at a suitable grade while providing additional protection from scour and erosion. This coarser material will assist with preventing the low flow channel from migrating over time towards the flood protection bunds.

It should be noted that flood protection bunds may require additional materials to accommodate closure requirements. The closure requirement is that the flood protection bund must withstand the 10,000 year ARI critical duration flood event which may require the embankment crests to be raised. Closure bund design will be finalised and, if required, bunds modified prior to closure occurring.

6.2.7 Interface with tributary channels

Tributary channels that intersect the diverted reaches will be modified with reference to existing tributary junctions in terms of both the geometry of the intersection and the approach slope to the channel. The existing gradients of 13 key tributaries were measured as a basis for designing approach slopes. Analysis of gradients indicated that tributaries typically had two distinct slope values; a relatively flatter upstream slope and a steeper approach slope as the tributary neared Marillana Creek. Upper and lower bounds of gradients are provided in **Table 6-4** for reference.

The gradient adopted for tributary approach slopes is 15%. This slope was selected as a compromise between allowing the tributaries to erode back themselves, and cutting the bed of the tributaries back for up to several kilometres at a lower gradient. Some head cutting and minor erosion will, however, occur which will provide a source of sediment to the diversions.

Table 6-4: Geometric properties of tributaries

Ranges	Upstream Slope (m/m)	Approach Slope (m/m)	Length of Approach Slope (m)
Upper Bound	0.022	0.140	167
Lower Bound	0.003	0.014	33

6.2.8 Spillways

While mining operations continue at Yandi with diversions in place, flood protection levels will remain consistent with that currently adopted on site (i.e. a freeboard of 2 m from the 100 year ARI flood level). This is referred to as the "operations phase" of diversions. During this time all flood events below the flood protection level will be routed through the diversions.

Once closure has commenced, spillways will be cut between Marillana Creek and the pit voids. Spillways are required to allow some floodwater in excess of the spillway height to pass safely and in a controlled manner into pits. This protects the flood bunds from overtopping failure and helps mitigate scour damage within the diversion channels. It should also be noted that the contribution of surface water into mine voids via spillways is part of an active strategy to manage salinity in pit-lakes and sustain desired ecological outcomes post closure.

The majority of spillways will be located in areas where they can be cut into competent material. Their nominal locations, based on an assessment of surface geology, are indicated in **Figure 6-8**. The spillway locations were selected as follows:

- The spillway design strategy was to divert as much water as possible into the W1 pit during the 10,000 year ARI flood event to reduce the risk posed to flood protection bunds and diversions downstream. The

W1 pit has the largest storage capacity so diverting water into W1 is the most effective means of managing flows;

- The spillway at W1 was incorporated into the 2D *TUFLOW* hydraulic model and the 10,000 year ARI flood event was simulated. Additional spillways were then added progressively, starting at the western (upstream) end of the Yandi mine area and moving east (downstream), until modelled flow velocities, depths, stream power and shear were within acceptable levels following mine closure. This process was iterative and resulted in nine spillway locations being adopted. The majority of spillways were located at the western end of the Yandi mine area as this is where the majority of available pit storage is located following mine closure; and
- Spillway locations were selected in areas where Upper Channel Iron Deposit (UCID) material was present based on analysis of surface geology maps. UCID material was preferred as this material is found at the pit edge and is more resistant to erosion.

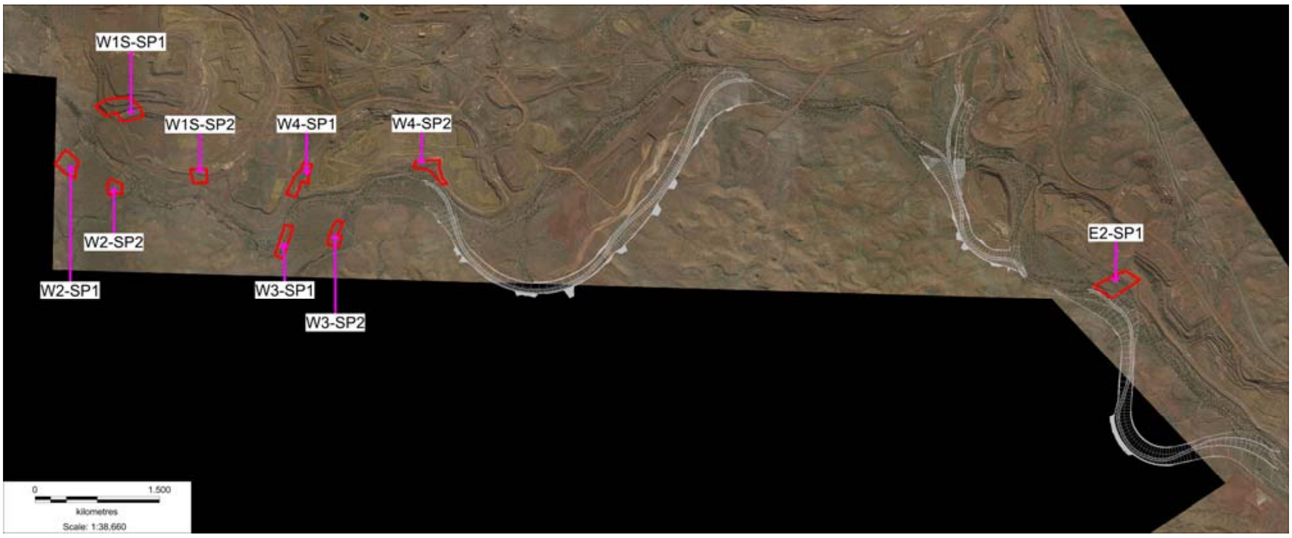


Figure 6-8: Spillway Locations.

Several concepts for spillways were evaluated and found to be potentially feasible, subject to further geotechnical and hydraulic investigations. The performance of concept spillway designs was assessed using HEC-RAS hydraulic modelling and the Chute spreadsheet program (CRC, 2003). Spillways were assumed to be rectangular in cross-section and a Manning's n roughness coefficient of 0.045 was assumed for all spillways. An example spillway concept is provided in **Figure 6-9**. The availability of UCID material in the pit walls is a critical element to the design as it helps protect against excessive erosion and head-cutting. The availability of UCID material will therefore influence which design option will be applied. At some locations the preferred option may be to use the final pit face as the spillway (assuming sufficient UCID is left remaining).

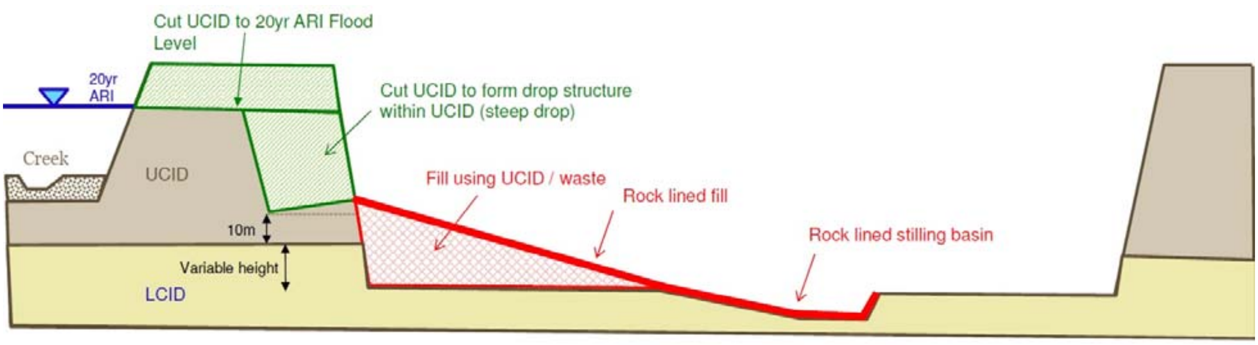


Figure 6-9: Spillway conceptual design option.

A range of spillway levels were tested in the design screening assessment. Spillway levels were set to the 100 year ARI flood level for Design Iteration 1 and then adjusted to just above the 20yr ARI flood level as one of several design refinements made for Design Iteration 2. By their very nature, spillways lower the peak flow (and hence peak velocity of flow) passing through the diversions. Understanding changes to peak discharges and total flow volumes was an important consideration in the design.

Comparison of flood hydrographs and flow volumes near the downstream extent of the Yandi lease shows that the introduction of spillways at closure will reduce peak discharges by approximately 31% and 15% for the 100 year ARI event and 50 year ARI events respectively. The hydrographs also show that the reduction in spillway levels has a smaller impact on the total flow volume, with a modelled reduction of 14% and 6% of total flow volume near the downstream extent of the Yandi lease. It should be noted that every flow event up to and including the 20 year ARI event is expected to pass through the diversions without any loss of flow or reduction in peak discharge rate due to the spillways.

Hydrological modelling by MWH (2016) indicates that, on average, the Marillana Creek catchment accounts for approximately half of the Weeli Wolli catchment contribution of surface water inflow to Fortescue Marsh, with approximately 8% of total input to Fortescue Marsh sourced from the catchment area defined at the downstream extent of the Yandi lease boundary. Changes to surface water contribution were modelled under a variety of development scenarios, including:

- Scenario 1: No creek diversion, northern tributaries (Herbert’s, Iowa and Slims Creek) remain connected to Marillana Creek (no development case)
- Scenario 2: Creek diversion in place, 1:100yr ARI spillway, northern tributaries draining to mine voids at closure (previously approved concept design case)
- Scenario 5: Creek diversion in place, 1:20yr ARI spillway, northern tributaries draining to mine voids at closure (alternate case)
- Scenario 7: Creek diversion in place, 1:20yr ARI spillway, northern tributaries remain connected to Marillana Creek (current concept case)

As demonstrated in **Table 6-5**, hydrological modelling shows that total inflow to Fortescue Marsh under the previous design concept (Scenario 2) can be maintained if a reduction in spillway heights is offset by maintaining flow from northern tributaries into Marillana Creek (Scenario 7).

Table 6-5: Hydrological modelling of stream flow under varying development scenarios.

Scenario	Description	Weeli Wolli inflow to Fortescue Marsh	Total inflow to Fortescue Marsh	Weeli Wolli contribution to Fortescue Marsh
1	No development	18.1 Mm^3/yr	100.9 Mm^3/yr	18.0%
2	Previous concept	17.4 Mm^3/yr	100.1 Mm^3/yr	17.4%
5	Alternate concept	16.9 Mm^3/yr	99.7 Mm^3/yr	17.0%
7	Current concept	17.6 Mm^3/yr	100.3 Mm^3/yr	17.5%

(extract from MWH, 2016)

Balancing the risk of excessive erosion of the diversions against excessive erosion of the spillways has been an important consideration in the design. Irrespective of the spillway levels, some erosion of the spillway structures is likely over the long term. Although this process will occur over a long period of time, there is an associated risk which would increase if spillway levels are reduced and the proportion of flood flows over the spillway progressively increases. This may be exacerbated if increased rates of sediment deposition occur within or upstream of the diversions. Diversion design has consequently focused on achieving velocities, and therefore associated shear stresses, that are neither too high (resulting in excessive degradation) or too low (resulting in excessive aggradation). Further modelling will be conducted as the design is refined to evaluate the likelihood of long-term aggradation or degradation trends.

6.3 Construction Programme

6.3.1 Construction method

The preliminary works sequence for construction of the diversions is summarised below and has been determined based on material requirements and appropriate means of obtaining these materials from geological domains.

1) Initial Access and Drill Pads

Construction will commence with cutting access tracks and establishing initial drill pads. Smaller construction equipment will be used for initial access. Some contouring and construction of ramps may be required to assist with access.

2) Removal of Common Material

Common material (i.e. material which does not require blasting) will initially be removed using smaller excavators and dump trucks until a working pad is established for access by larger mining equipment.

In areas where common material is relatively thin (e.g. 2 m or less) and the terrain is undulating, it may be preferable to leave this material in place prior to drill and blasting for use in pioneer access roads and platforms.

3) Bulk Drill and Blast

The objective of the first blast at high points along the trace will be to produce a level bench from which the subsequent drilling activities can proceed. Drill and Blast activities will then proceed at nominal bench depths of 12 m with material excavation at 6 m benches. The basement level of the bulk blasting activities will be the low flow creek level. The majority of these materials will be delivered to waste dumps.

4) Excavation and Carting

It is proposed that removal of the 6m benches be staggered to enable materials to be exposed in advance so that site decisions on materials can be made as early as possible. This can also facilitate ramping down of haul roads from higher to lower levels.

5) Detailed Drill and Blast

The objective of retaining overshot rock in lieu of removal and replacement with alluvial fill results in the work area being reduced in size at the bottom of the channel. This will require a more detailed blasting and removal method using smaller equipment to maintain equipment efficiency.

It is envisaged that the drill and blast operation below the diversion invert will be conducted on a closer drill pattern than bulk blasting. This will enable rock fracturing to meet the necessary aquifer material size specifications. Removed material will generally be taken to waste.

Detailed blasting will bypass locations where rock bars are proposed, leaving the previously blasted surface at the low flow invert level. Rock bars will be left approximately perpendicular to the diversion across the full width.

6) Placement of Flood Protection Bunds

Construction of the Flood Protection Bunds requires the use of low permeability fill and will involve spreading, watering and compaction during placement. This will be achieved using bulldozers for levelling dumped piles, graders to spread materials to an even thickness, water carts to provide soil conditioning and vibrating rollers to achieve necessary compaction. Material will be sourced from suitable geological domains during excavation of diversions.

7) Placement of Alluvial Material

The balance of the shallow aquifer not made up of in-situ blasted material will be filled with uncompacted alluvial materials. This operation will be conducted after the excavation has been completed and the diversion channel "opened". This will enable the flood protection bund to be completed and mining operations to commence, allowing the alluvial materials to be recovered during the mine pre-strip operation. Rock bars that are to be constructed using imported competent rock (e.g. fresh dolerite or BIF) will be placed prior to importing alluvial material.

6.3.2 Project staging

It is likely that the construction of diversions will proceed in a staged manner, ideally with construction fleet moving in a sequential fashion from one diversion to the next in order to maximise construction equipment utilisation. However, the ultimate sequence and timing of construction will be subject to business considerations regarding mine planning, project commercial analysis and supply requirements. As such, it is possible that not all diversions will be constructed. Development of this Diversion Management Plan has been based on a full development scenario as a maximum case.

The nominal sequencing of diversion construction is:

- E1
- E4
- W3W5

Continuous improvement will be achieved through the application of lessons learnt from initial diversion construction to subsequent diversions where applicable.

6.3.3 Interface with existing operations and overburden infill program

Construction of all three diversions will yield approximately 23 Mm^3 of material along the diversion route. While some of this material will be used for the construction of bunds and other flood protection measures, the majority is likely to be placed in-pit subject to mine planning requirements. Any material that is placed in ex-pit overburden storage areas (OSA's) will be rehandled or reshaped at closure in accordance with the mine closure plan.

6.4 Revegetation Programme

A key design objective is for a diversity of habitats to be established within diversions that supports representative flora and fauna species and provides ecological function and connectivity through the system. Consistent with other components of the diversion designs, a key approach has been to facilitate the development of a vegetation community that is similar to that of the existing system.

The principal strategies for achieving revegetation are selective rock armouring, topsoiling and direct seeding, as well as associated site treatments to stabilise soil, encourage water infiltration, and promote natural plant recolonisation.

6.4.1 Site Treatments and Natural Regeneration

Stabilisation techniques such as placement of logs and rock armouring will be considered for areas prone to erosion. Techniques for stabilisation also tend to promote natural colonisation of plants as they slow down water flows, which encourage deposition, not only of finer alluvium, but also seed being dispersed by water. Revegetation of sites through encouraging natural processes is likely to be the most successful revegetation approach. This method relies on a succession of communities from colonisers to a stable climax community over a 15 plus year timeframe.

Large woody debris is a common component of river beds in the region and where available will be placed in diversions to help slow down water flows, promote heterogeneity in channel form and encourage deposition of fine sediment. Such debris will be obtained from sections of the existing creek in the Yandi lease area which require vegetation clearing or from clearing elsewhere in the vicinity. Larger material (logs, large branches) is likely to be deposited in mounds within the diversions where it is determined additional roughness elements are required. Large boulders may also be used as roughness elements. Elsewhere available logs and large branches will used to stabilise banks where appropriate.

Although it will be mostly alluvium that is used for creating the new creek landforms, exposure, settling and/or vehicle traffic may result in compaction of this layer. Compacted layers can cause problems for root growth and spread in plants. Ripping will be used to loosen compacted layers where required.

6.4.2 Topsoiling

Surface topsoil from the creek bed, banks and floodplains is likely to contain seed from a range of species and hence is a valuable resource for revegetation when applied to newly created creek landforms. Fresh topsoil also has other useful functions and attributes for revegetation including nutrient store, organic matter, useful microbes and other soil biota, and generally is a better growth media for young plants than other soil, although generally riverine alluvium (which will be the main soil used for creating landforms in the new creek system) will have elevated nutrients compared to soil of slopes and terrestrial areas.

Topsoil is a limited resource. The following principles and guidelines will help to maximise benefits from it:

1. **Topsoil Storage.**
   Seed viability and soil health decline with time in storage and with depth of stockpiling. Depending on timing of works. The broad aim will be to maximise direct transfer of topsoil from cleared areas of old creekline to newly created landforms in diversions. If storage is required, it will be done in small stockpiles (<2.5 m high) and temporarily (<1 year where possible).

2. **Topsoil Separation and Zoning**.
   Although a number of stream habitat zones has been recognised, separating topsoil is only required between the stream habitat zone (bed, banks and floodplain) and that of true terrestrial environments (slopes and uplands). This is because of the major differences in species composition between these two environments and because plants growing from seed in topsoil from stream zones are unlikely to survive in the terrestrial environment, and vice versa.

   Terrestrial areas to be cleared are minor relative to the area of stream zones, and topsoil will be collected and stored separately before applying back to terrestrial environments adjacent to the new stream. Within the stream zone there is more overlap in species composition across identified habitats, and seed is likely to be mixed a lot more due to dispersal by wind and water. Consequently it is more likely species will find their own suitable niche within the stream zone.

3. **Topsoil Collection and Placement.**
   The bulk of viable seeds are generally in the first top 5 cm of topsoil, with few to no seeds found below 20 cm. Therefore, scraping of the top 15 cm of topsoil will be targeted where possible, whilst making allowances for the highly undulating and variable landforms such as creek beds. This is likely to result in some reduction in seed density with the benefit of having more topsoil recovered.

   Topsoil will be spread onto newly created diversion landforms at much the same depth as it was collected. Topsoil will be preferentially allocated to the floodplains and upper banks where flooding will be less frequent. This will minimise potential loss of topsoil downstream from flood events. It may also be necessary to allow newly constructed diversions to settle for some period before adding topsoil.

4. **Weed Management.**
   Based on previous studies and experience, topsoils are likely to be full of annual plants (grasses and forbs), but they are also likely to contain weeds given their prevalence in drainage lines across the region. Experience has shown that seed bank density of weeds such as Buffel Grass and Mexican Poppy varies with their above-ground cover, and hence soil collection from areas where weeds proliferate will be avoided or such weeds controlled well before topsoil collection. Machinery used for topsoil collection will be cleaned and checked prior to use in these areas to avoid spreading weeds from other parts of the site.

   Although it will be important to avoid using topsoil infested with weed seed, some weeds are inevitable and will need to be dealt with via ongoing monitoring and management (e.g. weed control) as described in **Section 6.4.4** below.

5. **Collection Times.**
   Topsoil is best collected and handled when relatively dry, but during extended dry periods is when there is likely to be the lowest diversity and density of seed in topsoil. This is because flowering and seed set of arid zone plant species are highly pulsed and cued to major rainfall events, and although seed longevity lasts for many years to decades in some perennial species (e.g. *Acacia*, *Senna* spp.), it may be relatively short for others (e.g. some *Triodia,* maybe *Eucalyptus*), and is generally unknown for most species. Therefore, where practicable, topsoil collection will preferentially occur in the few months after major rainfall episodes.

6.4.3 Direct Seeding

Although topsoil is expected to provide adequate seed for many species, coverage and diversity of seedlings arising from topsoil can be patchy and unpredictable in semi-arid/arid environments, especially as some species may not maintain a persistent soil seed bank. Therefore directly adding extra seed will be required in some areas. Seeds are generally best sown following topsoil application. Seeding may be particularly important for the dominant perennial species to make sure they are established at the required densities. Local seed collection is carried out within a 100km radius to minimise the potential for genetic differentiation of populations at a regional scale. Given the likelihood of extensive gene exchange along river systems (mainly due to downstream seed dispersal, but also movement of pollen and seed by fauna), much of Marillana Creek upstream towards the Hamersley Ranges will be preferentially targeted.

Seeding with relatively high densities of native grasses (both annual and perennial) will be used for areas which need rapid stabilisation and/or in revegetation zones where such species are typically dominants (e.g. floodplains).

Rates of plant emergence and establishment (survival > 1 year) following direct seeding can be extremely variable, both spatially and temporally, in arid/semi-arid environments, mainly due to the highly variable climate. Given the importance of establishing plants quickly and densely to stabilise soils, methods to improve the chances of seed germination and early seedling survivorship will be considered, including:

1. Seed encapsulation techniques (at least for key dominant species) where seeds are coated in substances which improve water retention around the seed;
2. Mulching or adding organic matter to soil (to improve moisture retention;
3. Collecting seed when it has the highest viability (i.e. in right season or following big rains); and
4. Timing seeding to periods just after major rainfall events (although follow-up rains, important for survivorship of seedlings, are difficult to predict).

Direct seeding will be concentrated on floodplains and upper banks where flooding and surface water flows are uncommon. Seeding of raised mounds, banks, islands etc. in the channels will be carried out, where appropriate, to speed up the natural revegetation of these areas. Timing of seed application will generally be done after topsoil application or when landforming has been completed and will be combined with any surface roughening or ripping.

6.4.4 Weed Management

Weeds are identified as an environmental risk on all BHP Billiton Iron Ore operating sites and as such are managed so that activities from mining operations do not accelerate spread. The current approach to managing weeds at Yandi will be applied to the diversions.

Weed mapping will be conducted annually. Weed intensity and weed occurrence will be recorded from targeted weed searches and the data loaded into a spatial database for review. A risk assessment to determine areas most at risk of weed infestation will be identified and a scope for weed treatment will be established. Recommended treatment measures (e.g. spray, spray and/or hand removal, spray and seed head removal) will then be implemented.

A weed spraying program is typically conducted before the end of June or seed set, whichever comes first. Should there be winter rains, further weed spraying may be initiated to control emerging weeds at this time.

After each weed management program, weed data will be reviewed, risk assessments and management tables updated, performance metrics reviewed and target species identified for the next round of weed management.

6.5 Closure

6.5.1 Revised Yandi Closure Strategy

The Closure objective for BHP Billiton Iron Ore operations is to create a safe, stable, non-polluting and sustainable landscape that is consistent with key stakeholder agreed social and environmental values and aligned with creating optimal business value.

Yandi operations have a specific closure objective defined in MS 1039, condition 5-1 to "*ensure that the proposal is decommissioned and rehabilitated in an ecologically sustainable manner*". For Creek Constrained Ore this requires a final landform at closure that is safe, stable and non-polluting that does not require ongoing care and maintenance. The closure design should foster the development of a sustainable ecosystem with the analysis of performance criteria demonstrating that the system is on a pathway towards becoming self-sustaining.

Understanding and appropriately managing surface water and groundwater is the key to developing an acceptable Closure Strategy for Yandi. Given the strong relationship of Yandi final landform closure engineering with local and regional environmental outcomes, a set of specific Yandi Closure Guiding Principles have been derived as the foundation for developing a stakeholder agreed, sustainable closure solution. These are specified in the Yandi

Closure Plan, Objectives and Guiding Principles (BHP Billiton, 2016b). Through collaboration with key stakeholders (adjacent mines, Banjima), Yandi closure will maintain the three key regional environmental receptors of Fortescue Marsh, Weeli Wolli Creek and Marillana Creek by committing to sustain an appropriate surface water flow regime (water resource, hydraulic conditions and fluvial system).

CID groundwater recovery and through flow is not required to sustain Fortescue Marsh. However, the removal of portions of CID aquifer has implications for local mine void outcomes at closure that include:

- Having insufficient overburden to infill mine voids to pre-mining levels due to the low strip ratio;
- Final pits will form depressions, groundwater levels will recover to equilibrium lower than pre-mining condition;
- Functional behaviour of pit lakes as either groundwater sinks or local through flow systems will vary; and
- Evaporative loss of groundwater from the pit lakes will contribute to increased salinity in some lakes.

Consequently, the final mine void closure solution will be a mix of landscape types (as detailed in the Yandi Closure Plan; Ecohydrology) using available mine waste. Outcomes will be determined through BHP Billiton's forward closure improvement technical work actions and stakeholder consultation consistent with the Yandi Closure Guiding Principles.

Based on the above drivers, revision of the Yandi Closure Strategy has been undertaken. The timing of this revision coincides with the scheduled (5 yearly) review of the Yandi Closure Plan, with an updated Closure Plan due for submission in 2016.

6.5.2 Key Considerations for Creek Diversion

From a physical design perspective, key interfaces between the Closure Strategy and the design of Marillana Creek diversions principally relate to:

- the height of Flood Protection Bunds (FPBs), which at closure are required to accommodate more extreme events;
- the spillway structures that allow some stream flow above a particular height to be diverted into mine voids at closure; and
- the treatment of tributaries at closure, whether they discharge to mine voids or remain connected to Marillana Creek.

Concept-level geotechnical designs for FPBs have been developed as well as earthworks quantities. The concept designs for operations and mine closure are largely the same however the closure designs require higher FPBs to prevent overtopping during the 10,000 year ARI flood event and larger rock sizing for protection against the higher velocities associated with such an event.

The implementation of spillways is required irrespective of diversion development to control discharge volumes passing through reaches where CID has been mined either side of Marillana Creek. Spillways also provide protection to flood bunds from overtopping failure. As discussed in **Section 6.2.8**, several concept design options for spillways were evaluated and found to be potentially feasible subject to further geotechnical and hydraulic investigations.

The use of spillways progressively reduces peak discharges for flood events greater than a 20 year ARI while having a relatively smaller impact on total flood volumes. As demonstrated in **Section 6.2.8**, retention of surface water inputs from northern tributaries, in particular IOWA creek, minimises downstream changes in flow volumes. A modelled reduction in annual contribution to Fortescue Marsh of 0.5% is expected which is consistent with the environmental impact assessment that supported the life of mine proposal.

7 Assessing Design Performance

7.1 Hydraulic Modelling Results

Hydraulic modelling was conducted and results analysed across a range of discharge events: 2, 5, 10, 20, 50 and 100 year ARI. Frequency distributions of 2D hydraulic modelling of peak velocity, bed shear and stream power from model grid cells were plotted to characterise the hydraulic performance of diversions and evaluated based on comparison of modelled results of the existing system. Comparative data were plotted for the following geomorphological domains in the model:

- the length of Marillana Creek from immediately upstream of W1W2 to the railway crossing downstream of E7;
- the incised sections of creek only; and
- the anabranching sections of creek only

Modelled data for diversions were analysed for each successive target reach type (anabranching or incised) along the length of each diversion.

Evaluation of 1D and 2D hydraulic modelling indicates that they are generally in agreement with the exception of two reaches where the 1D (HECRAS) modelling indicates velocities, shear and stream power all lower than the existing conditions, while the 2D (TUFLOW) modelling and sediment transport modelling suggested that there are only minor differences. Based on a comparison of model resolution, it was concluded that the 2D modelling approach provided a more accurate representation of the creek system and diversions, and therefore provides more reliable estimates of hydraulic behaviour.

A summary of 2D modelling results for all reaches is provided in **Table 7-1** and discussed below. The frequency distributions (S-Curves) for velocity, bed shear and unit stream power derived from the 2D modelling are provided in **Appendix A** for reference. Hydraulic modelling results indicate that the overall performance of the diversions is generally consistent with the natural system, with behaviour of all diversion reaches similar to that of anabranching and incised reaches of Marillana Creek. For channel reaches where modelling results were at the upper end or in excess of natural ranges, the risk has been assessed in these cases and mitigation measures have been implemented in the design through the use of rock bars and induced roughness measures.

Table 7-1: 2D Hydraulic Performance Assessment Results

Diversion	Section #	Target Planform Type	2yr	5yr	10yr	20yr	50yr	100yr
W3W5	1	Anabranching						
W3W5	2	Incised						
W3W5	3	Anabranching						
W3W5	4	Incised						
W3W5	5	Anabranching						
E1	1	Anabranching						
E1	2	Incised						
E1	3	Anabranching						
E4	1	Anabranching						

	Within range
	Slightly outside range but considered acceptable
	Outside range but can be managed (e.g. through placement of rock bars)
	Design improvements required

The frequency distributions for all ARI's demonstrate the effectiveness of the induced roughness measures in reducing velocity, shear and stream power to within the natural range of variability during operations. This reduces the risk of excessive scour and potential net loss of alluvial material downstream, and subsequently increases the likelihood that vegetation will establish and be retained within the diversions. It is recognised that some erosion will occur during the first few wet seasons depending on the magnitude and frequency of events, however, the evolution of channel form is a desired design outcome.

The frequency distributions for the 2 year ARI event were often skewed towards lower velocity values. This was due to the majority of the flow being contained within the low flow channel and floodwater spilling out over the floodplain area at very shallow depth. This has particularly affected results for W3W5 Sections 4 and 5. As the frequency distributions are based on all wet cells within the 2D model domain, the results were dominated by the large number of cells with very shallow depth and low velocities. This is an artefact of the initial uniform channel design and is expected to resolve itself naturally as the variability in channel form develops over time.

The 2D modelling results also identified an area immediately upstream of the W3W5 diversion and adjacent spillway where minor reductions in peak velocities occur. While net aggradation was not evident in the sediment transport modelling (discussed in **Section 7.2** below) this may indicate a potential for increased sedimentation upstream of the W3W5 diversion and potentially within the diversion following mine closure to occur. This risk will be evaluated further as the engineering design is finalised. Design measures to address this risk may include limiting the placement of roughness elements in this part of the diversion to increase sediment transport capacity or reducing the volume of alluvial material placed in this part of the channel.

The downstream reach of the E1 diversion (E1, Section 3) had hydraulic behaviour that was close to or slightly exceeding the natural range of variability observed in Marillana Creek. While initially targeted as an anabranching reach, the hydraulic behaviour was similar to the natural range of variability for an incised reach. Therefore this section of creek is expected to behave more like a transitional section from an incised reach to an anabranching reach in the existing Marillana Creek.

An additional comparison of the frequency distributions for the incised reaches within the diversions and a sub-set of those derived from the more "featureless" incised reaches of Marillana Creek was also completed. This was undertaken to "sensitivity test" the results against the spectrum of incised channel forms seen in Marillana Creek. The results indicate that the hydraulic behaviour of diversion reaches targeted as incised appears similar to existing reaches that include some sediment storage and vegetation stabilisation. It is therefore expected that diversions have the potential to produce a range of channel forms and vegetation compositions that are consistent with what is observed in Marillana Creek.

It should be noted that the hydraulic performance of diversions is dependent on the assumed channel geometry. In the case of anabranching reaches, a single low flow channel was included in the design and it is expected that the observed natural geomorphological characteristics of Marillana Creek will develop in the diversions over time. Many of the anabranching reaches in Marillana Creek have more than one low flow channel which influences the results of the existing conditions hydraulic modelling. This difference in assumed and observed channel geometry is a potential source of observed differences in modelled hydraulic behaviour that is likely to resolve over time.

Sensitivity analysis was performed to test the effect that adopting higher Manning's n values may have on flood levels and freeboard to the flood protection bunds during operations. This corresponds to a scenario where vegetation has established quickly during the operations period and is denser/rougher than the existing conditions in Marillana Creek. The results indicate that such an increase in Manning's n values generally resulted in an increase in flood levels from 0.8 to 2.0 m, which is just within the 2 m freeboard allowance provided in the flood bund design.

Spillway performance was evaluated for both the 100 year and 10,000 year ARI flood events, with the 10,000 year ARI event used to inform the design due to the higher associated velocities. The main objective of the hydraulic modelling was to evaluate velocities along the face of the spillway chutes in the lower portion of the pit containing LCID (where present). The maximum velocity does not necessarily occur at the same time as the peak flow due to the mitigating effects of the rising water level in the pit (tail water conditions). Therefore the hydraulic modelling was performed using a quasi-unsteady approach by applying a time series of inflows and tail water levels to identify the timing of the maximum velocity.

The hydraulic modelling demonstrated that velocities vary along the length of the spillway and over the duration of the flood event. The results suggest the following:

- Peak velocities occurring along the spillway chutes are independent of the spillway design options considered i.e. the peak values are the same. This is due to all options having the same chute design which governs peak velocities in the portion of the spillway corresponding to LCID;
- All options are potentially feasible however the batter slopes needed to achieve design velocities varied between spillway locations;
- The batter slopes for spillway chutes are limited by the available pit void area and have been restricted to a nominal 1V:10H. Further reductions in peak velocity could be achieved using alternative spillway designs or geometries.

Preliminary closure scenario modelling was also performed to simulate what effect various closure scenarios may have on flooding during the 10,000 year ARI and Probable Maximum Flood (PMF) events. Further work is required as outlined in the Yandi Closure Plan, Closure Improvement.

7.2 Sediment Transport Modelling Results

An assessment of sediment transport was undertaken to compare the modelled pre and post diversion conditions and determine whether the range of bed elevation changes (erosion and deposition) in the diversions estimated by the models for the 100 year ARI event are consistent with the existing conditions scenario. It should be noted that this assessment makes relative comparisons of bed elevation changes rather than being focused on absolute values, recognising the limitations of sediment transport modelling discussed in **Section 5.3**.

The magnitude and range of modelled erosion and deposition under post development conditions is within the natural range of variability observed in the existing conditions model. The 2D modelling results for the post development scenario indicate:

- Maximum modelled bed elevation changes ranged between +/- 5 m and +/- 4 m using the Englund and Hansen and Meyer Peter and Müller sediment transport functions respectively.
- While the magnitude of change varied between sediment transport functions, the locations of erosion and deposition were generally consistent.
- Irrespective of the sediment transport formulae applied, 99.6 % of model grid cells had bed elevation changes of less than 3 m.
- The modelled range of bed elevation changes with rock bars in place is higher than without rock bars due to the formation of localised scour holes immediately downstream of the rock bars as well as deposition upstream.
- Bell curves of data under post development conditions for the W3W5, E1 and E4 diversions are symmetrical and centred on the zero change in bed elevation (indicating a balance between aggradation and degradation).
- E4 and E1 demonstrated a less widespread change in bed elevations when compared with the existing conditions (a higher proportion of the cells having “zero” change in bed level).
- The introduction of rock bars at W3W5 improved the fit between the existing conditions and post development bell curves.

Based on the modelling results it is concluded that there are no obvious (and consistent) differences between the range of bed elevation changes predicted by the model in diversions and that seen under existing conditions.

7.3 Independent Design Review

At completion of the SPS, Alluvium Consulting undertook an independent technical peer review of the proposed design. The principal reviewer was a co-author of reports for the ACARP diversion projects in 2001-02 (C8030 and C9068) that have been adopted as guidelines against which diversions are assessed and licenced in Queensland. More recently, Alluvium completed ACARP project C20017, in consultation with the Queensland Department of Natural Resources and Mines, titled *Criteria for functioning river landscape units in mining and post mining landscapes*, which provides the current best practice design approach for diversions at mine sites in Queensland.

The review by Alluvium Consulting largely focussed on the Basis of Design and, where appropriate, the geomorphic and hydraulic studies that provide key inputs to the physical form of the design. The review concluded that the approach taken to identify a range of design parameters from natural analogues at Yandi and use them to inform the design was a reasonable first premise to base the design on. The review did, however, highlight that an opportunity may exist to further refine the design by drawing on analogues beyond the immediate Yandi area, subject to achieving appropriate environmental outcomes for the stream system.

The review also identified that the next phase of design could also reappraise the timeframes for diversion design performance, particularly with regard to placement of alluvial bedload sediments and proposed timber/boulder roughness elements. It is suggested that these design outcomes may be naturally achieved by the fluvial system doing such work over a period of time. Amendments to the initial diversion channel characteristics could therefore be made if such timeframes are considered acceptable.

Within the detail of the design, the hydraulic conditions at the off-take and tie-in locations for the diversions to the remaining natural reaches of Marillana Creek were a particular focus in the review. Analysis of the hydraulic conditions in these zones highlights the potential for areas of both aggradation and degradation respectively. While hydraulic conditions are modelled to be consistent with the existing environment, further interrogation in the next design phase was recommended with consideration given to amending the amount of alluvial material imported to the diversions. The review also indicated that for constructed channels through substrate that is alluvial, hydraulic parameters initially often need to be more conservative than existing conditions while the diversion is not vegetated and constructed surfaces are fresh.

The proposed design of the shallow aquifer utilising ‘over blast’ to fracture in situ material and importing alluvial material from the existing reaches to be diverted was also considered in the review. Further investigation to potentially increase the proportion of overblast material was recommended should it be deemed adequate to provide shallow aquifer conditions required for the woody species that populate the waterway. Preferential placement of alluvial material to create an armour layer or reduction in hydraulic parameters was also recommended to aid the retention of imported alluvial material within diversions.

The review also recommended further consideration of the treatment of tributary inlets in the design. Should the tributaries have alluvium where intercepted by the diversion, the proposed arrangements could cause erosion, both deepening and widening of the tributaries, to migrate some distance upstream.

The use of spillways was also considered in the review. It was acknowledged that their premise, to allow floodwater to pass safely and in a controlled manner into pits, is logical and was part of the conceptual design included in the Environmental Impact Assessment originally approved through MS 679. The review raised the question as to whether or not alternate mine planning and subsequent land-forming with waste material could offer an alternate approach, however, mine planning indicates there is insufficient waste material to contemplate such an alternative. The review highlighted that spillways, by their very nature, will have some impact on the hydrology and hydraulics of the system, however it was recognised that BHP Billiton is proposing mitigation measures to minimise impacts.

The review concluded that the diversion studies and design are adequate and with considered implementation should produce diversions that meet expected performance criteria. While it is recognised that there is further opportunity to refine the design as engineering progresses, the current design is considered suitable and practicable, consistent with current best practice.

7.4 Definition Phase Study Engineering

During the next phase of the project, known as the Definition Phase Study (DPS), the engineering design will be further developed and refined to:

- Mitigate risks;
- Reduce uncertainty in key design parameters; and
- Optimise capital costs.

Design changes will continue to be assessed against the management objectives outlined in **Section 6.1.2** with the prevailing intent to meet the Condition Environmental Objective that *diverted sections of Marillana Creek function as a fluvial system in a similar manner to the existing creek system*.

As described in this document, key design focus areas in DPS will include:

- Refinement of channel dimensions and nominal planform types subject to achievement of appropriate hydraulic conditions.
- Further refinement of the low-flow channel, including reviewing the width:depth ratio adopted within incised reaches.
- Development of options for the placement of large boulders and woody debris including targeted placement and selection of placement methods.
- Review of shallow groundwater aquifer thickness based on additional geotechnical investigations and consideration of natural re-working and placement of alluvial material.
- Consideration of greater use of over-blast material to achieve shallow aquifer design objectives.
- Investigation of the feasibility of preferential placement of alluvial material to create a more armoured channel surface.
- Review of rock bar dimensions including crest heights at or below the low-flow channel invert.
- Further development of flood bund designs for closure conditions.
- Refinement of channel characteristics at off-take and tie-in locations for the diversions.
- Further consideration of the treatment of tributary inlets to mitigate extensive erosion.

The DPS is expected to be completed by mid-2017.

8 Management Targets, Monitoring and Reporting

8.1 Management Targets

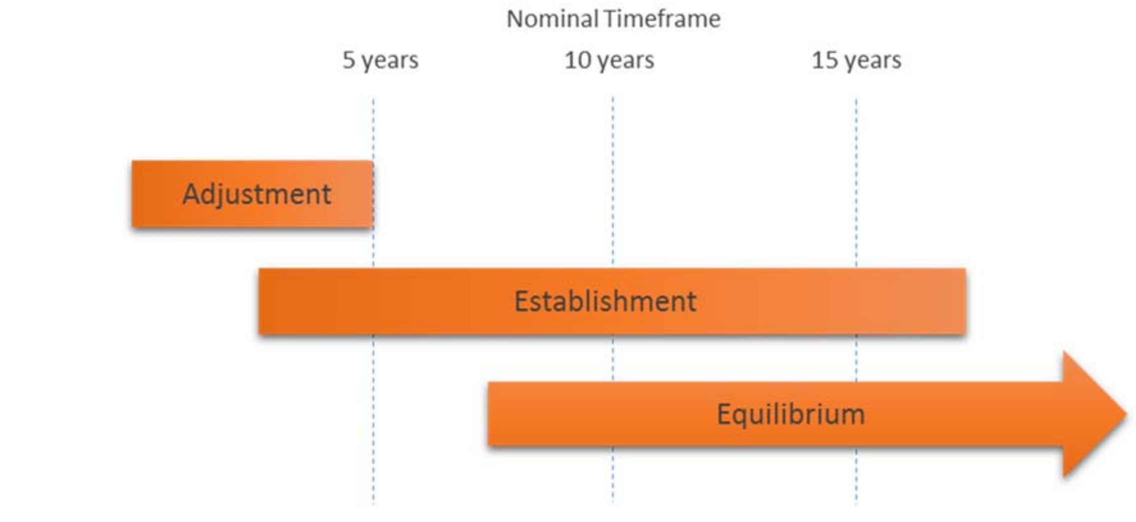
Recognising that fluvial systems are inherently dynamic in nature, the design philosophy has been to construct diversions in which their form and function will continue to evolve over time. In a fluvial system with high inter-annual flow variability, such as Marillana Creek, morphological change is intrinsically event driven. However, while large flood events have the ability to instigate significant change, the morphology of Marillana Creek is closely associated with flows that occur relatively frequently.

Baseline geomorphological studies and flood modelling indicates that:

- the primary channel in anabranching reaches is overtopped by events with between a one to two year ARI;
- the floodplain is inundated by events with an ARI of between two and five years; and
- flows up to the ten year ARI event are capable of transporting the majority of bedload sediment in the system.

This suggests that these reasonably regular flows are important in doing the geomorphic work that facilitates the development of stream channel morphology (Entura, 2014).

While the nature and rate of morphological change in the diversions will be subject to the magnitude and frequency of flood events that occur, nominal timeframes for the evolution of channel form are provided in **Figure 8-1** for guidance. The likely phases of morphological development and their indicative timeframes provide an important context when establishing appropriate performance criteria.



Adjustment Phase	The diversions will have significant changes for the first few floods. A large flood in the first few years of the life of diversions is likely to cause substantial redistribution of sediment through scour and aggradation. Duration ~ 2-3 floods.
Establishment Phase	Basic features of the channel are beginning to form (benches, anabranch ridges) and the bed is likely to be covered by a dense cover of saplings. Duration ~ 5-8 floods.
Equilibrium Phase	The morphology of the diversions reflects the natural system as far as is practicable.

Figure 8-1: Expected phases of development of the diversion channels

The principal criteria for assessing diversion performance will be the Index of Diversion Condition (IDC). The IDC was developed through the Australian Coal Association Research Program (ACARP) in 2001-02 for diversions in the Bowen Basin and has been adopted by the Queensland government as a guideline against which diversions have been assessed and licenced since. The IDC provides a rapid assessment of the condition of stream diversions through an integrated suite of indicators that measures their geomorphic and riparian condition (ACARP, 2001).

The IDC is derived for three channel reaches:

- an upstream control reach;
- a reach within the diversion; and
- a downstream reach.

Within each reach, four transects are established and the indicators for the geomorphic index and riparian index assessed within each transect. The indicators for the geomorphic index and riparian index are listed in **Table 8-1**.

Table 8-1: Indicators for the Index of Diversion Condition (IDC)

Indicators for Geomorphic Index:	Indicators for Riparian Index:
• Width of high flow channel, active channel and low flow channel • Bank condition • Piping of banks • Bed condition • Spoil piles • Recovery • In-stream structures	• Width of riparian zone • Structural intactness • Regeneration • Longitudinal continuity

Each indicator is assigned a score at each transect. The average score for each indicator from the four transects is 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 determines the score for the IDC. While absolute scores provide an indication of diversion condition, it is the relativity of scores between the upstream reference reach and both the diversion and downstream reaches, as well as trends in scores, which provide insight into diversion performance.

Management Target 1 for Marillana Creek diversions is to achieve a total IDC score in diversion reaches that is comparable (>70%) with the total IDC score for the upstream control reach during the Establishment Phase of diversion morphological development.

Through the Establishment Phase of diversions, evaluation of performance using IDC scores will be supplemented by a suite of Ecological Indicators developed specifically for Marillana Creek. This approach expands on data already collected through the riparian index for the IDC to more broadly evaluate ecological functionality through a series of targeted indicators including key physical features, vegetation community composition and structure, recruitment and connectivity. Key Ecological Indicators for Marillana Creek diversions are listed in **Table 8-2.**

Management Target 2 for Marillana Creek diversions is to achieve 8 out of 10 Key Ecological Indicators during, or prior to, the Equilibrium Phase of diversion morphological development.

Table 8-2: Key Ecological Indicators

Vegetation:		
Structural intactness	Is the structural intactness of vegetation for diversions comparable to natural channel reaches?	Y / N
Recruitment	Is there evidence of recruitment in diversions?	Y / N
Connectivity	Is the longitudinal continuity of vegetation cover in diversions comparable to natural channel reaches?	Y / N
Self-sustaining	Are there a variety of ages evident in vegetation in diversions?	Y / N
Presence of key species	Are the following key species from natural channel reaches present in diversions: - Trees (1 out of 4 present): *Eucalyptus victrix*, *Eucalyptus camaldulensis* subsp. *refulgens*, *Corymbia hamersleyana*, and *Melaleuca argentea*. - Lower Trees (2 out of 5 present): *Atalaya hemiglauca*, *Acacia citrinoviridis, Acacia coriacea* subsp. *pendens, Acacia pruinocarpa,* and *Acacia ampliceps*. - Shrubs (3 out of 9 present): *Melaleuca glomerata*, *Gossypium robinsonii*, *Acacia pyrifolia, Acacia tumida var. pilbarensis*, *Acacia bivenosa, Acacia ancistrocarpa, Acacia monticola, Petalostylis labicheoides* and *Grevillea wickhamii*. - Low Shrubs (1 of 2 present): *Corchorus crozophorifolius, Tephrosia rosea* var.Fortescue creeks (M.I.H. Brooker 2186) - Grasses (2 out of 5 present): *Eulalia aurea*, *Themeda triandra, Triodia longiceps, Triodia pungens,* and *Eriachne tenuiculmis*.	Y / N
Weeds	Are new weed species absent from diversions?	Y / N
Pools:		
Presence	Is there evidence of pools having formed in diversions?	Y / N
Persistence	Is the persistence of pools comparable to that seen in natural channel reaches?	Y / N
Evidence of nutrient cycle	Is there evidence of organic matter (e.g. leaf litter, vegetation debris) in or adjacent to pools?	Y / N
Aquatic vegetation	Is there presence or evidence of macrophytes and/or algal cover in pools?	Y / N

8.2 Monitoring

The focus of watercourse diversion monitoring is to evaluate channel condition, manage risk to mining infrastructure and confirm that the trajectory of diversion performance is progressing towards equilibrium. The monitoring programme presented herein is designed to meet the requirements of MS 1039 and draws on methods adopted for monitoring watercourse diversions in Queensland in accordance with industry guidelines (ACARP 2001, 2014; DNRM 2014).

This approach includes a heightened monitoring effort in the early life of diversions followed by an ongoing risk-based approach to monitoring intensity thereafter, with consideration also given to the event based nature of flow in the Marillana Creek system. A risk profile is established based on the environmental performance of the diversion, in particular whether it is developing key features of a fluvial system and trending towards equilibrium. This risk profile guides subsequent monitoring tasks. Large flow events may also trigger additional monitoring efforts.

Operational risk will also be identified during monitoring efforts. Consideration of operational risks will not be used to identify monitoring frequencies or tasks, but to assist site-based personnel to identify risks to mine infrastructure adjacent to a diversion and inform appropriate personnel within the mine site management structure as required.

Annual monitoring will typically occur between April and June following the wet season. It should be noted, however, that more frequent inspection of diversions may occur as part of core operational routines in addition to the monitoring programme specified herein.

Annual monitoring intensity will be determined based on the amount of data that have already been collected on diversion performance, the prevailing performance risk rating of the diversion and the size of recent discharge events. A flow diagram outlining the method used for determining annual monitoring intensity is provided in **Figure 8-2**. Three levels of monitoring intensity are proposed, as outlined in **Table 8-3**.

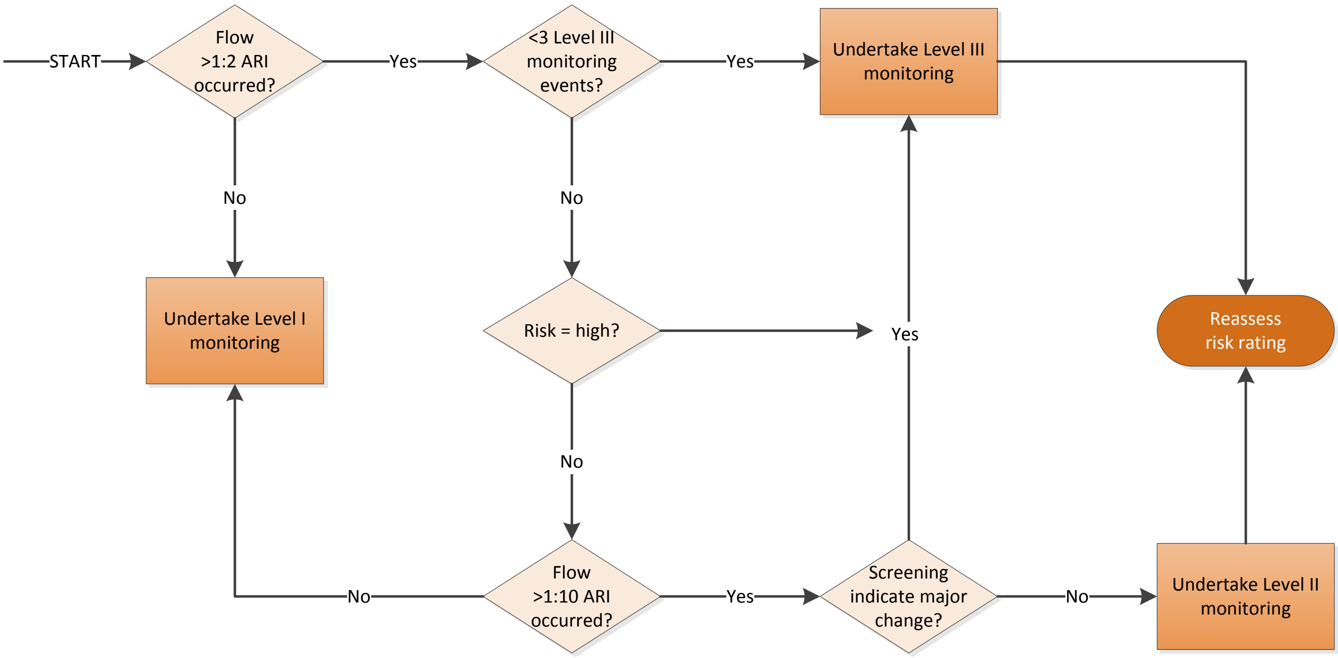


Figure 8-2: Flow diagram for determining annual monitoring intensity

If there has not been discharge greater than a 2 year ARI event since the preceding monitoring effort then Level I monitoring activity will be undertaken, namely a full walk-through of the diversions (including taking photographs with GPS coordinates) to get an overview of the diversion performance.

If discharge greater than a 2 year ARI event has occurred in the preceding 12 months, new diversions will be monitored using the Level III monitoring methodology until at least three Level III monitoring events have been undertaken. This will enable a detailed understanding of initial performance to be gained while diversions are most susceptible to change (i.e. during the initial adjustment phase).

In addition to Level I activity, Level III monitoring will also include scoring of diversion performance using the IDC method (ACARP, 2001). Fixed point field photographs and aerial photography will be acquired and analysed to identify changes in channel form and position over time. LiDAR data will also be acquired, with changes in elevation since the previous monitoring effort used to approximate sediment transport based on digital elevation models of difference. Total Suspended Solids (TSS) data[3] will be reviewed as the key water quality parameter for diversion performance. Hydrological data will also be analysed to identify and quantify flow events since the previous monitoring effort. Level III monitoring will also include an assessment of the condition of any rectification or rehabilitation measures (e.g. bank stabilisation works, structures) that have been installed within the diversion based on an informed visual assessment of whether the measure is operating as it was designed. In addition to riparian indicators measured as part of the IDC, ecological function will also be assessed using Key Ecological Indicators developed for Marillana Creek as outlined in **Table 8-2**.

Following the first three Level III monitoring events, the ongoing level of monitoring will be determined based on the performance risk rating derived from the previous monitoring event. Level III monitoring will continue to be undertaken if the performance risk rating remains high (as defined in **Table 8-4**).

[3] Following establishment of a relationship between TSS and turbidity, the later may be used as a surrogate for the former.

Table 8-3: Tiered approach to annual monitoring methods

Level I Monitoring	Level II Monitoring	Level III Monitoring
A full walk-through of the diversion, plus upstream and downstream reaches to get an overview of the diversion performance and to understand whether natural features are developing throughout. This will include photographs with GPS coordinates.	A full walk-through of the diversion, plus upstream and downstream reaches to get an overview of the diversion performance and to understand whether natural features are developing throughout. This will include photographs with GPS coordinates.	A full walk-through of the diversion, plus upstream and downstream reaches to get an overview of the diversion performance and to understand whether natural features are developing throughout. This will include photographs with GPS coordinates.
	Index of Diversion Condition (IDC) monitoring.	Index of Diversion Condition (IDC) monitoring.
	Measurement of Total Suspended Solids (TSS) / turbidity.	Measurement of Total Suspended Solids (TSS) / turbidity.
	Comparative LiDAR assessment to determine changes in elevation since the previous monitoring effort to approximate sediment transport based on digital elevation models of difference.	Comparative LiDAR assessment to determine changes in elevation since the previous monitoring effort to approximate sediment transport based on digital elevation models of difference.
	Photographs taken at established photo points.	Photographs taken at established photo points and analysis of historical photographs undertaken to determine changes over time.
	Identification and assessment of operational risk where necessary.	Aerial photograph analysis to identify lateral shifts in channel position.
		Flow event overview/analysis to identify events since the previous monitoring effort.
		An assessment of the condition of any rectification or rehabilitation measures (e.g. bank stabilisation works, structures) that have been installed within the diversion based on an informed visual assessment of whether the measure is operating as it was designed.
		Evaluation of Key Ecological Indicators.
		Identification and assessment of operational risk where necessary.

Table 8-4: Performance Risk Evaluation Criteria

Risk Category	Primary Performance Assessment Criteria	Supplementary Performance Assessment Criteria
High	Total IDC Scores for diversion and/or downstream control reaches are significantly lower (<60%) than the Total IDC Scores for the upstream control reach; **OR**	
	Total IDC Scores for diversion and/or downstream control reaches are moderately lower (60-70%) than the Total IDC Scores for the upstream control reach **AND**	Diversion/downstream scores have remained static or are reducing; **OR**
		Natural features (e.g. benches/bars/vegetation) are non-existent or largely absent / disturbed within the diversion; **OR**
		LiDAR comparisons show significant reach-wide net sedimentation / erosion within diversions between monitoring events; **OR**
		Flow durations at the downstream monitoring site(s) are significantly different to upstream reference site(s) after consideration of the spatial pattern and timing of rainfall events; **OR**
		Mean Total Suspended Solids (TSS) / turbidity at the downstream monitoring site(s) is significantly different to local baseline conditions and the upstream reference site(s) for that event; **OR**
		Diversion protection / rehabilitation works are required or have been implemented within the previous 12 months.
Low	Total IDC Scores for diversion and/or downstream control reaches are comparable (>70%) with the Total IDC Scores for the upstream control reach; **OR**	
	Total IDC Scores for diversion and/or downstream control reaches are moderately lower (60-70%) than the Total IDC Scores for the upstream control reach **AND**	Diversion/downstream scores are increasing; **OR**
		Natural features (e.g. benches/bars/vegetation) forming or present in areas of the diversion; **OR**
		LiDAR comparisons show no significant reach-wide net sedimentation / erosion within the diversions between monitoring events; **OR**
		Flow durations at the downstream monitoring site(s) are similar to upstream reference site(s) after consideration of the spatial pattern and timing of rainfall events; **OR**
		Mean Total Suspended Solids (TSS) / turbidity at the downstream monitoring site(s) is consistent with local baseline conditions or the upstream reference site(s) for that event; **OR**
		Examples of bank and bed instabilities / damage to structures are limited and require little or no maintenance.

Notes:

1. *Static refers to no discernible (<10%) change over the previous 3 monitoring periods OR if scores change by more than 10% between monitoring efforts in one direction then shift back in the opposite direction in the following monitoring effort.*
2. *Reducing/increasing refers to a reduction/increase in IDC scores by more than 10% over the previous 3 monitoring periods.*
3. *If a diversion meets more than one risk category above, the highest risk category is adopted.*
4. *Protection / rehabilitation works refers to additional creek diversion remediation works implemented as part of the monitoring and evaluation program. The risk is automatically reverted to High to increase monitoring effort and improve the likelihood of successful implementation.*

If the prevailing performance risk rating is low then event size will be considered when determining subsequent monitoring intensity. If a 10 year ARI event or greater occurs then a pre and post event LiDAR comparison is to be completed as soon as practicable. If the LiDAR comparison shows major changes that are impacting on the integrity of the diversion then a suitably qualified professional will be consulted to assess diversion performance and identify if any rectification actions are necessary.

If the LiDAR comparison between pre and post event morphology shows changes that are not impacting on the integrity of the diversion but potentially require rectification works to restore the diversion, then a Level III monitoring event will be undertaken prior to the next wet season. If the LiDAR comparison does not indicate that major change has occurred, then a Level II monitoring event will be undertaken.

In addition to the comparative evaluation of LiDAR data, Level II monitoring will include a full walk-through of the diversion, upstream and downstream reaches and scoring of diversion performance using the IDC (ACARP, 2001). Fixed point field photographs will also be acquired to document changes in key features over time. Total Suspended Solids (TSS) data[3] will also be reviewed as part of Level II monitoring.

After all monitoring events, a reassessment of the risk rating for each diversion will occur in order to inform the monitoring intensity for the following year. Monitoring activity will shift to Level I if at least three Level III monitoring events have occurred, the risk rating for diversion performance is low, and flow has not exceeded that of a 10 year ARI event.

Annual monitoring will cease once Level I monitoring has been reached post construction of spillways.

Given the timeframes associated with the Adjustment and Establishment Phases of diversion development and the evolution of diversion channel form and behaviour anticipated over this time, the primary focus of monitoring is on the principal “building blocks” of fluvial system function, namely the physical environment. Fauna monitoring within diversions would offer limited value prior to the establishment of a suitable physical habitat. However, as part of an adaptive management approach to diversion monitoring, the potential for fauna monitoring, and its associated scope and frequency, will be considered in further revisions of this Diversion Management Plan.

8.3 Inspection and Maintenance

The monitoring programme described above will enable a whole-of-reach condition assessment to be undertaken on a regular basis where any specific issues can be identified and addressed as appropriate.

In addition to annual monitoring, more frequent inspection of diversions may occur as part of core operational routines. It is expected that observation of diversion condition will be undertaken at readily accessible locations in the lease area following flow events, particularly during the early operational life of diversions.

Operational risk will determined in accordance with the GLD *Risk Management Our Requirements* consistent with other aspects of mine operations. Rectification actions may be identified as controls arising from risk assessments. While the nature of rectification actions will depend on the type and scale of changes observed, and an understanding of the drivers of such change, potential actions could include:

- Revetment of banks using rip-rap;
- Replacement of or addition to existing rip-rap with larger clast-size material;
- Placement or removal of boulders and/or large woody debris;
- Targeted seeding of vegetation;
- Adjusting batter angles of channel banks; and
- Replacement or removal of alluvial material.

It should be noted however that diversions, like existing channel reaches, are dynamic in nature and are expected to undergo morphological change. This will particularly be the case during the initial Adjustment Phase of diversion operation. Intervention may not be required unless there is an unacceptable operational or environmental risk identified or an undesirable trend in behaviour is established.

As described in **Section 6.5,** the objective for diversions at closure is for the final landform to be safe, stable and non-polluting that does not require ongoing care and maintenance.

8.4 Review and Revision of Management Actions

Management Actions will be reviewed, and if appropriate, revised following assessment of performance against Management Targets as described in **Section 8.1**.

Any changes to Management Actions will be reported in accordance with **Section 8.5** below and reflected in subsequent revisions of this Diversion Management Plan.

8.5 Reporting

BHP Billiton Iron Ore completes an Annual Environmental Report (AER) across all sites at the end of each Financial Year. The AER meets the reporting requirements of all Regulatory approvals conditions relating to the environment. The AER provides results of environmental monitoring programmes and assessment of compliance with Licence requirements. Where appropriate, a summary report including findings is provided as an appendix to the AER.

The results of monitoring required under this Diversion Management Plan will be included in the AER.

9 Audit and Review

BHP Billiton Iron Ore adopts a tiered approach to auditing and review across all Ministerial Statements through the AER process. In consultation with the Office of the Environmental Protection Authority (OEPA), Ministerial Statements are prioritised based on the:

- Level of Assessment applied to the Proposal;
- Number of environmental factors considered by the EPA;
- Number of conditions addressing environmental factors and/or requiring management plans;
- Proponent performance/engagement; and
- Environmental significance/consequence of non-compliance.

The ranking applied to each Ministerial Statement dictates the extent of content included in the AER for that year, summarised as follows:

- Ranking 1 – Brief details about project/operation; summary of proposal implementation status; statement of compliance and details of declared compliance status including populated audit table and supporting information/evidence for all key requirements and/or objectives outlined in relevant management plans.
- Ranking 2 – Statement of compliance and details of declared compliance status including populated audit table.

Activities under MS 679 and MS 1039 will continue to be audited and reviewed in this manner, including requirements under Condition 7 satisfied by this Diversion Management Plan and any subsequent revisions.

10 Abbreviations

The following abbreviations are used throughout this Management Plan.

Abbreviation	Definition
ACARP	Australian Coal Association Research Program
AEP	Annual Exceedance Probability
AER	Annual Environmental Report
AH Act	*Aboriginal Heritage Act 1972*
AHD	Australian Height Datum
ALARP	As Low As Reasonably Practicable
ARI	Average Recurrence Interval
BIF	Banded Iron Formation
CID	Channel Iron Deposit
DEM	Digital Elevation Model
DPS	Definition Phase Study
EAG	Environmental Assessment Guideline
EP Act	*Environmental Protection Act, 1986*
EMP	Environmental Management Plan
EPA	Environmental Protection Authority
GLD	Group Level Document: *Our Requirements*
IDC	Index of Diversion Condition
IPS	Identification Phase Study
LCID	Lower Channel Iron Deposit
LiDAR	Light Detection and Ranging
MS 679	Ministerial Statement 679
MS 1039	Ministerial Statement 1039
mtpa	Million tonnes per annum
OSA	Overburden Storage Area
PEAHR	Project Environmental Aboriginal Heritage Review
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SRE	Short-range endemic
SPS	Selection Phase Study
UCID	Upper Channel iron Deposit
WAIO	Western Australian Iron Ore

11 References

ACARP (2001). *Monitoring and Evaluation Program for Bowen Basin River Diversions*. Project C9068.

Beard, J.S. (1990). *Plant Life of Western Australia*. Kangaroo Press, Perth.

BHP Billiton (2014). *Marillana Creek (Yandi) Mine Surface Water and Groundwater Management Plan*. Revision 3.

BHP Billiton (2016). *Pilbara Strategic Assessment*. Draft Impact Assessment Report.

BHP Billiton (2016b). Yandi Closure Plan.

Biologic (2011). *Yandi Vertebrate Fauna Review.* Unpublished report prepared for BHP Billiton Iron Ore.

Biologic (2013a). *Terrestrial Vertebrate Fauna Impact Assessment for the Yandi Mine*. Unpublished report for BHP Billiton Iron Ore.

Biologic (2013b). *Yandi Mine Short Range Endemic Invertebrate Survey and Impact Assessment*. Unpublished report for BHP Billiton Iron Ore.

Biologic (2014). *Consolidation of Regional Fauna Habitat Mapping BHP Billiton Iron Ore Pilbara Tenure*. Internal Report for BHP Billiton Iron Ore.

Biologic (2015). *Yandi Tenement Short-range Endemic Invertebrate Survey.* Unpublished report for BHP Billiton Iron Ore.

Charles SP, Fu G, Silberstein RP, Mpelasoka F, McFarlane D, Hodgson G, Teng J, Gabrovsek C, Ali R, Barron O, Aryal SK, Dawes W, van Niel T and Chiew FHS (2013*), Interim report on the hydroclimate of the Pilbara past, present and future*, A report to the West Australian Government and industry partners from the CSIRO Pilbara Water Resource Assessment, CSIRO Water for a Healthy Country, Australia.

DNRM (2014). *Guideline: Works that interfere with water in a watercourse – watercourse diversions.* Department of Natural Resources and Mines. Queensland, Australia.

EPA (2015). *Environmental Assessment Guideline for preparation of management plans under Part IV of the Environmental Protection Act 1986.* EAG 17.

Ecologia Environment (2008). *Marillana Creek (Yandi) Iron Ore Modification Level 2 Fauna Survey.* Unpublished report for BHP Billiton Iron Ore.

Entura (2014). *Marillana Creek Geomorphology Study. Yandi Mine Site.* Unpublished report prepared for BHP Billiton Iron Ore.

GHD (2007), Marillana Creek Realignment. Review of realignment options and recommendations for Phase 2 work. Unpublished draft report prepared for BHP Billiton Iron Ore.

GHD (2012). *Yandi Flood Study.* Unpublished report prepared for BHP Billiton Iron Ore.

GHD (2014).*Yandi Flood Study Model Update*. Unpublished report prepared for BHP Billiton Iron Ore.

Gilbert and Associates (2004). *Marillana Creek (Yandi) Mine. Hydrological and Hydraulic Assessment of Proposed Diversion of Marillana Creek for Life of Mine and Closure Concept Plan*. Unpublished report prepared for BHP Billiton Iron Ore.

Hiscock, P. and Wallis, L. (2005) "Pleistocene settlement of deserts from an Australian perspective". In P. Veth, M. Smith and P. Hiscock (eds) Desert Peoples: archaeological perspectives. Blackwell. pp. 34–57.

Johnstone, R and G. M. Storr (1998). *Handbook of Western Australian Birds Volume 1 – Nonpasserines (Emu to Dollarbird).* Western Australian Museum, Perth, Australia.

Knighton, D. (2014). Fluvial Forms and Processes: A New Perspective. Routledge.

Maunsell (2003). *Yandi Life of Mine Fauna and Flora*. Unpublished Report to BHP Billiton Iron Ore.

MWH (2016). *Marillana Creek Flow Study.* Unpublished report prepared for BHP Billiton Iron Ore.

Nanson, G. C. (2013). *Anabranching and anastomosing rivers*. In E. Wohl (Eds.), Treatise on Geomorphology: Volume 9: Fluvial Geomorphology (pp. 330-345). London: Elsevier.

Onshore Environmental (2013a). *Targeted Survey for Lepidium catapycnon at Karijini Nathional Park*. Unpublished Report for BHP Billiton Iron Ore.

Onshore Environmental (2013b). *Yandi Flora and Vegetation Environmental Impact Assessment Mining Lease ML270SA and M42/292*. Unpublished report for BHP Billiton Iron Ore.

Onshore Environmental (2015a). *Marillana Creek Riparian Flora and Vegetation Survey*. Unpublished Report for BHP Billiton Iron Ore.

Onshore Environmental (2015b). *Dynasty and West Jimblebar Level 2 Flora and Vegetation Survey*. Unpublished Report for BHP Billiton Iron Ore.

Pearson, D (2003). *Giant Pythons of the Pilbara*. Landscope 19, 32-39.

Pilgrim, D. H. (ed.) (2001). *Australian Rainfall and Runoff. A guide to flood estimation*. Volume 1. The Institute of Engineers Australia.

Rio Tinto Iron Ore (2014). *Yandicoogina closure plan*. RTIO-HSE-0208486. https://consultation.epa.wa.gov.au/seven-day-comment-on-referrals/yandicoogina-pocket-and-billiard-south-iron-ore-mi/supporting_documents/Appendix%208%20Yandi%20LoM%20Closure%20Plan.pdf

Tyler, I. M.. Hunter, W. M. and Williams, W. M. (1991). *Newman, Western Australia*. 1:250 000 Geological Series Explanatory Notes. Geological Survey of Western Australia. Perth, Western Australia.

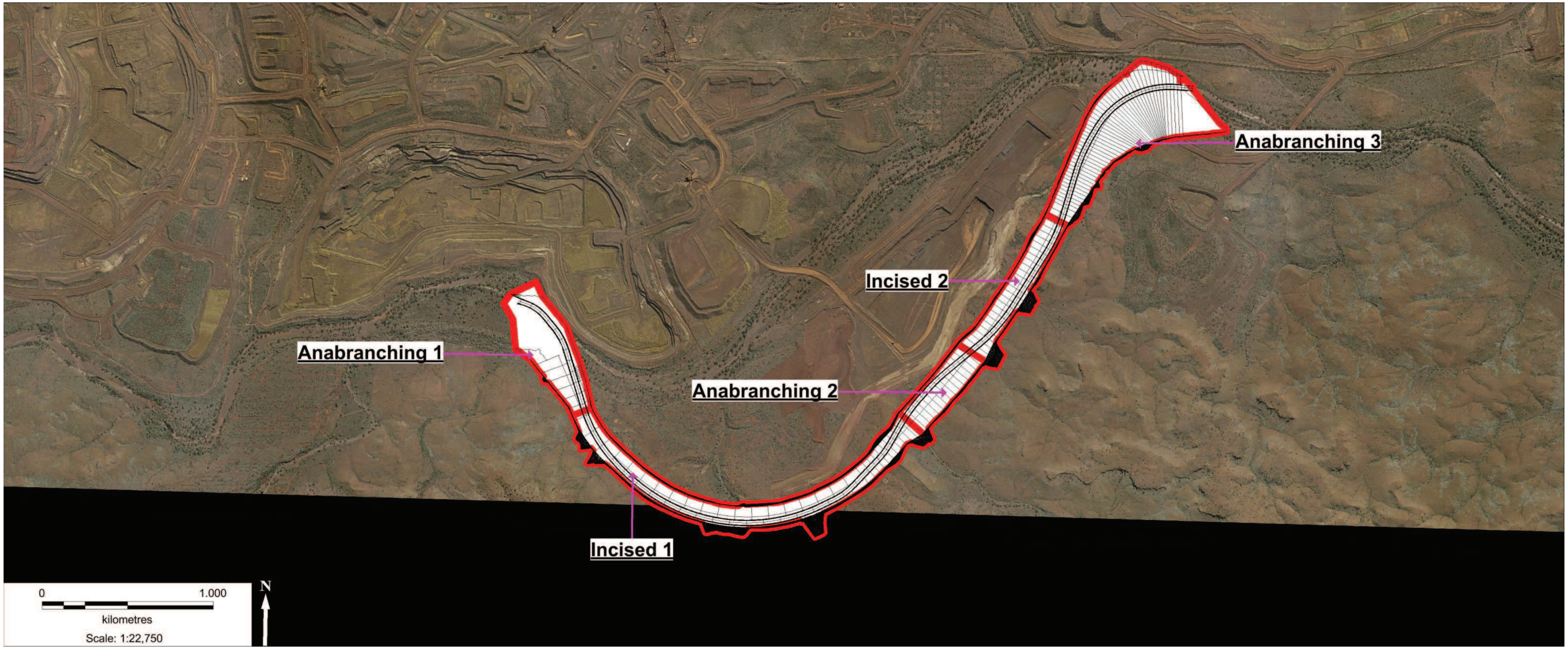
USACE (2010). *HEC-RAS River Analysis System User Manual, Version 4.1.* US Army Corps of Engineers. Hydrologic Engineering Centre.

van Dyck, S and Strahan R (2008). *The Mammals of Australia*. Third Edition. Reed New Holland, Sydney.

Veth, P.M. 1993 Islands in the Interior: The Dynamics of Prehistoric Adaptations Within the Arid Zone of Australia. International Monographs in Prehistory. Archaeological Series 3. Ann Arbor, Michigan.

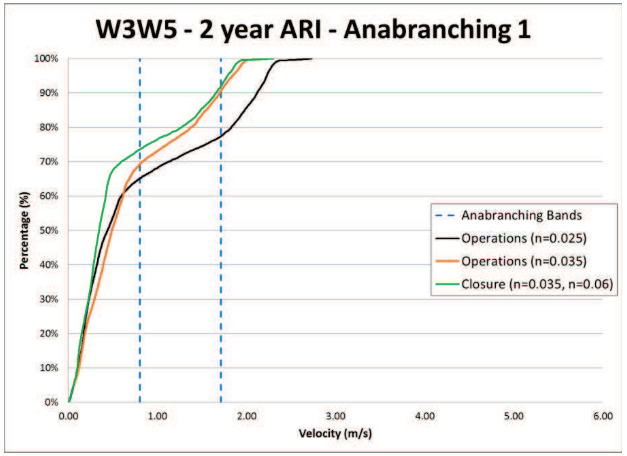
WRM (2015). *Yandi Aquatic Fauna Survey. Wet & Dry Season Sampling 2014.* Unpublished report prepared for BHP Billiton Iron Ore.

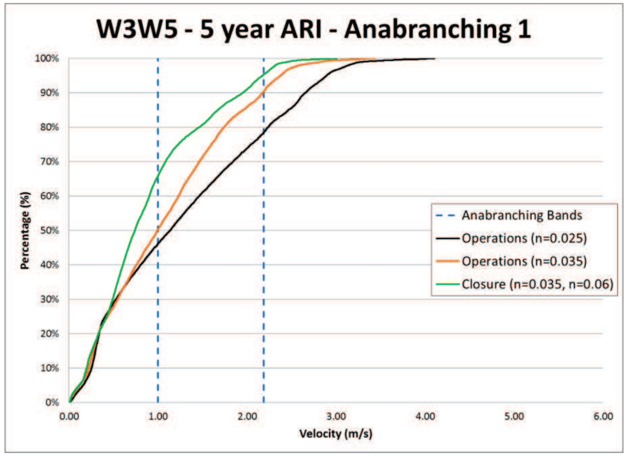
APPENDIX A: Hydraulic Modelling Results

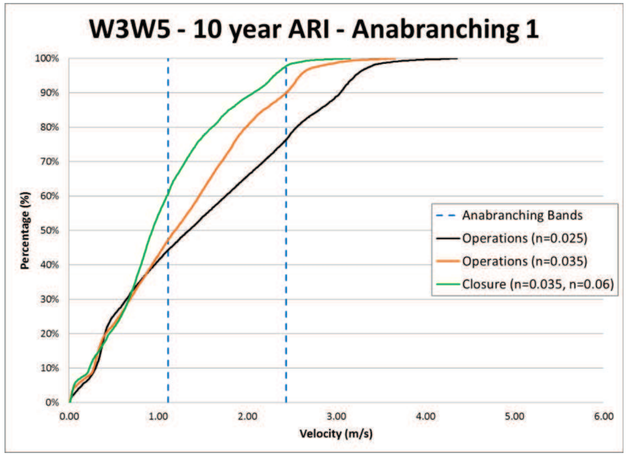


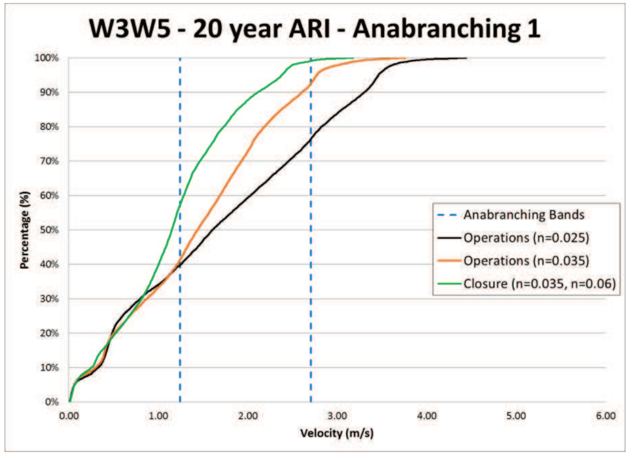
W3W5 Diversion - Hydraulic Modelling Results

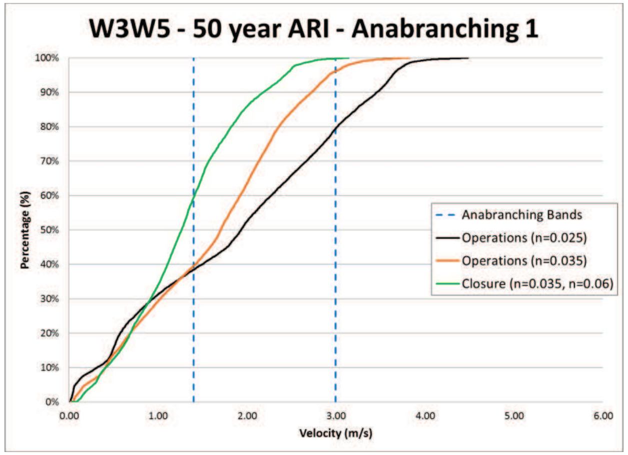
W3W5 - Anabranching 1: Velocity

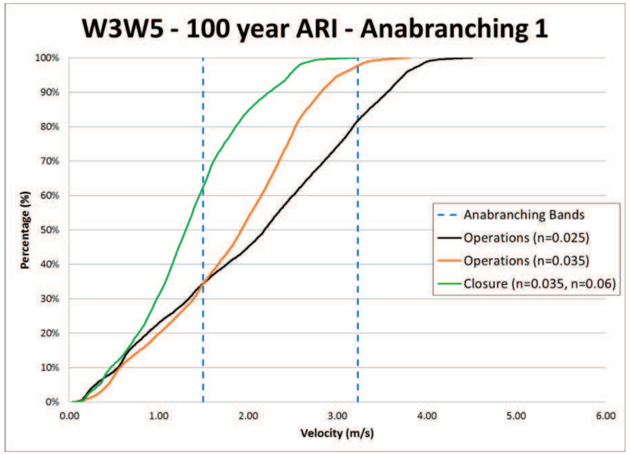




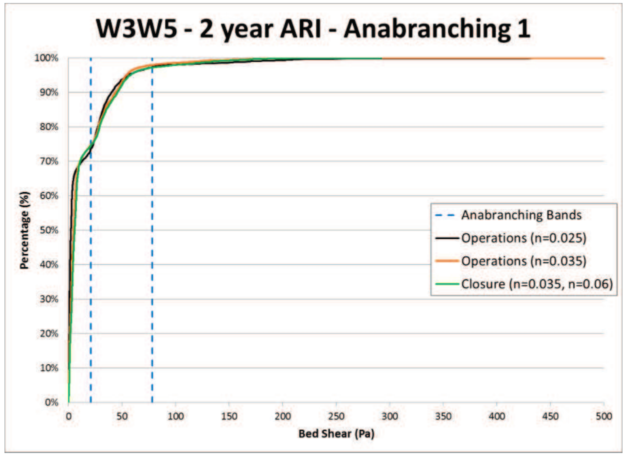


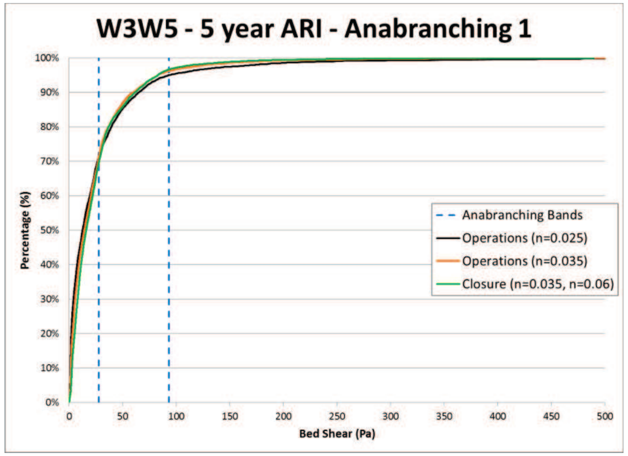


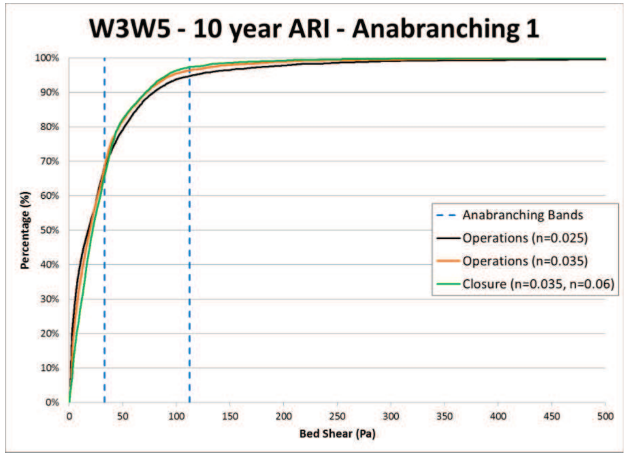


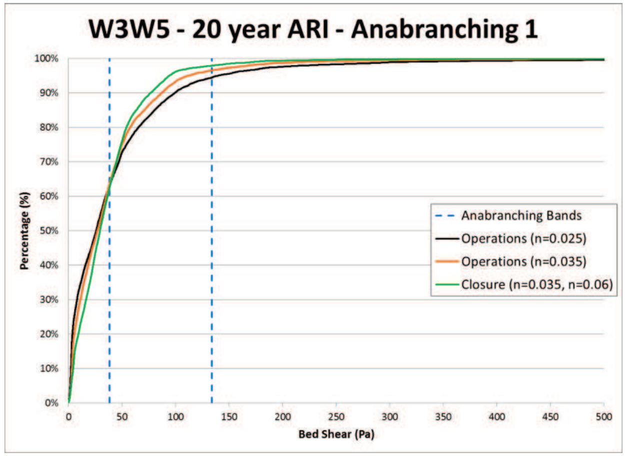


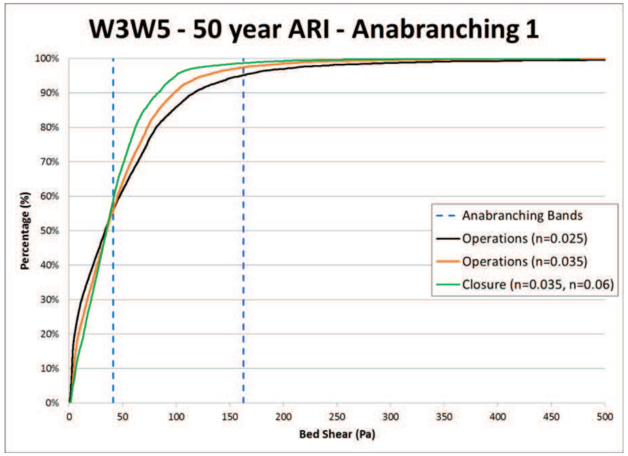
W3W5 - Anabranching 1: Bed Shear

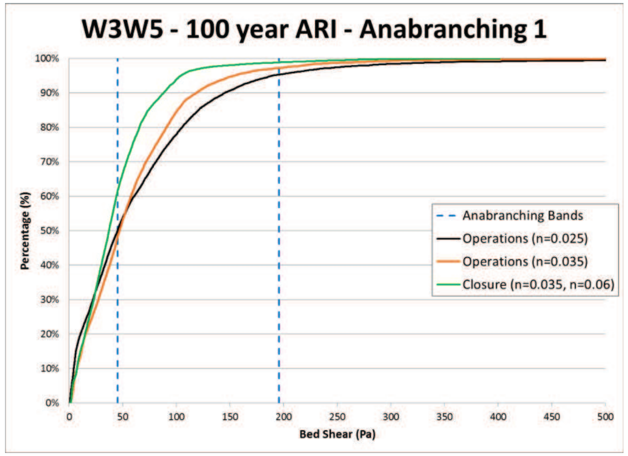












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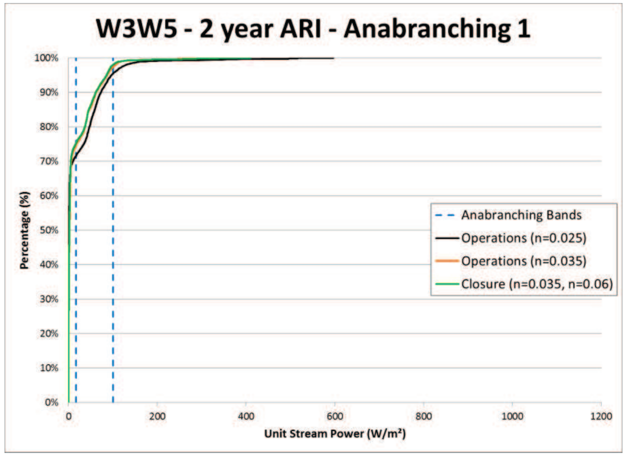

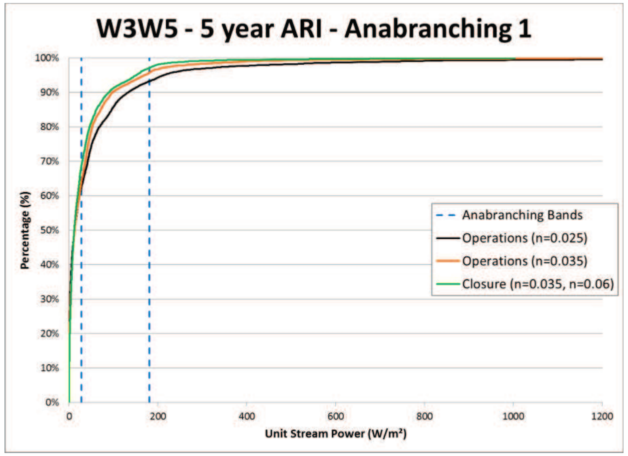

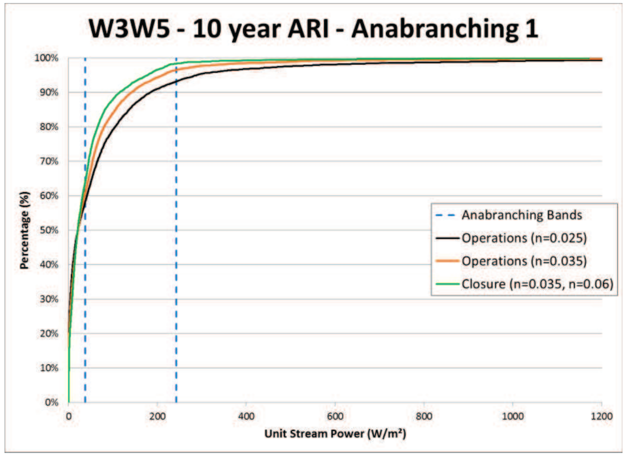

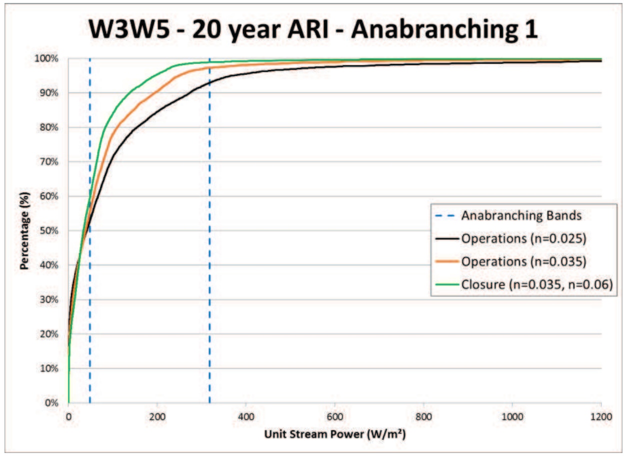

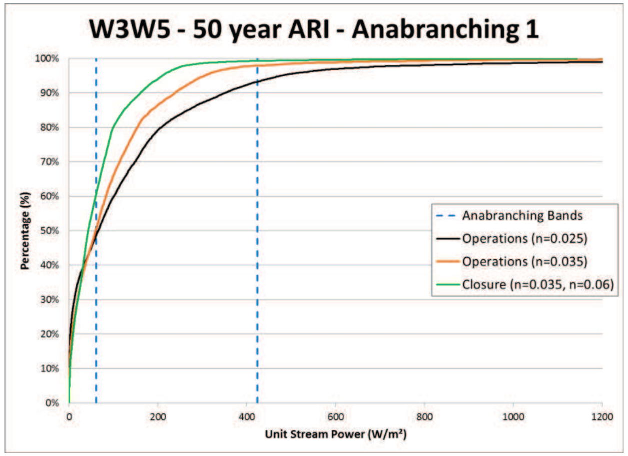

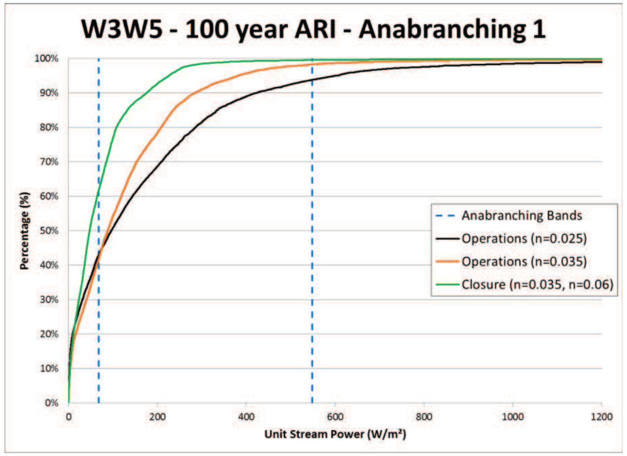

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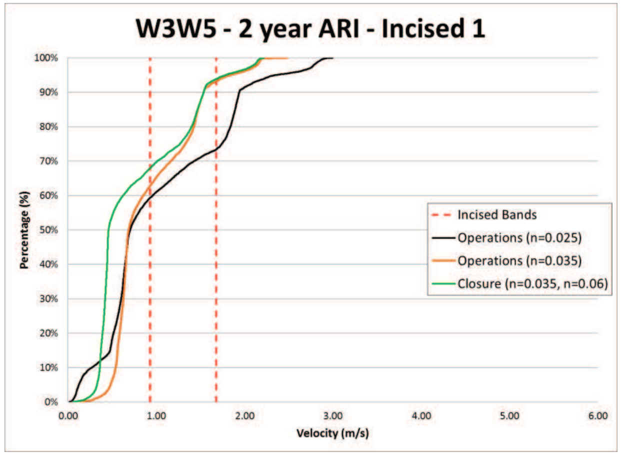

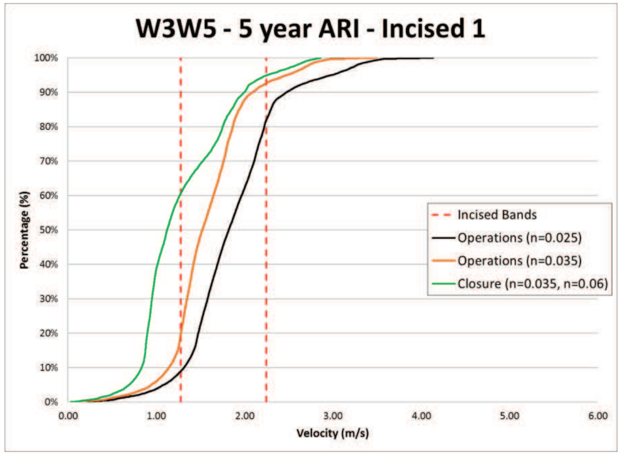

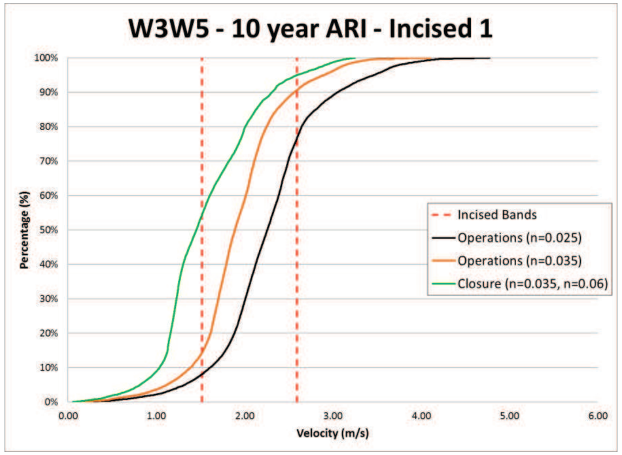

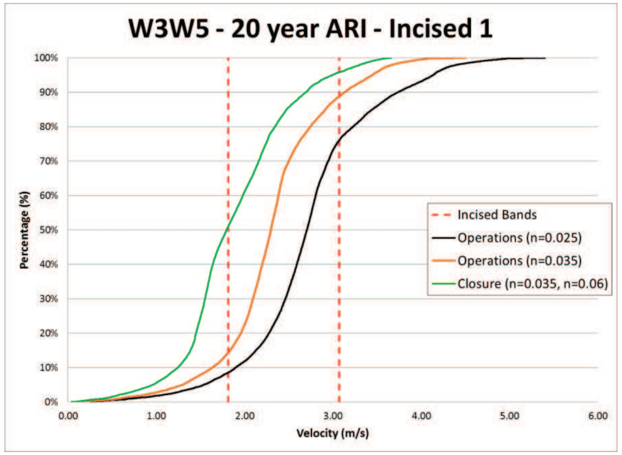

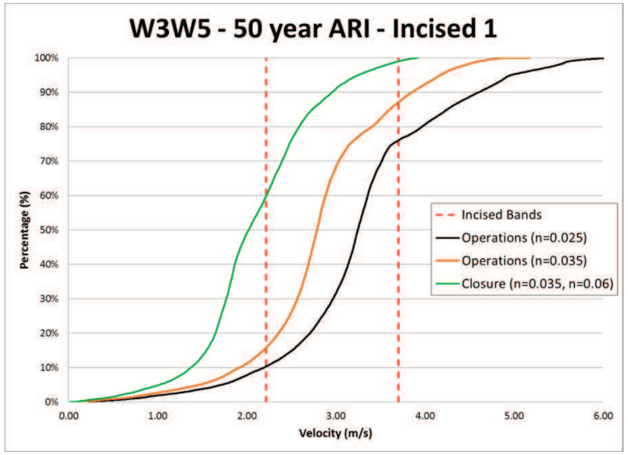

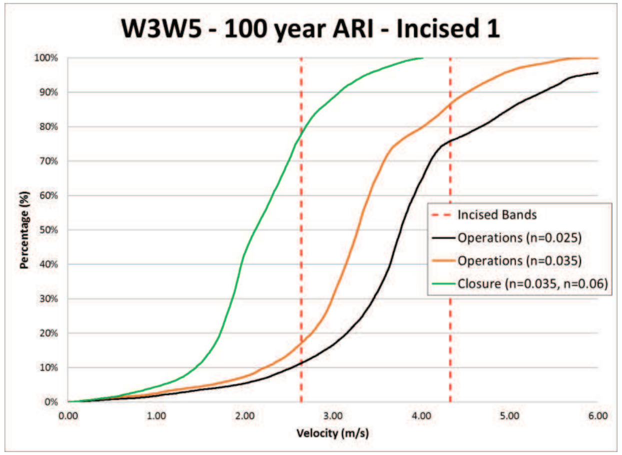

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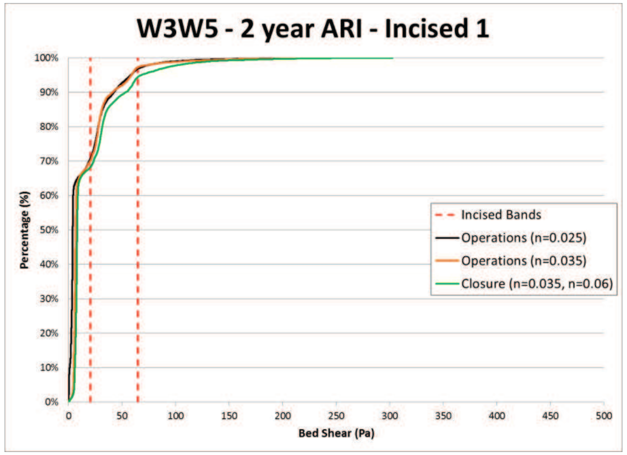

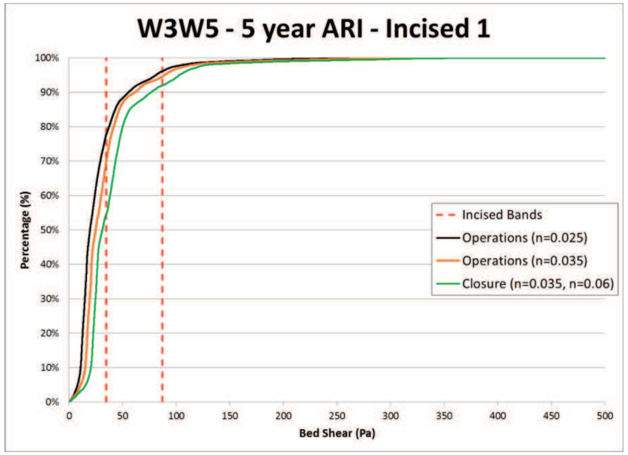

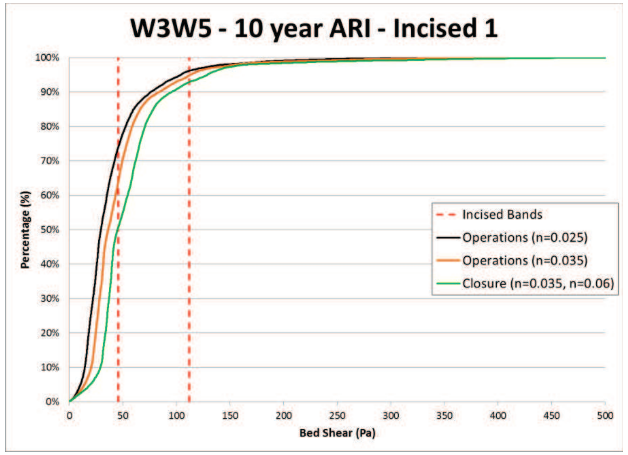

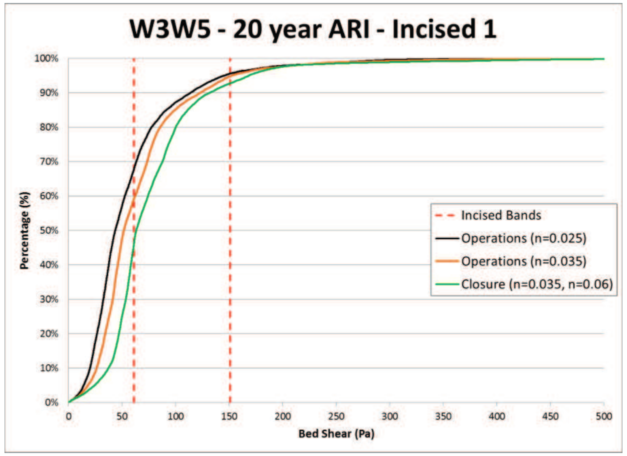

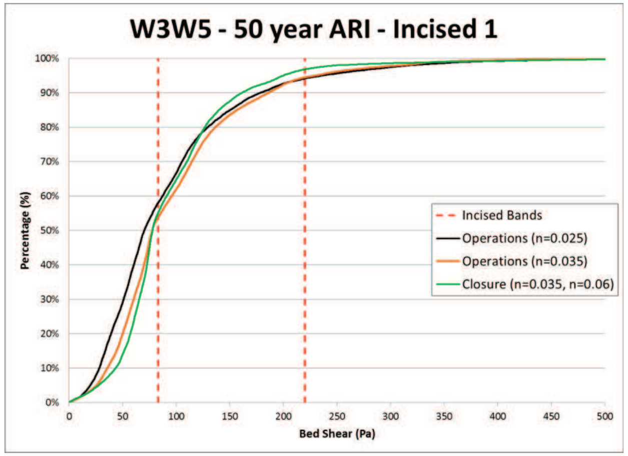

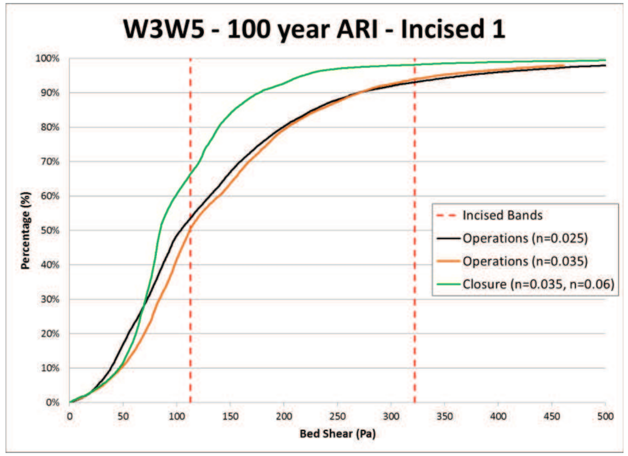

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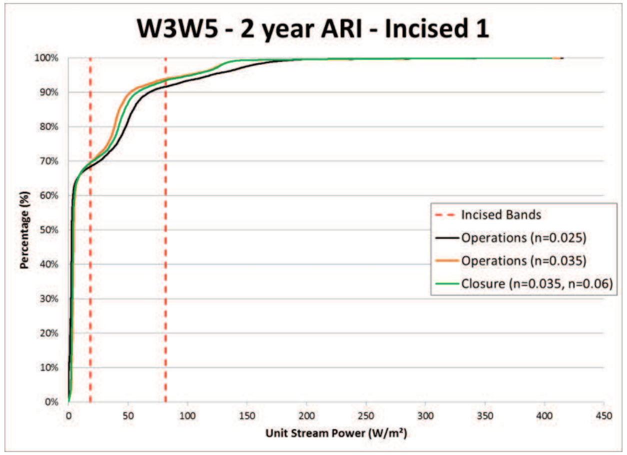

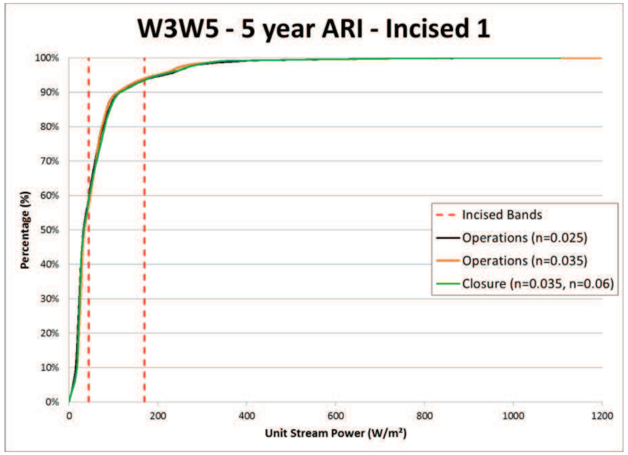

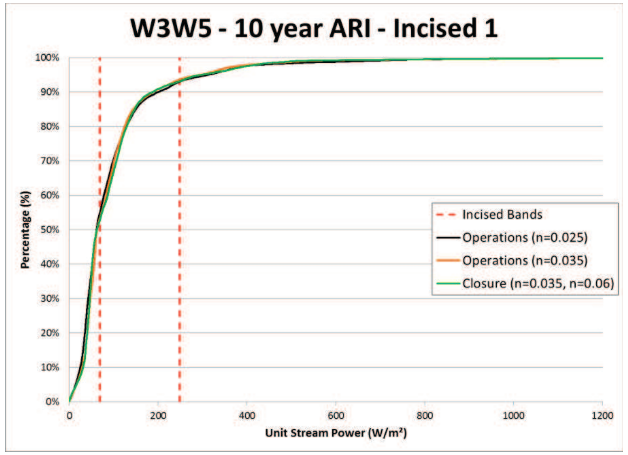

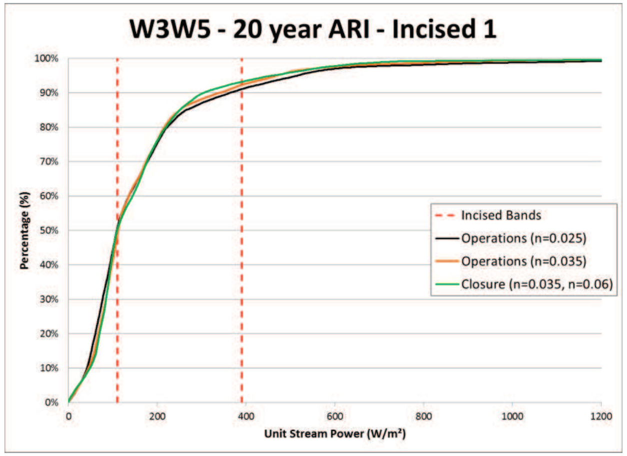

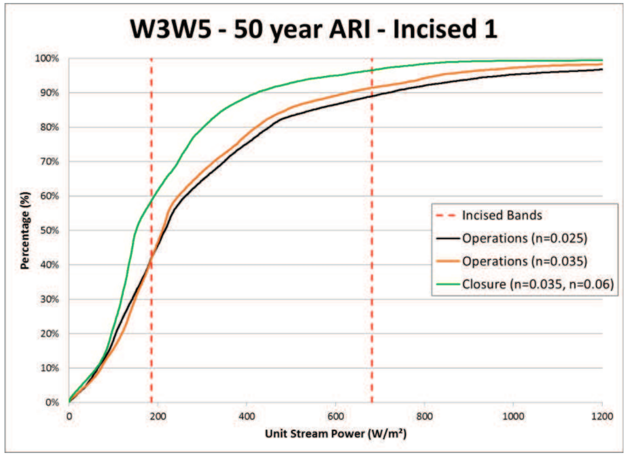

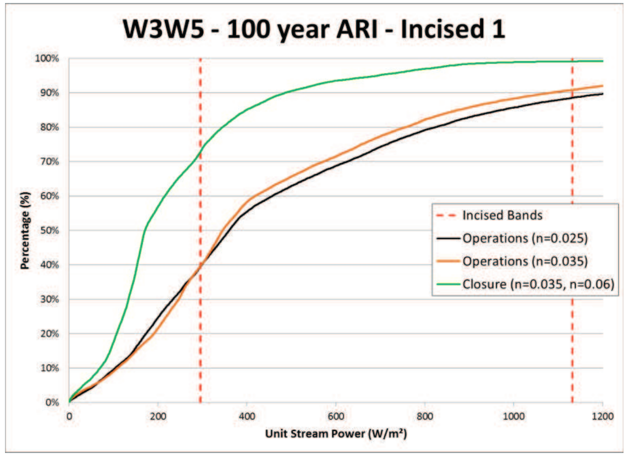

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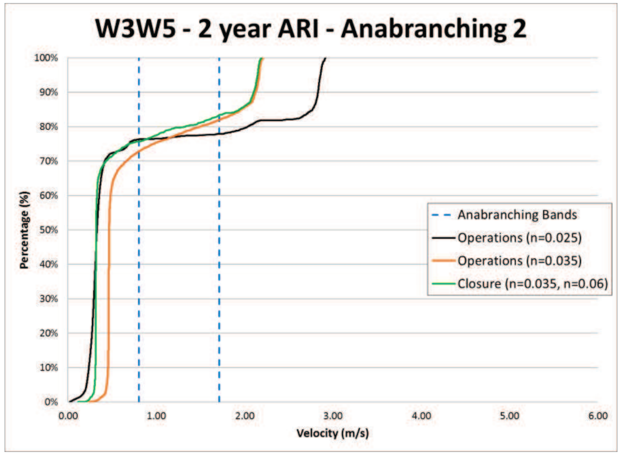

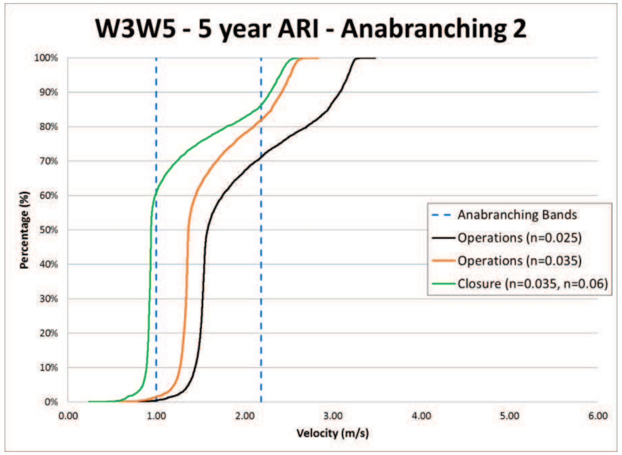

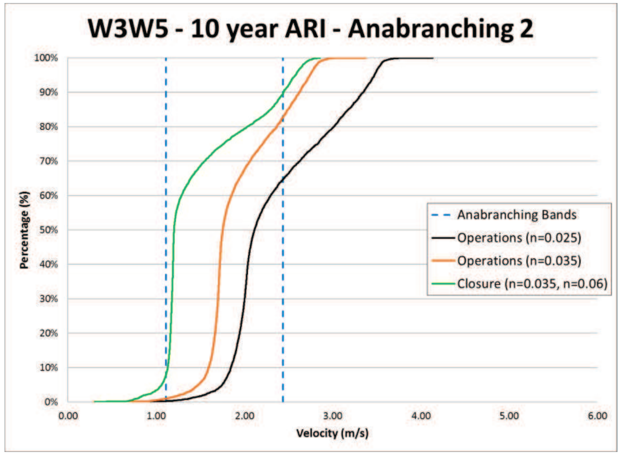

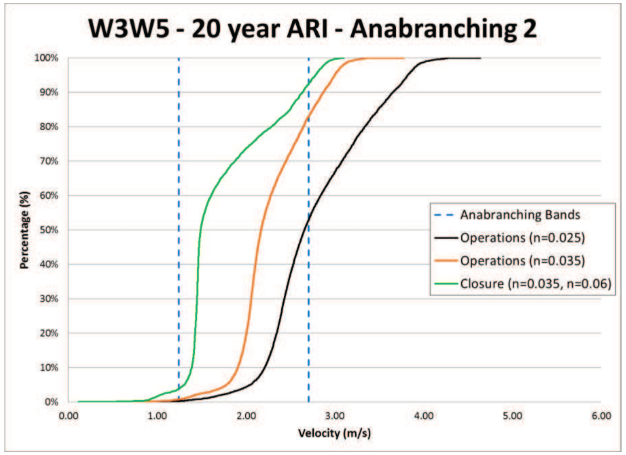

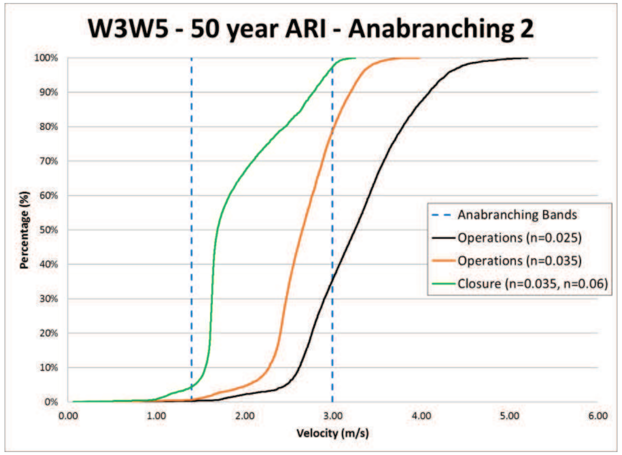

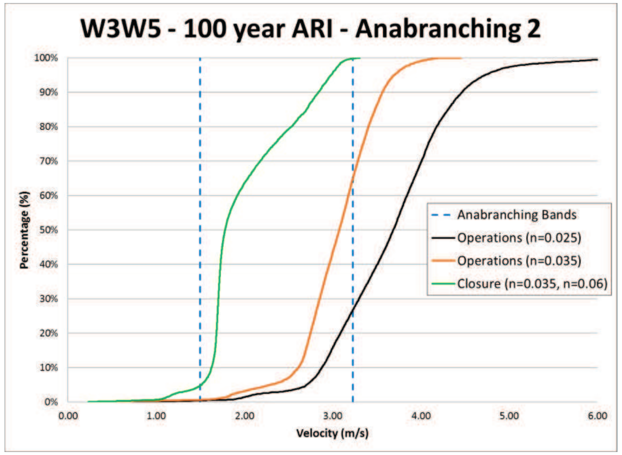

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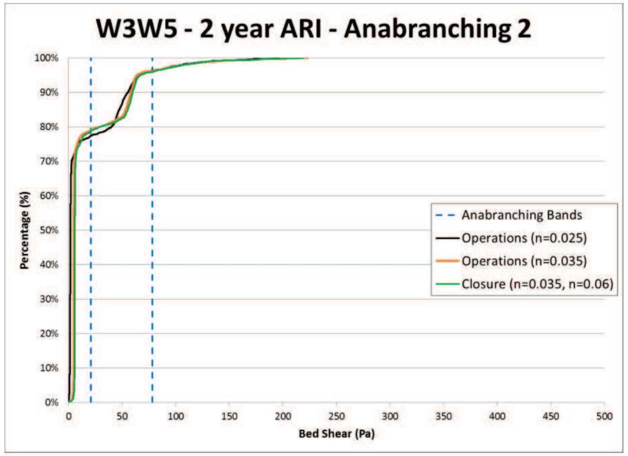

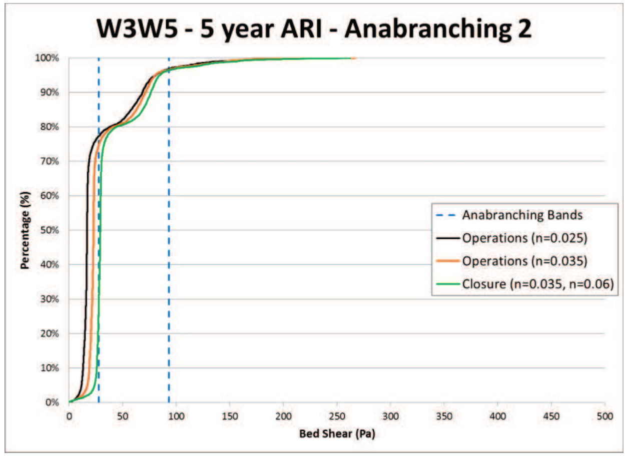

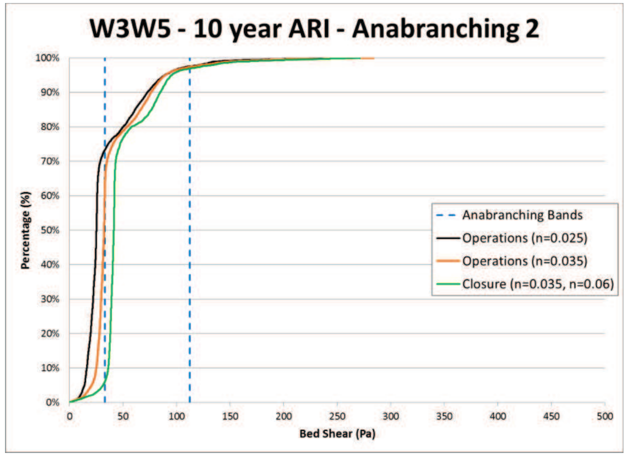

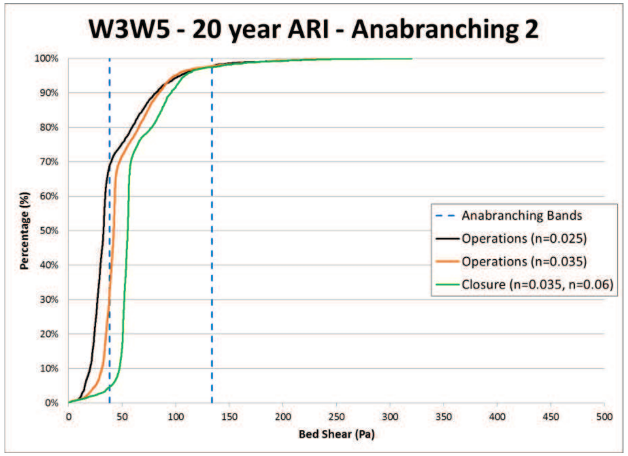

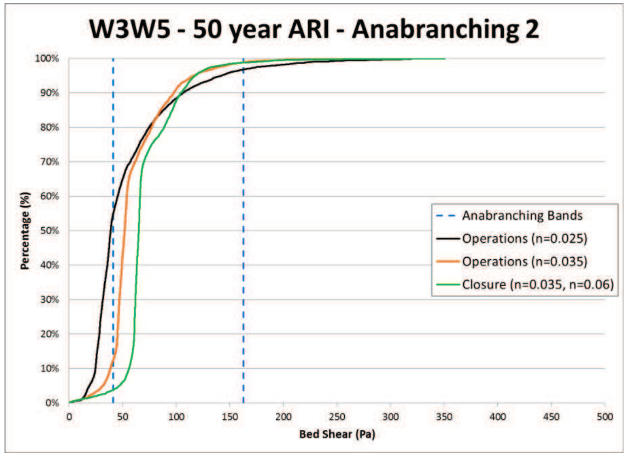

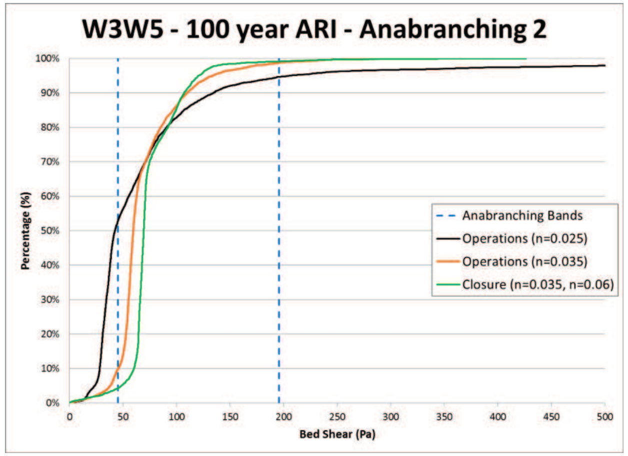

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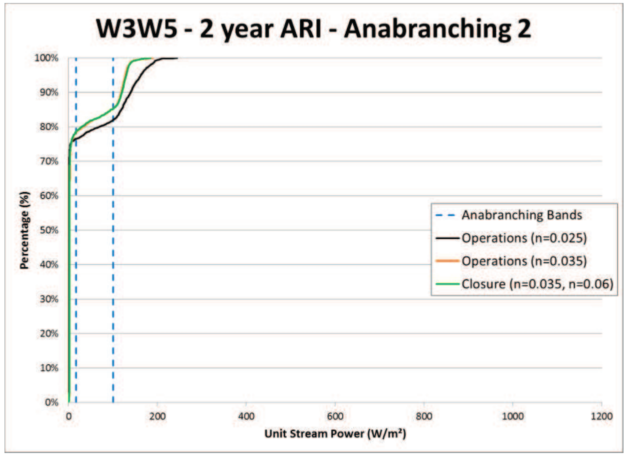

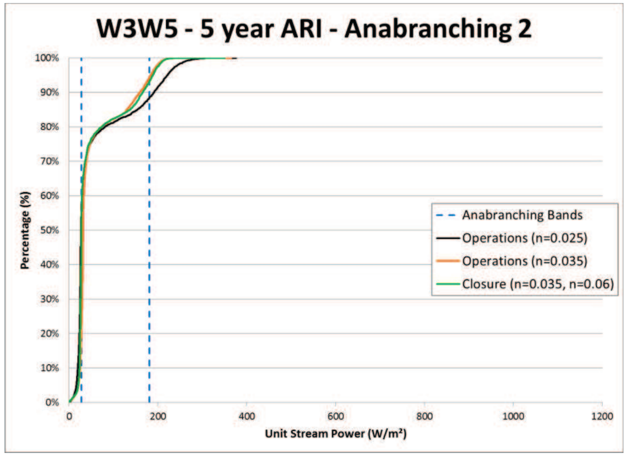

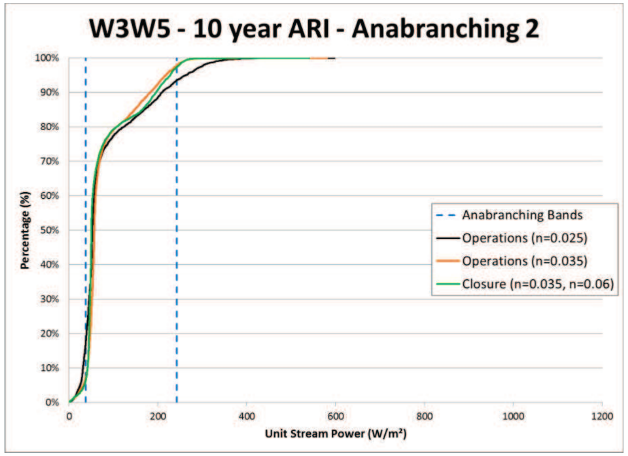

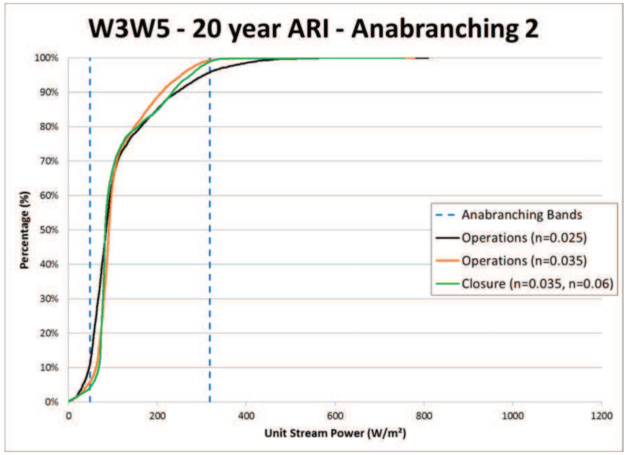

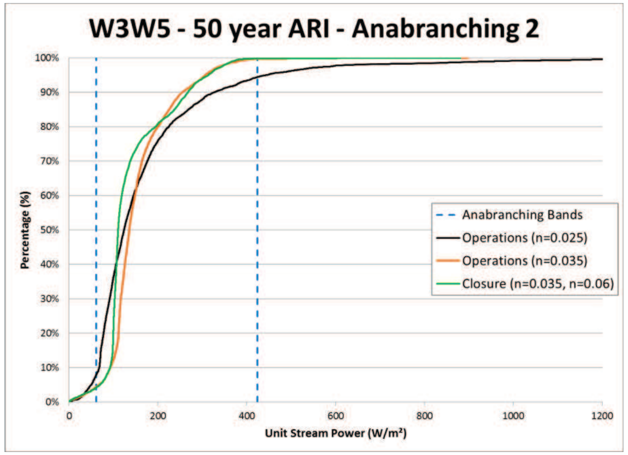

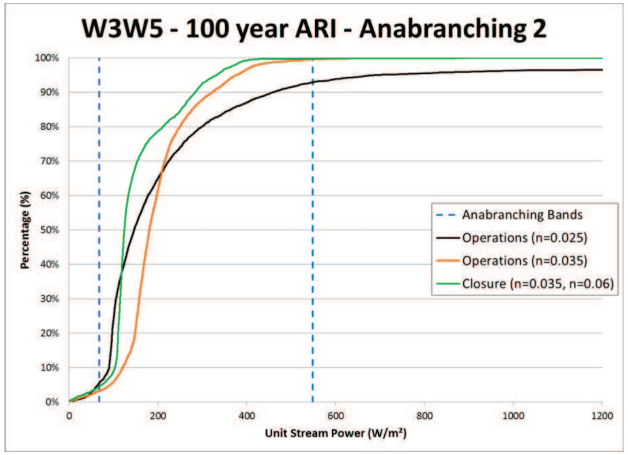

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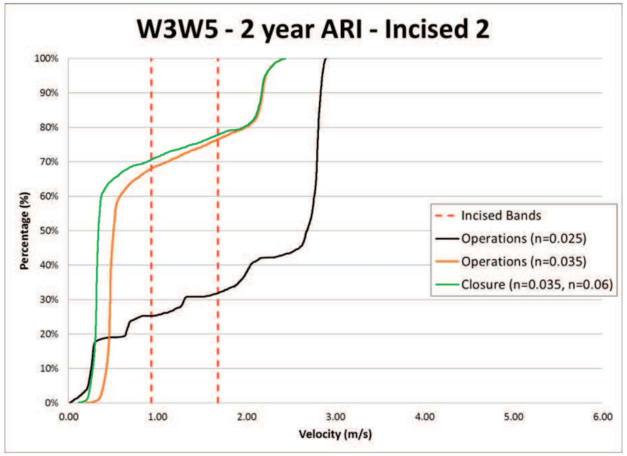

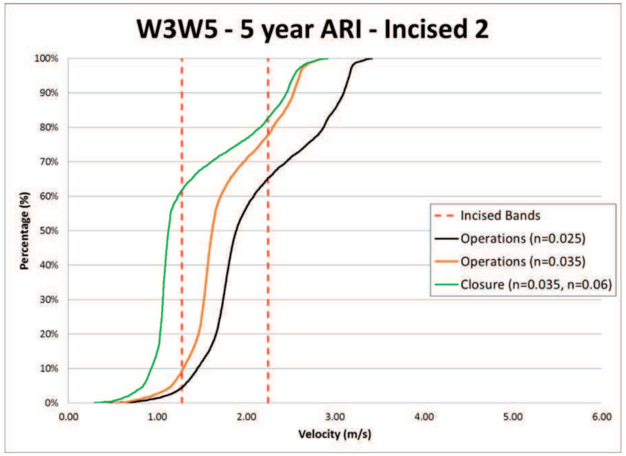

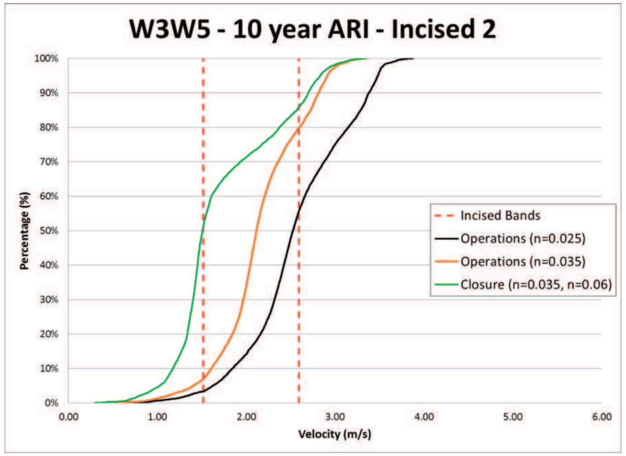

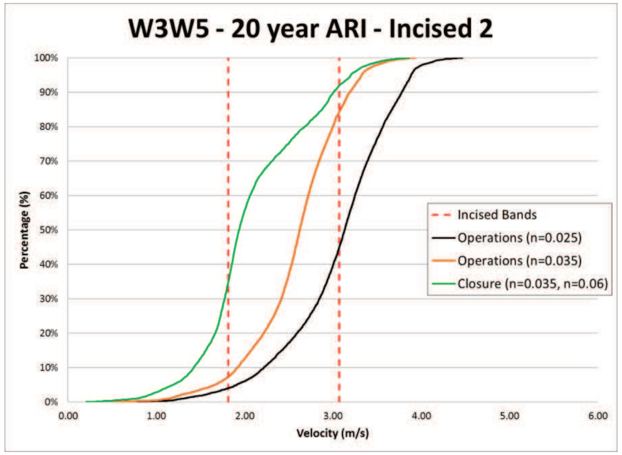

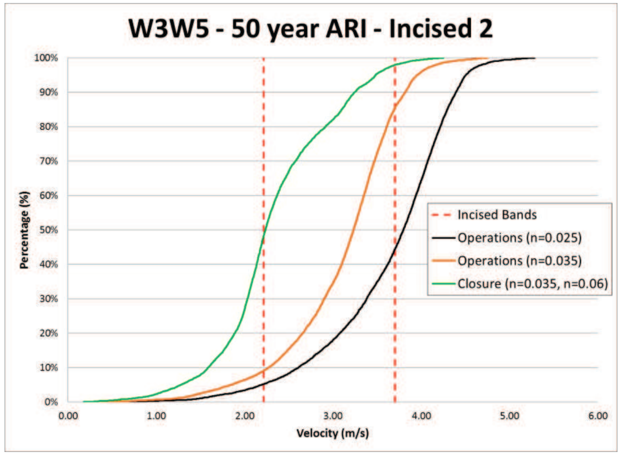

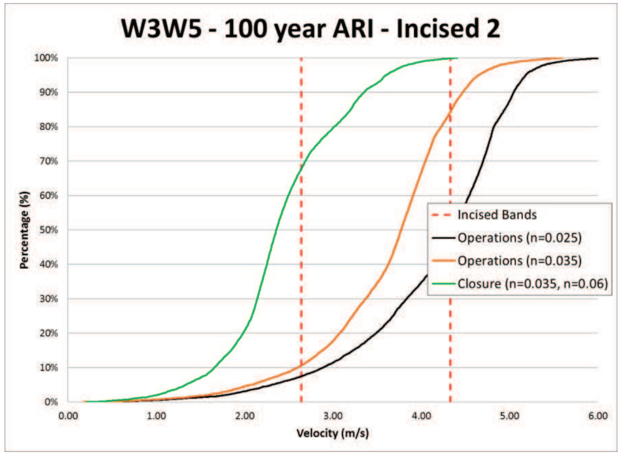

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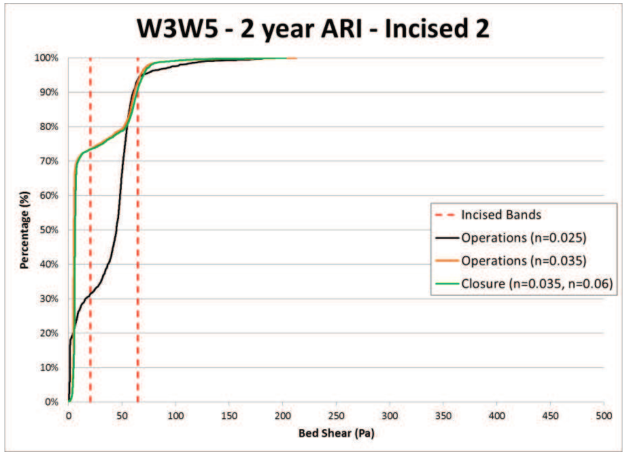
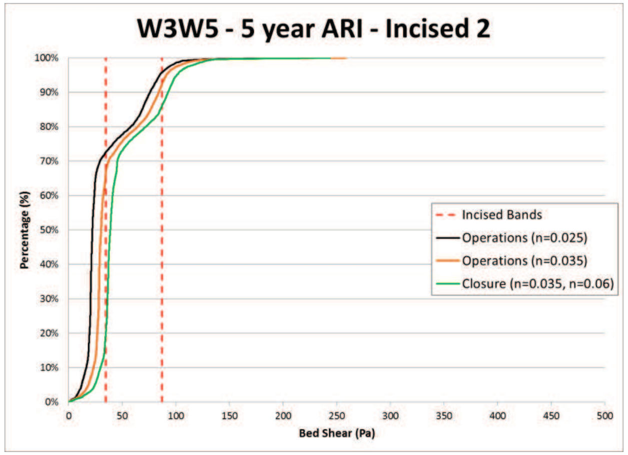
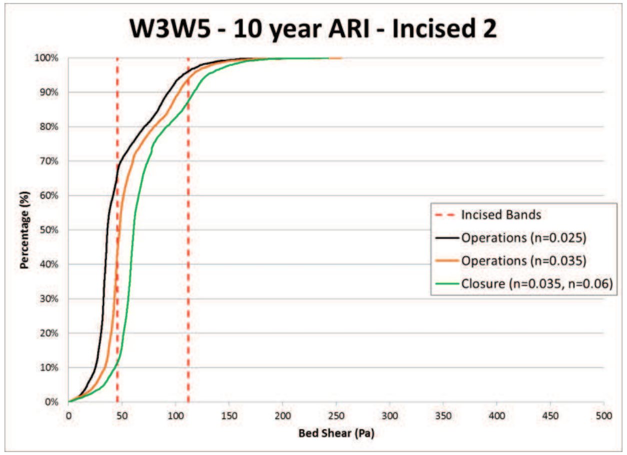
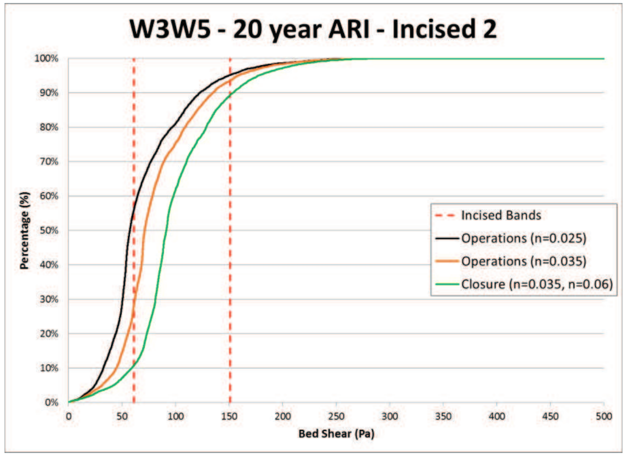
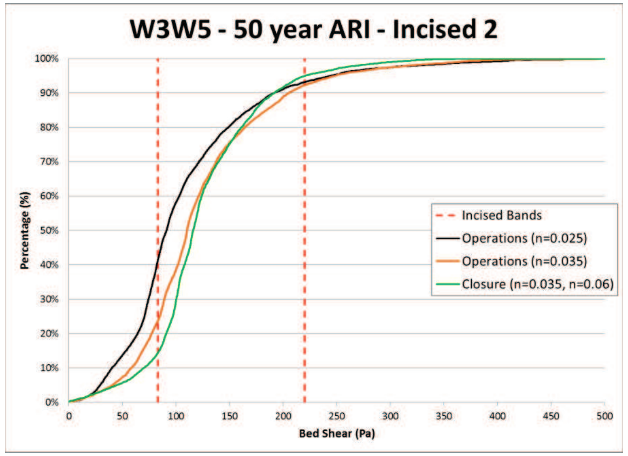
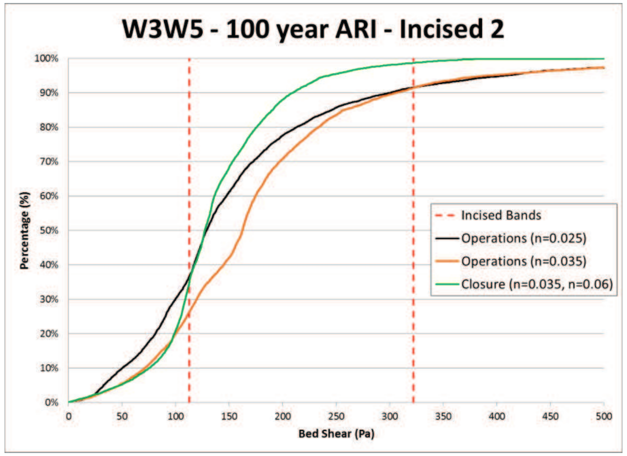




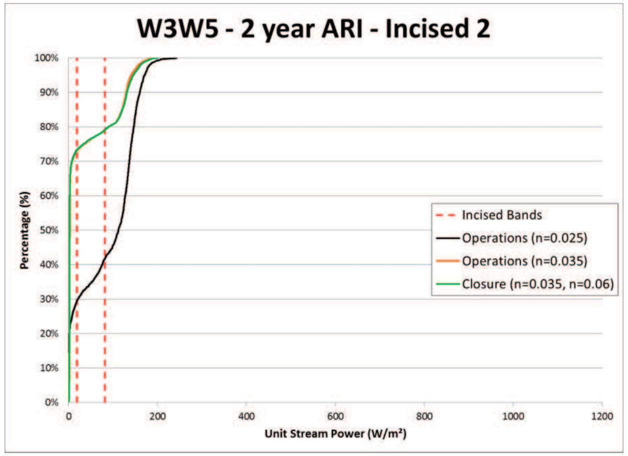


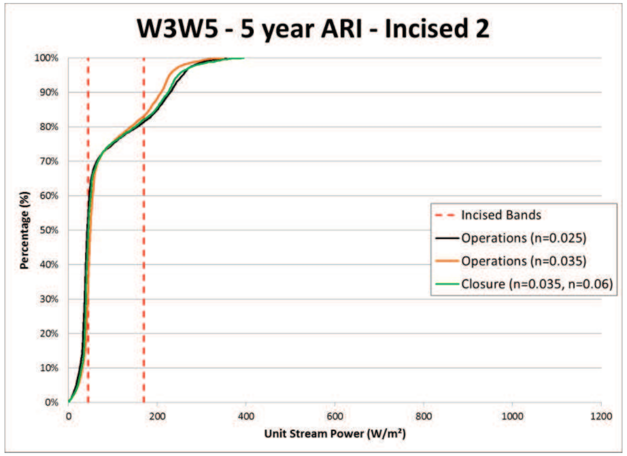


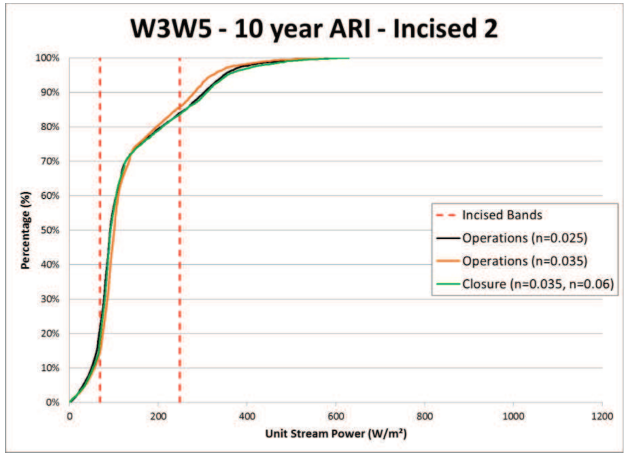


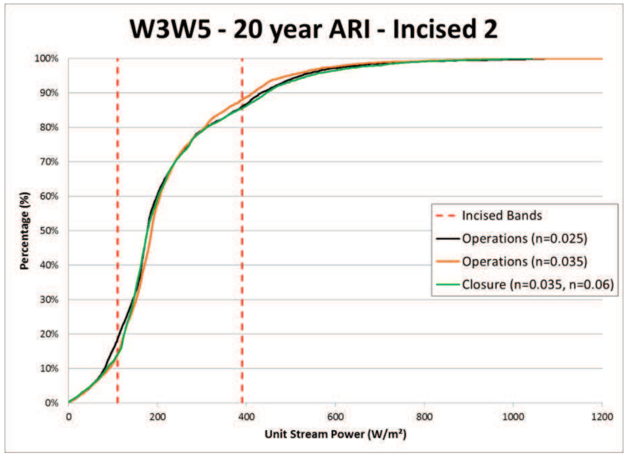


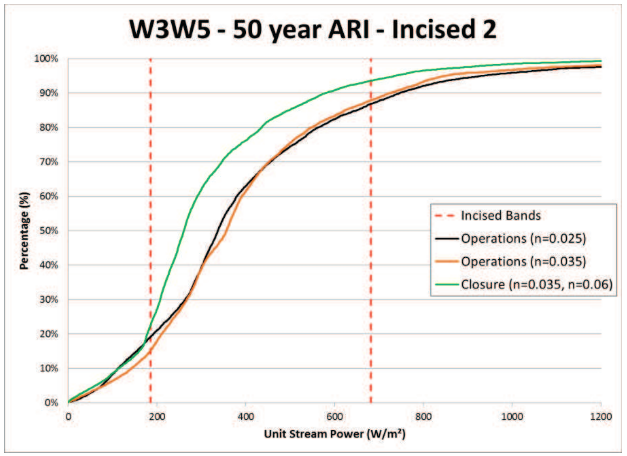
W3W5 - Incised 2: Stream Power

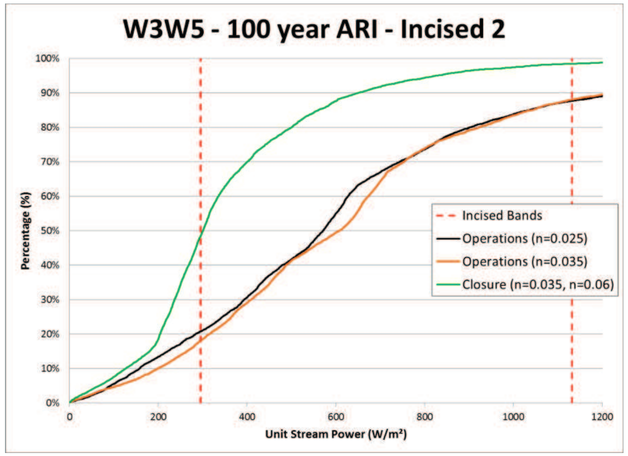












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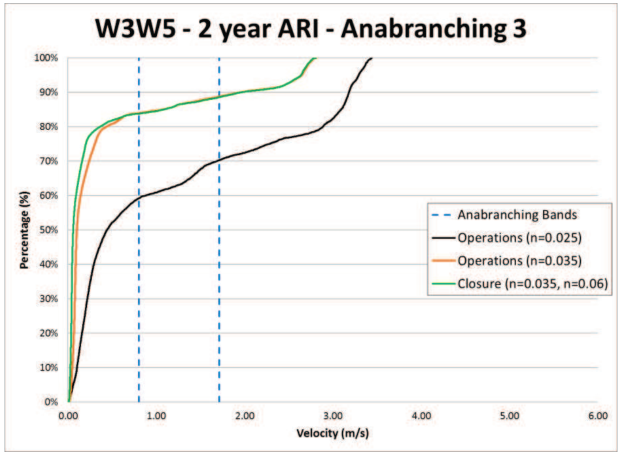
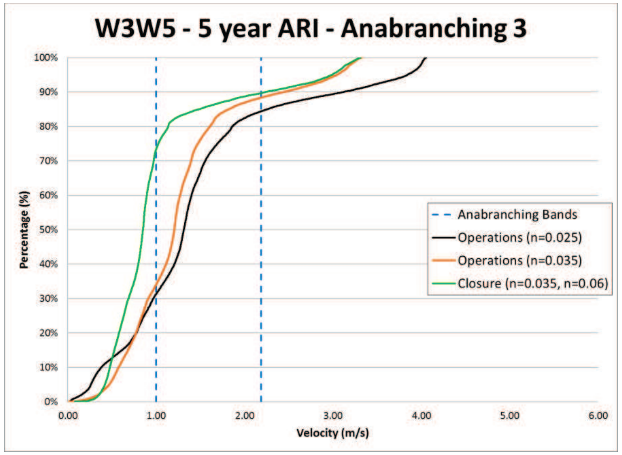
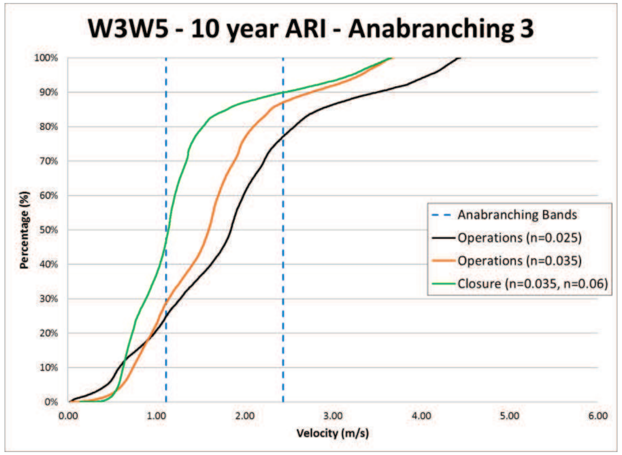
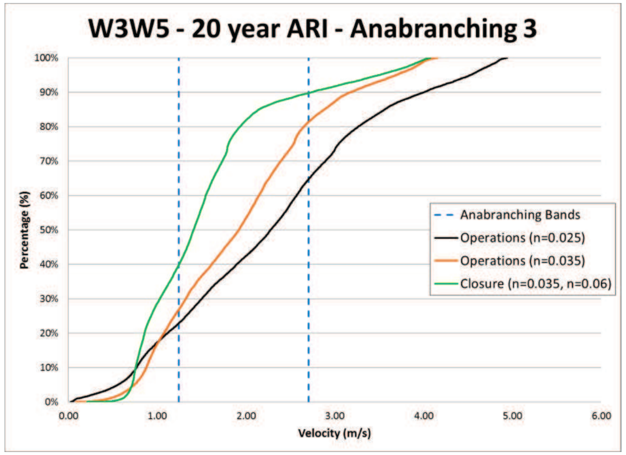
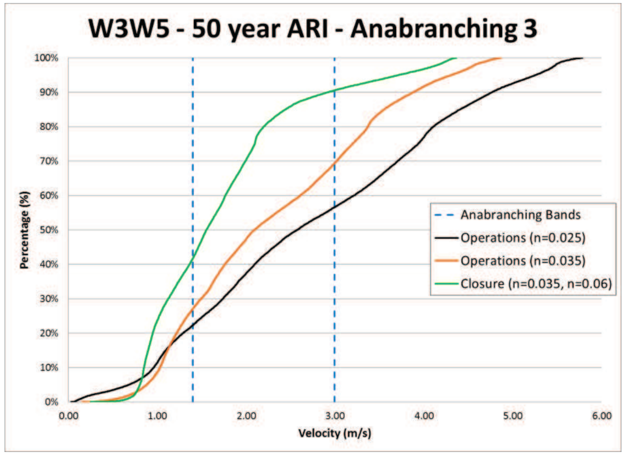
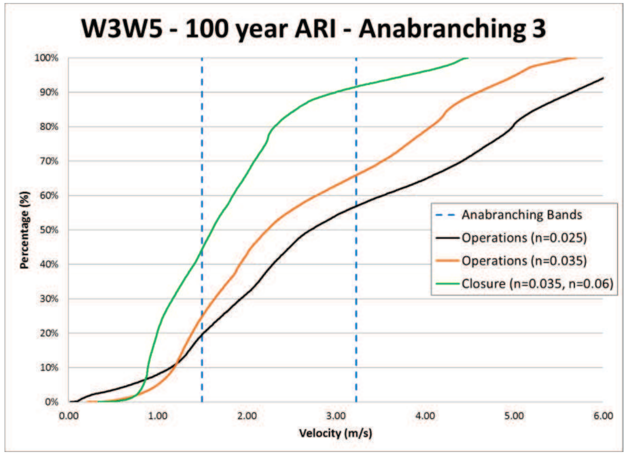




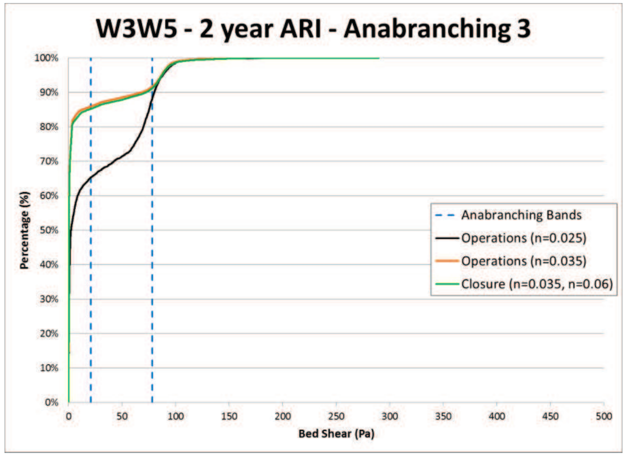


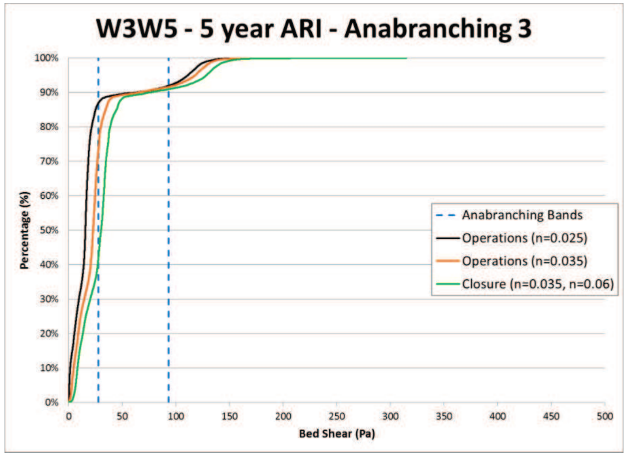


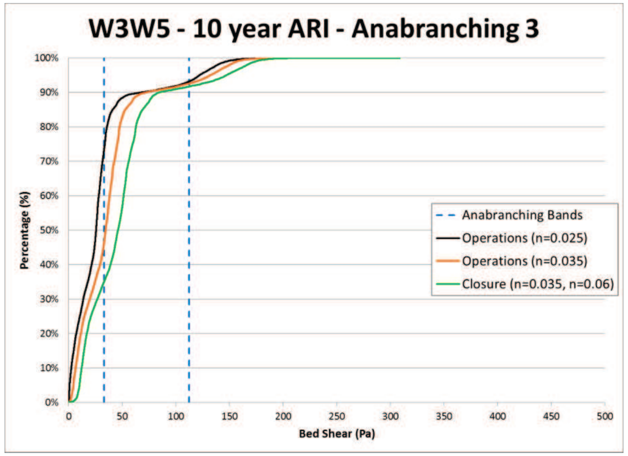


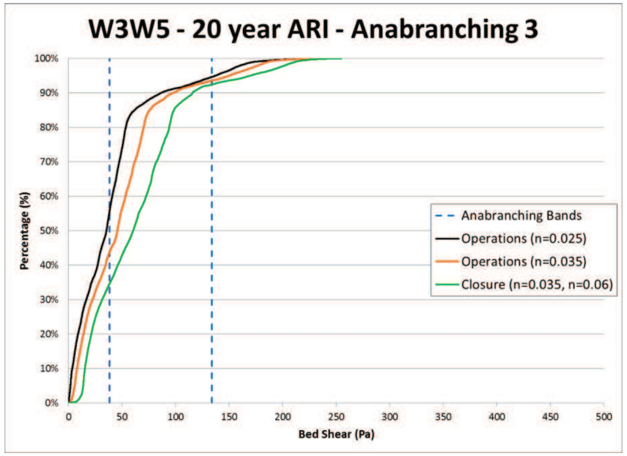


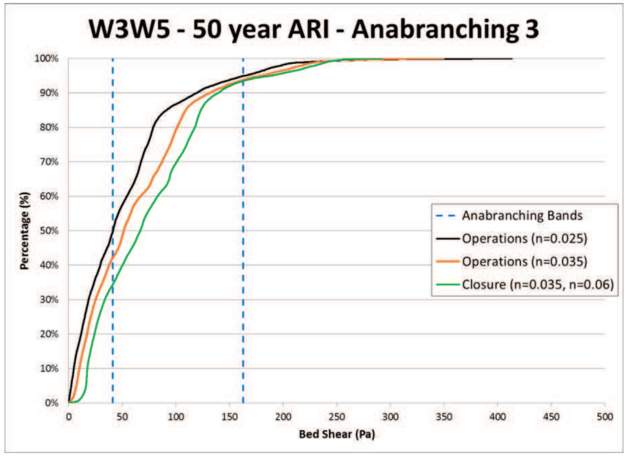
W3W5 - Anabranching 3: Bed Shear

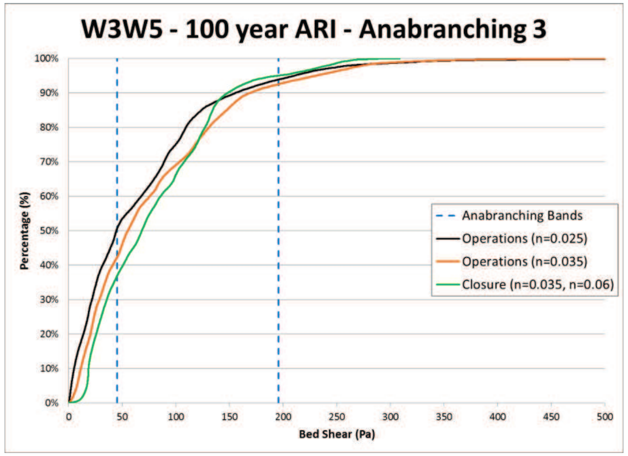




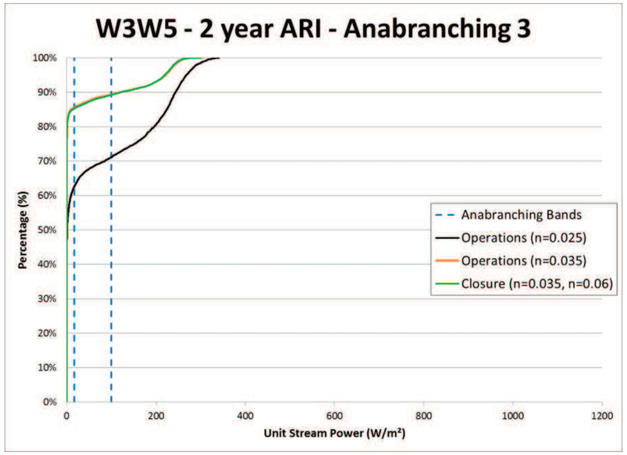


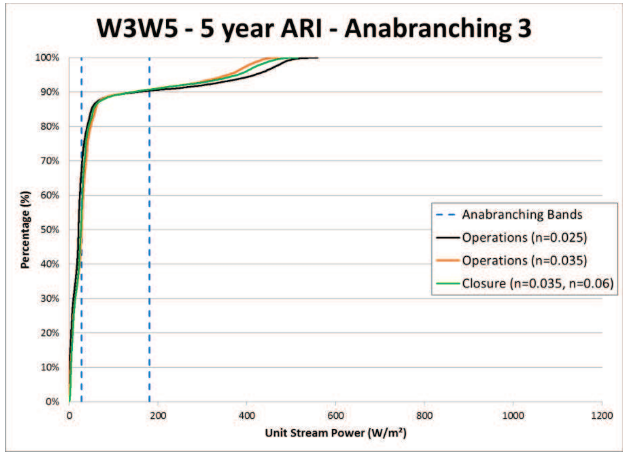


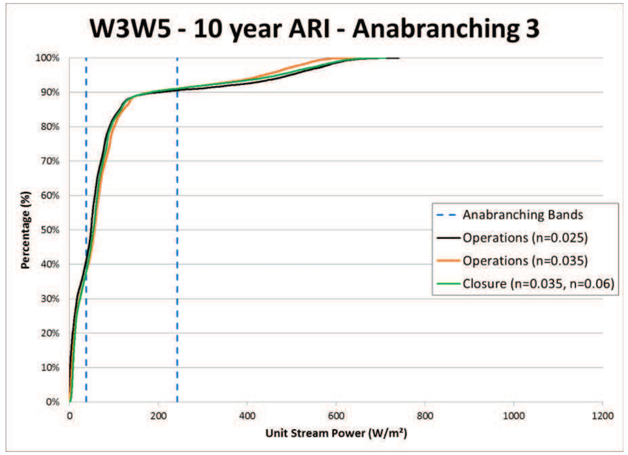


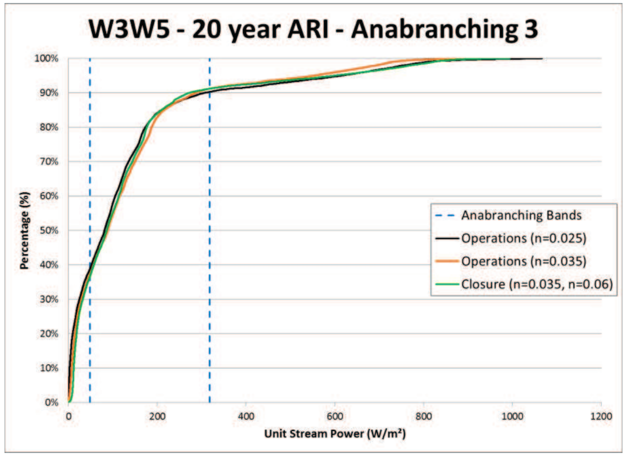


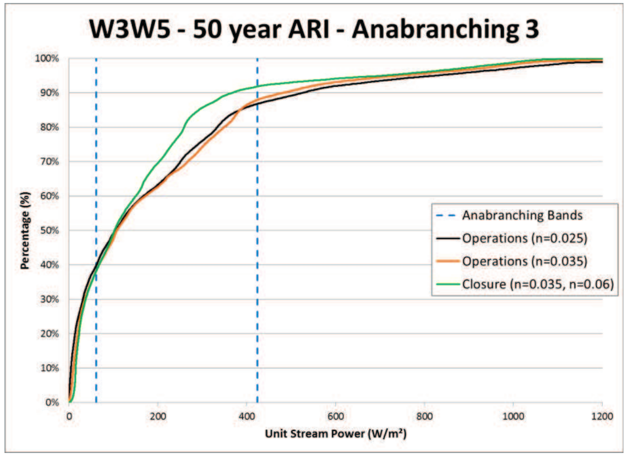
W3W5 - Anabranching 3: Stream Power

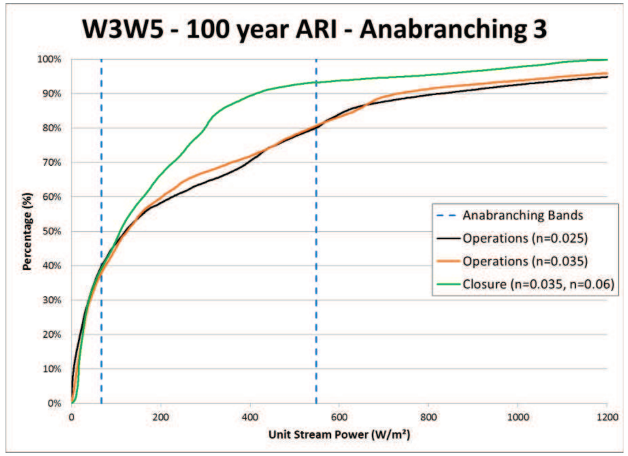


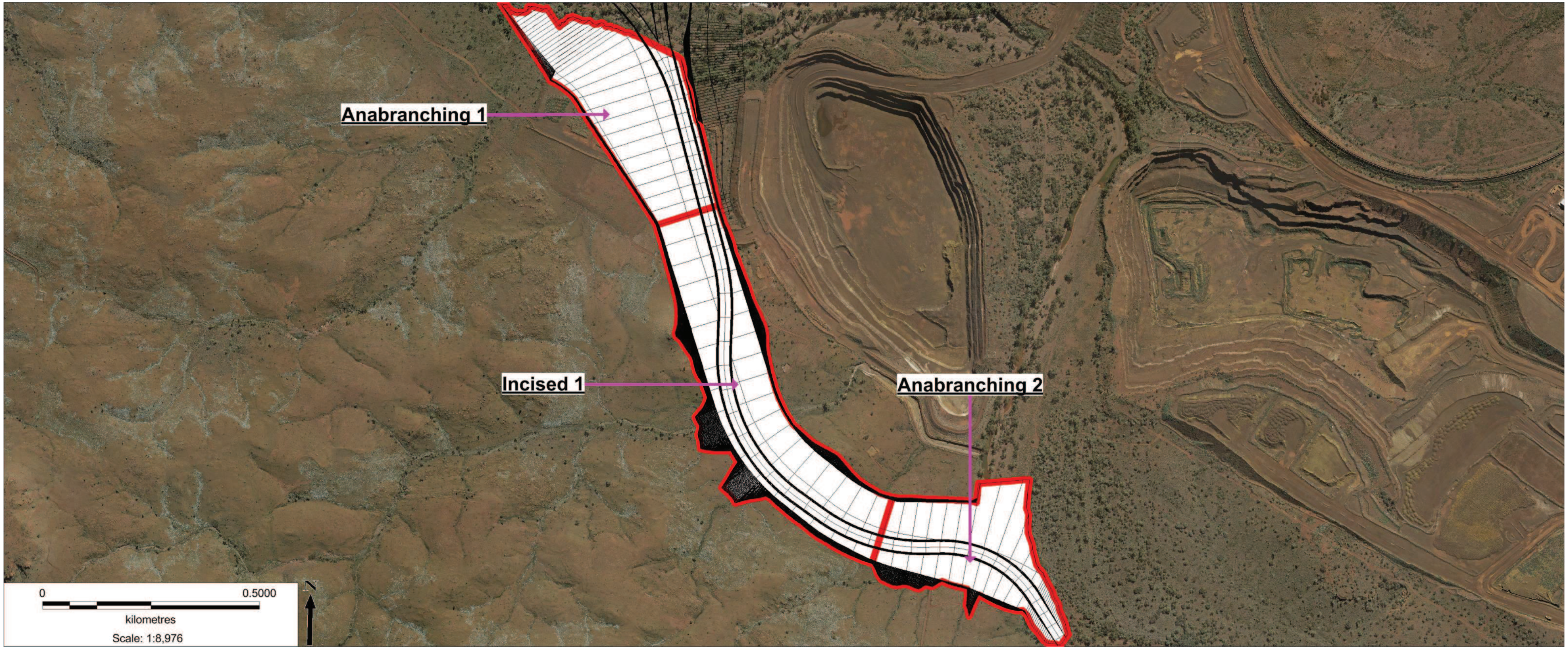






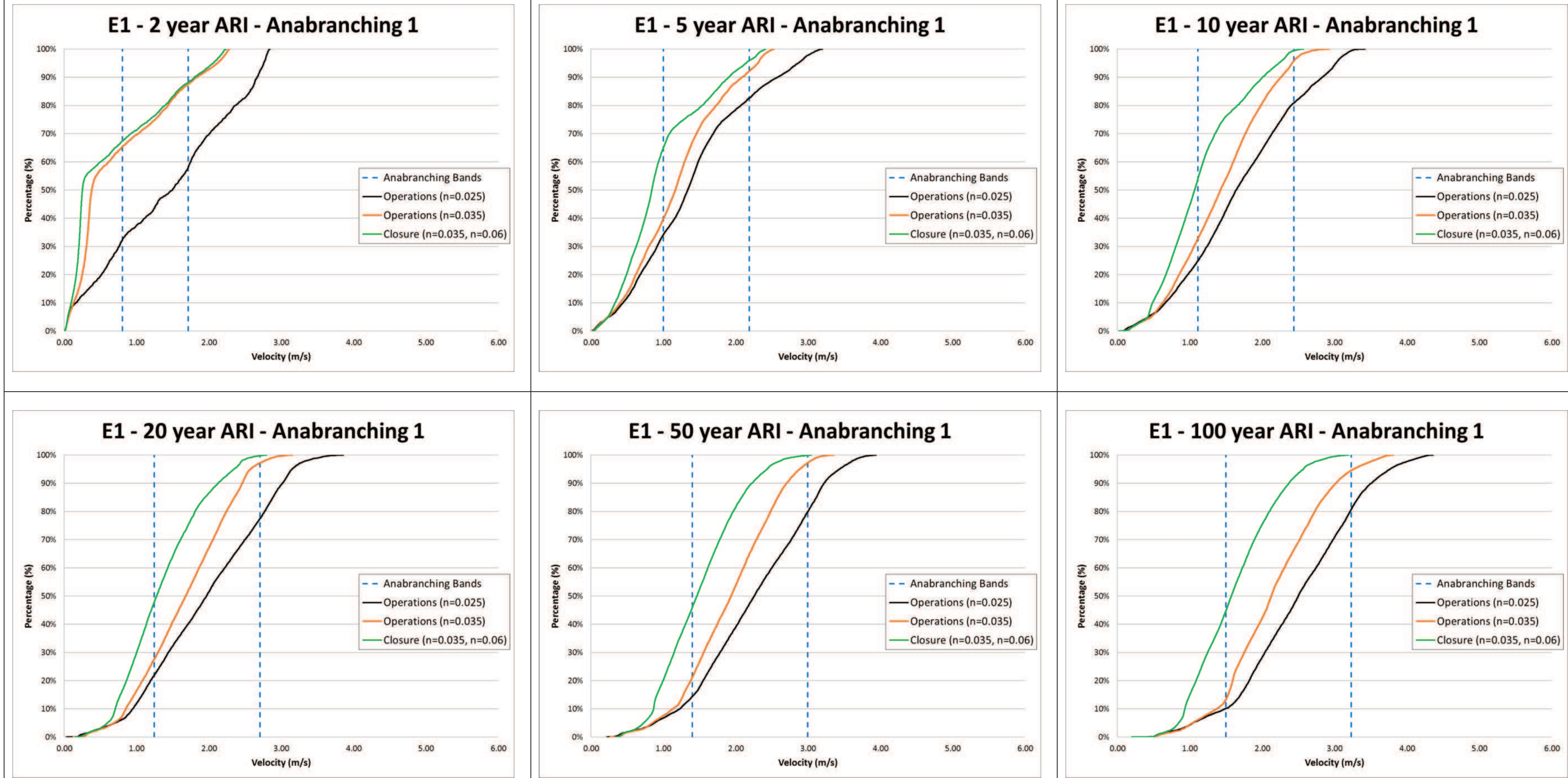




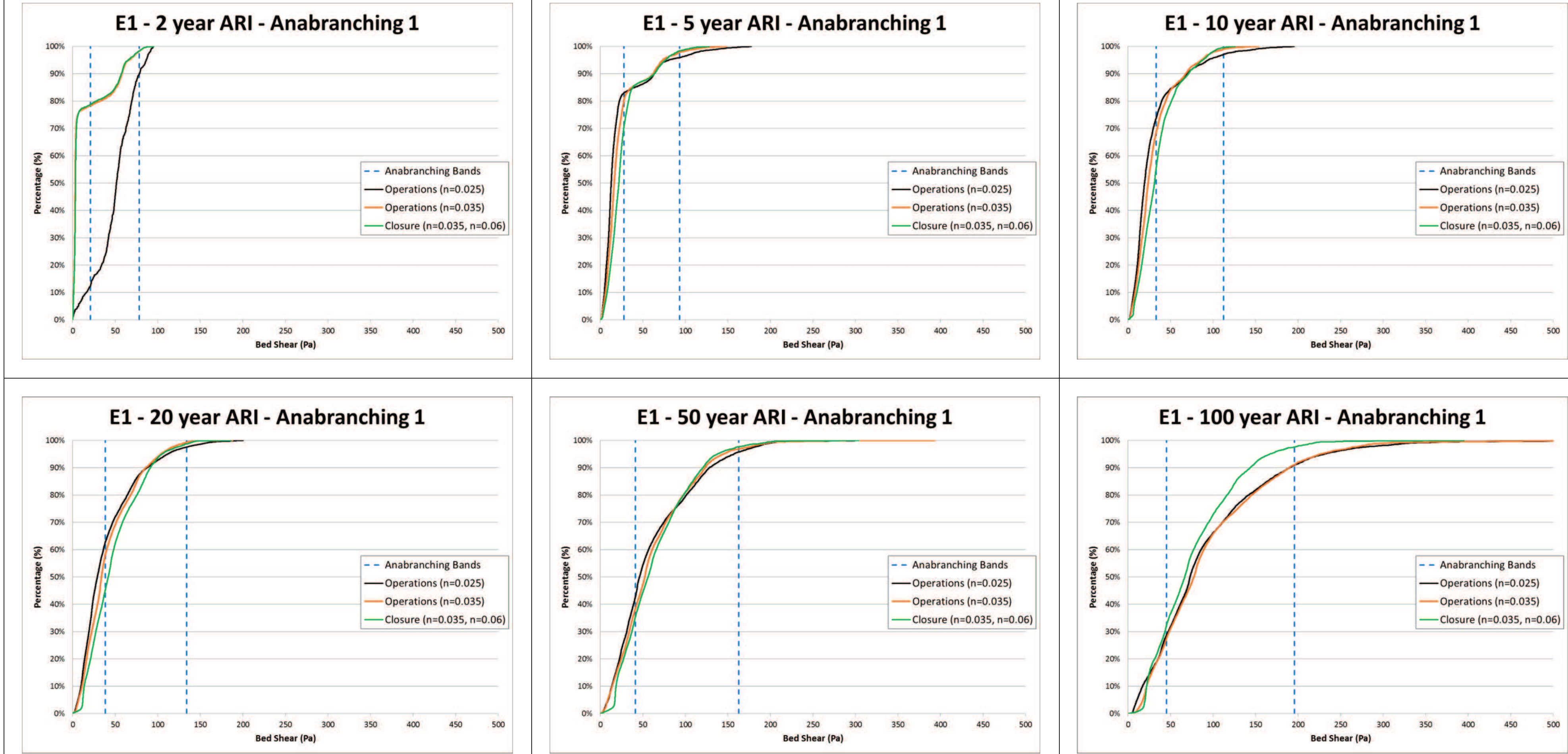


E1 Diversion - Hydraulic Modelling Results

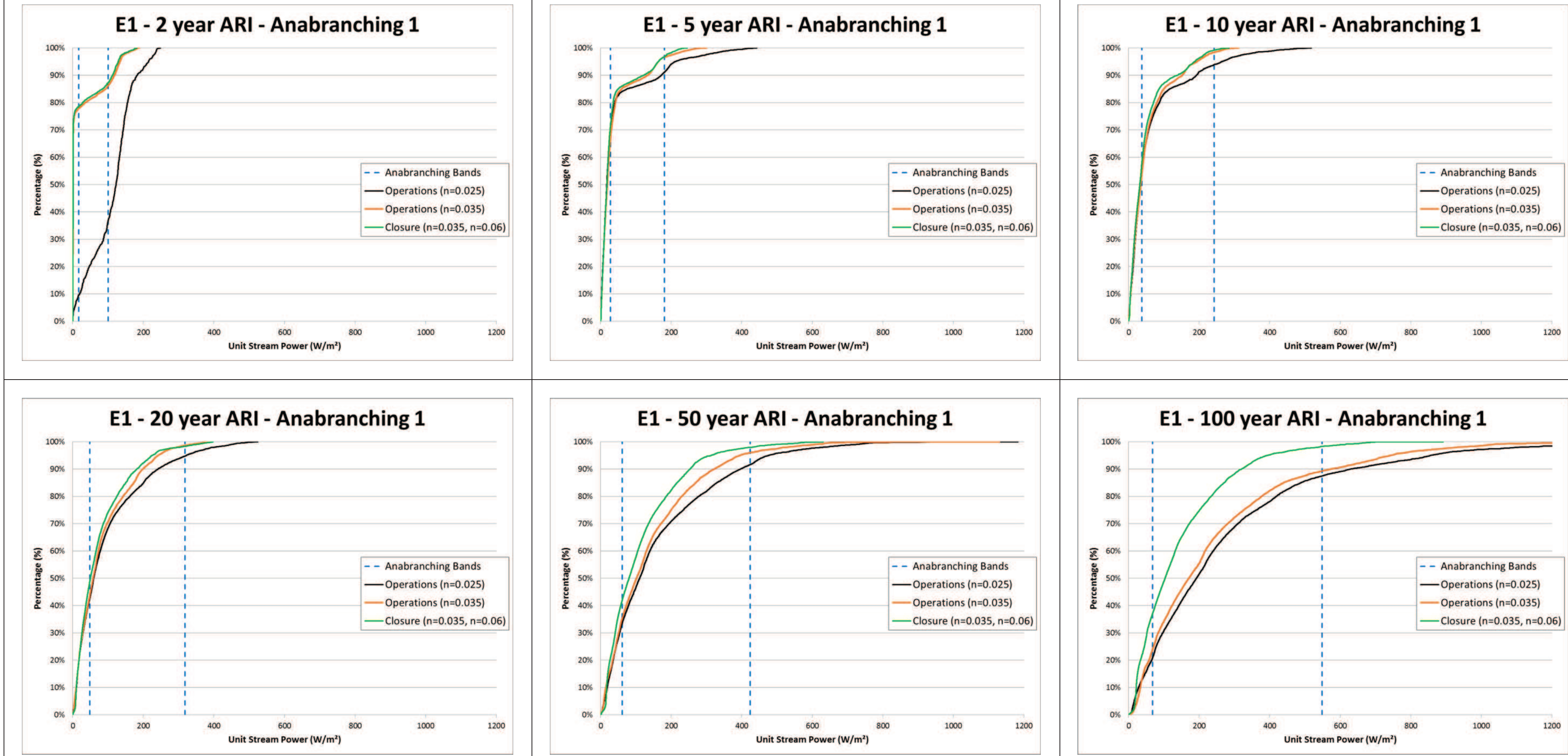
E1 - Anabranching 1: Velocity



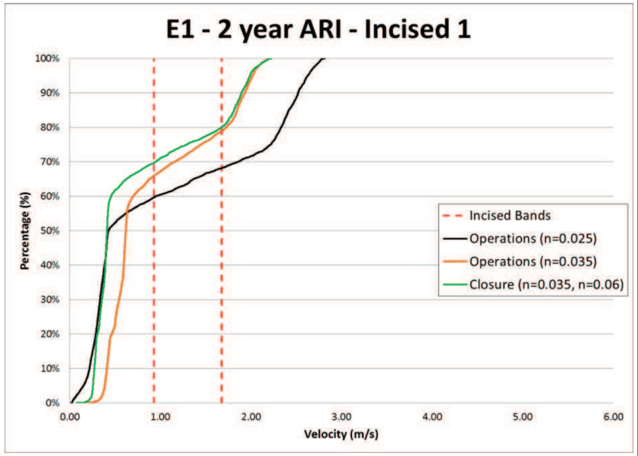
E1 - Anabranching 1: Bed Shear

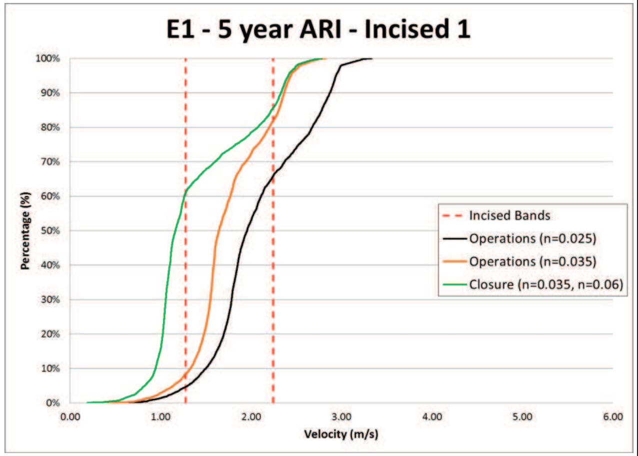


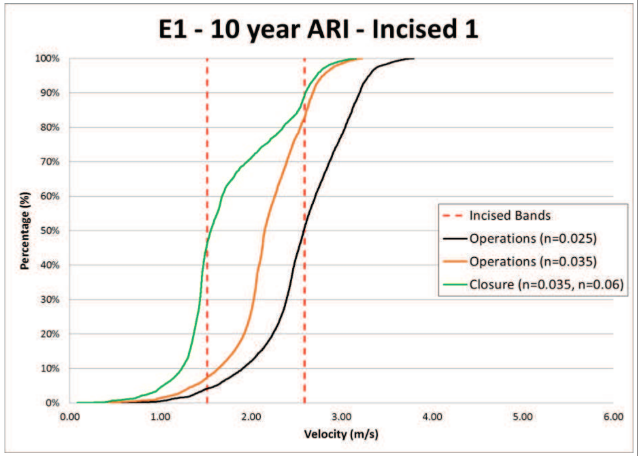
E1 - Anabranching 1: Stream Power

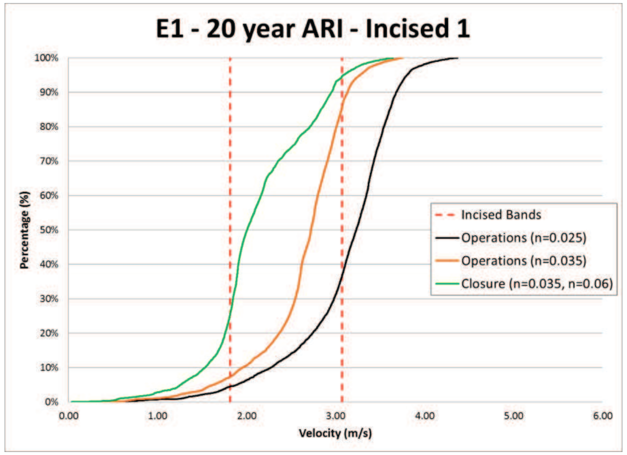


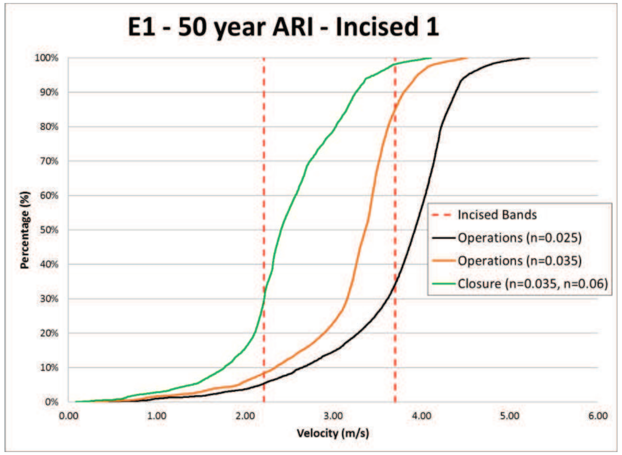
E1 - Incised 1: Velocity

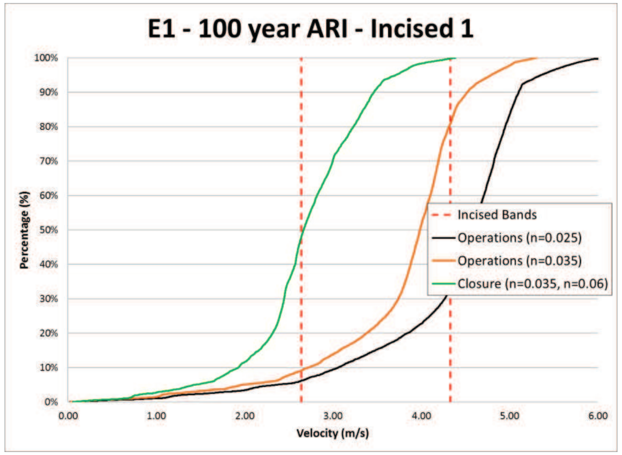




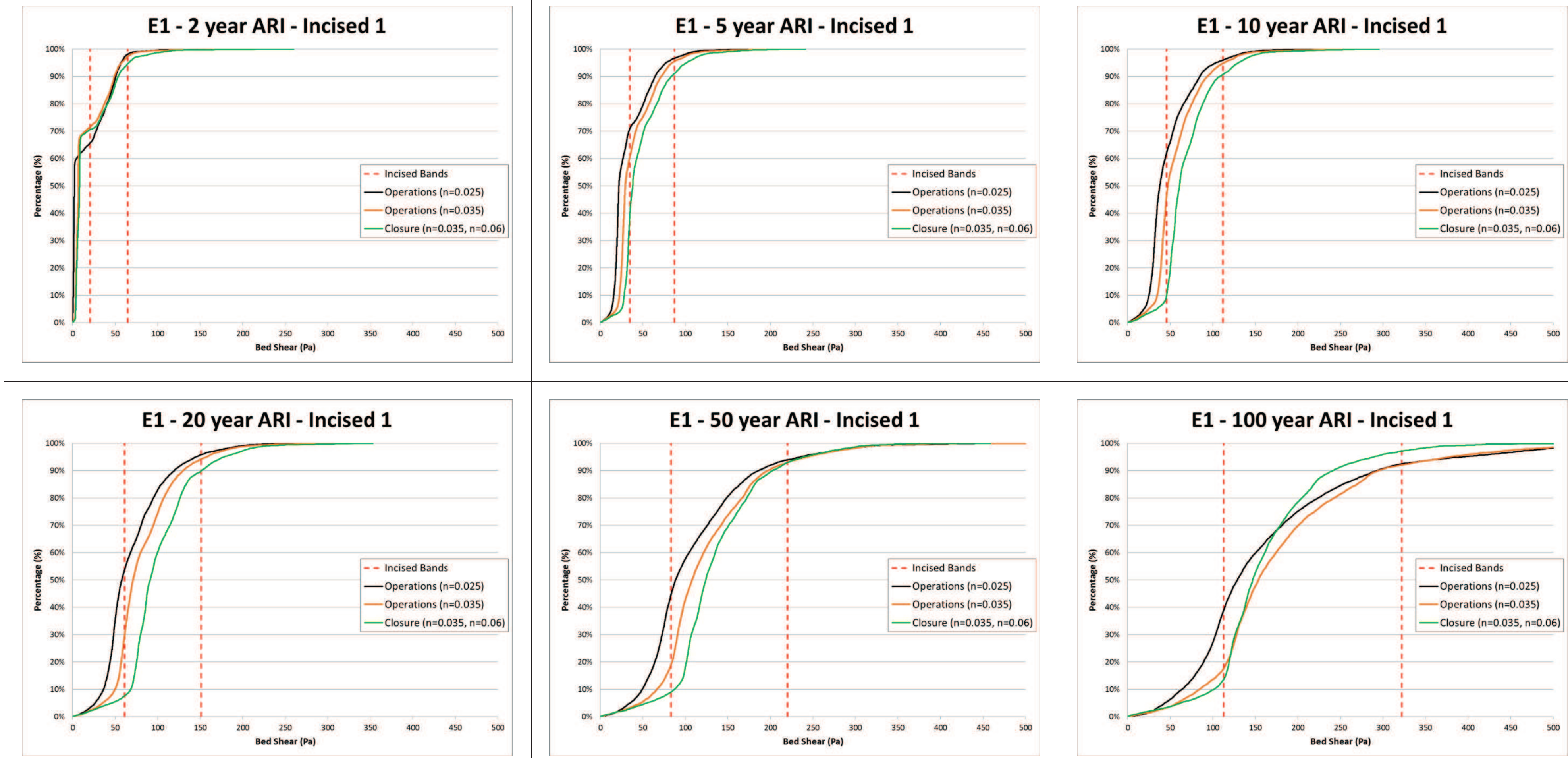




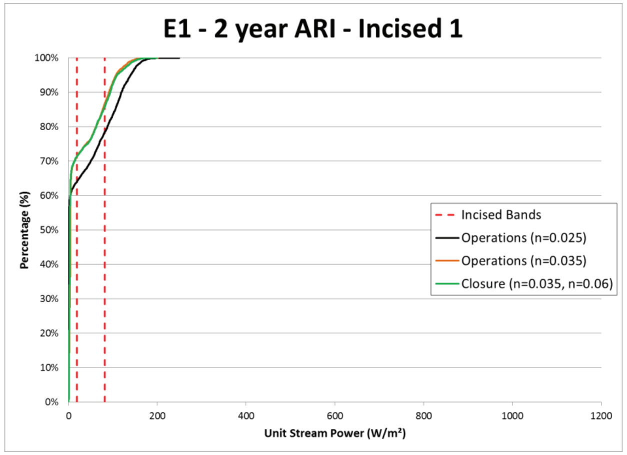


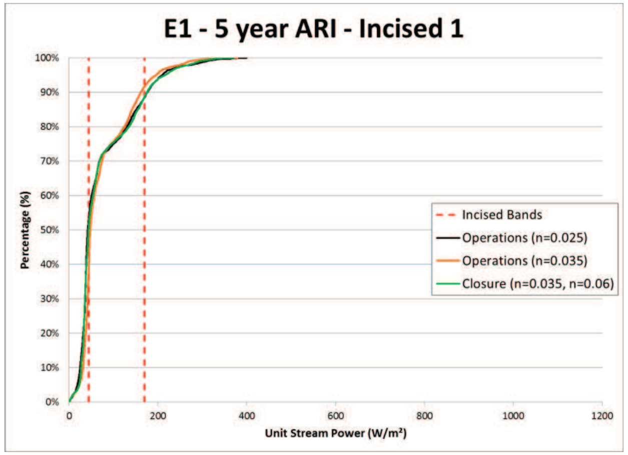


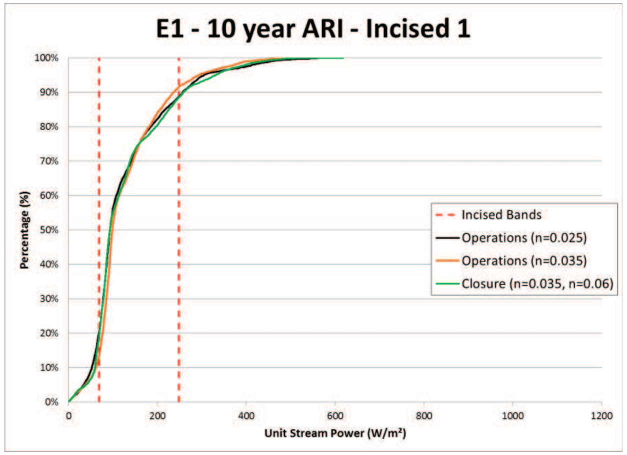
E1 - Incised 1: Bed Shear

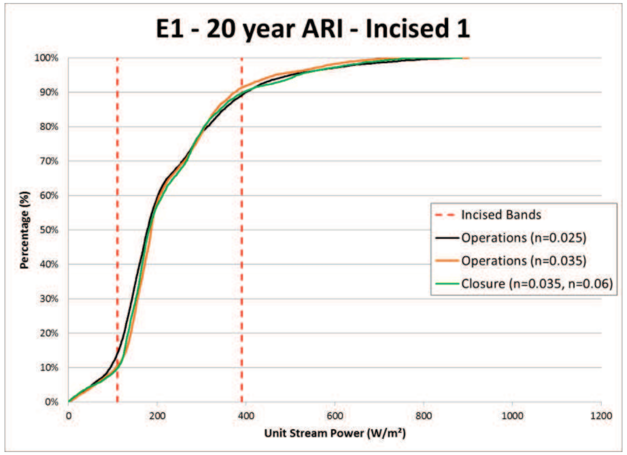


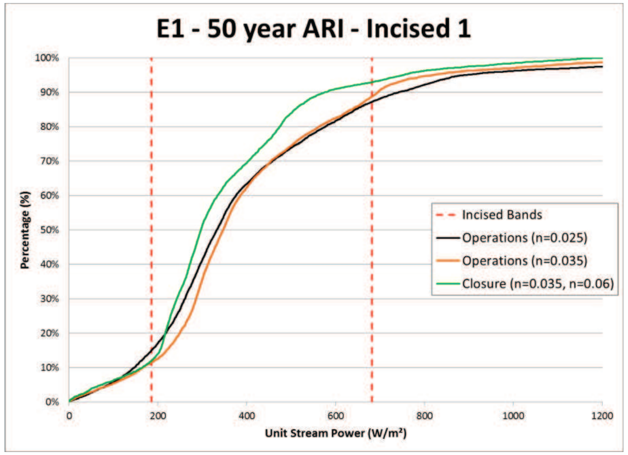
E1 - Incised 1: Stream Power

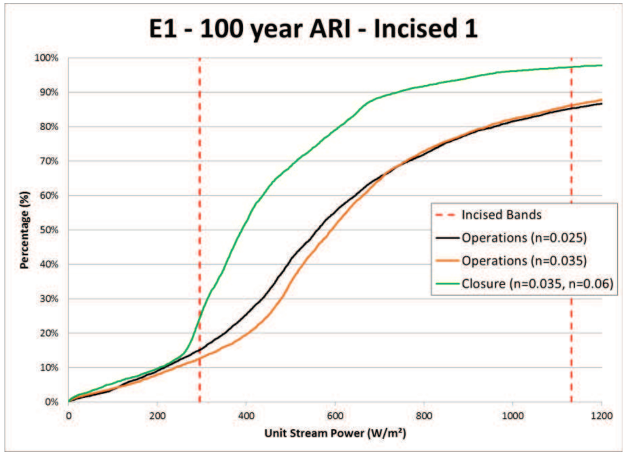




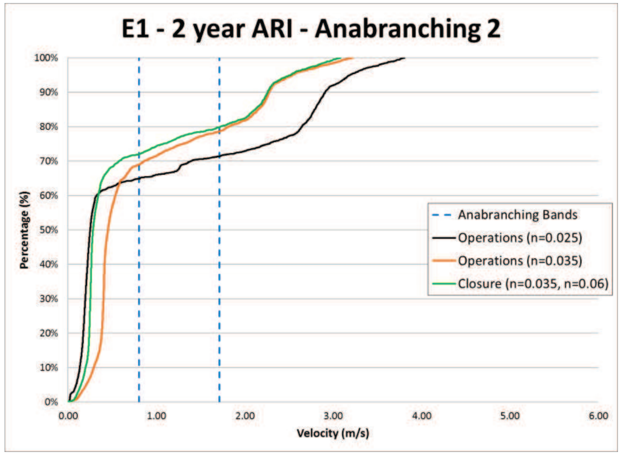


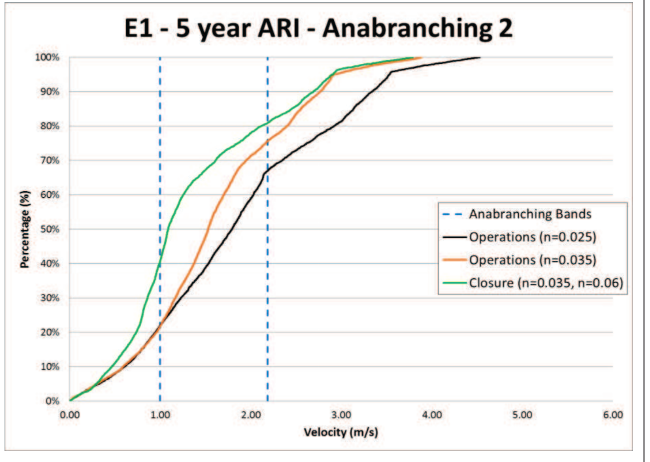


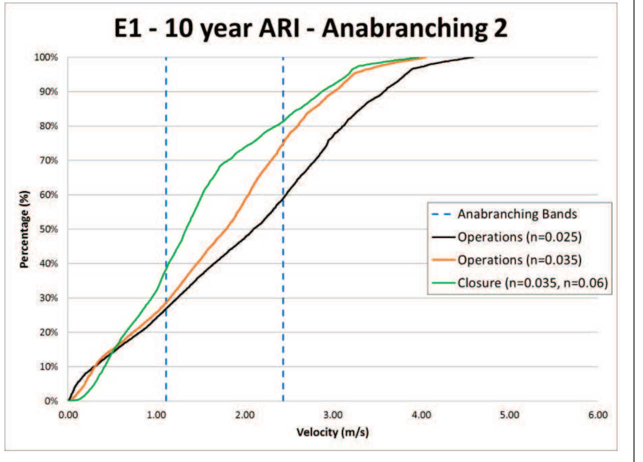


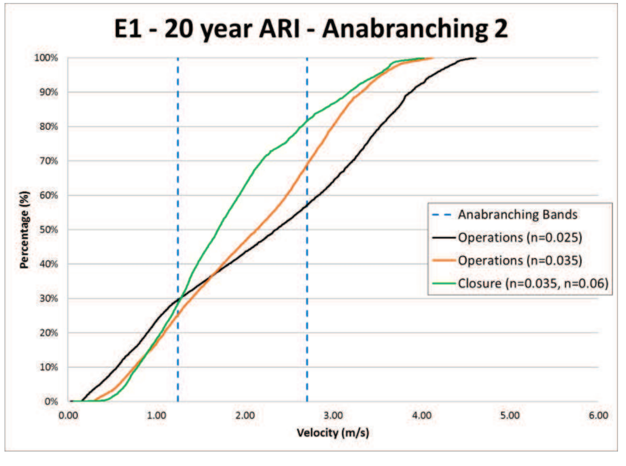


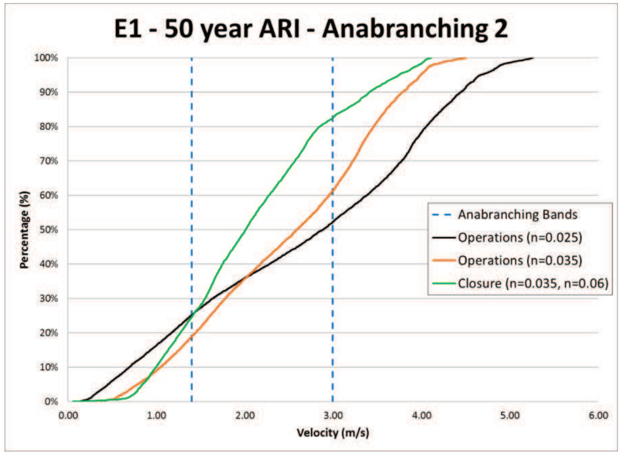
E1 - Anabranching 2: Velocity

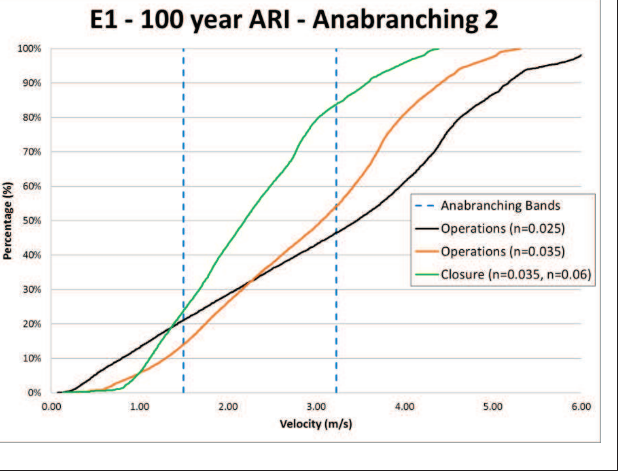




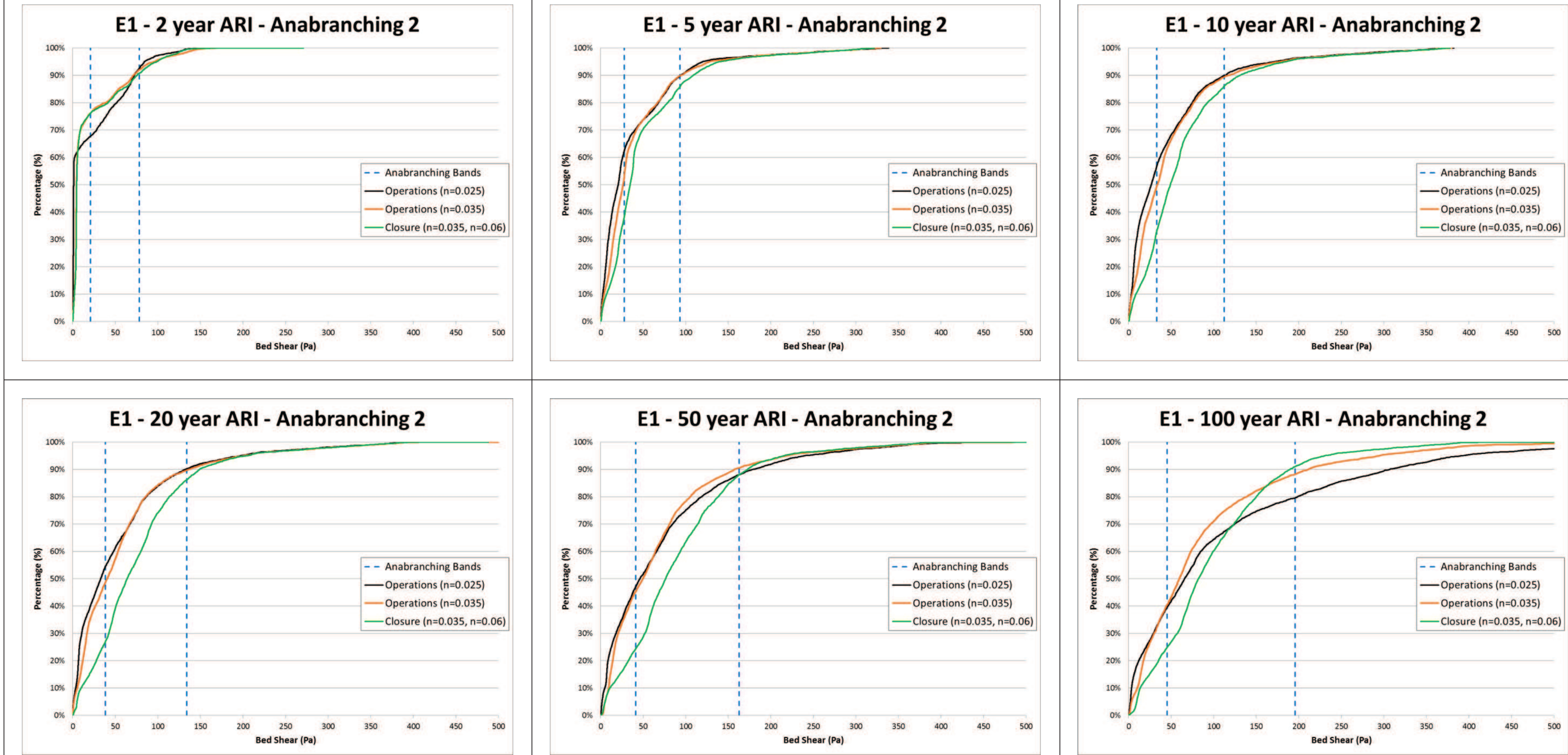




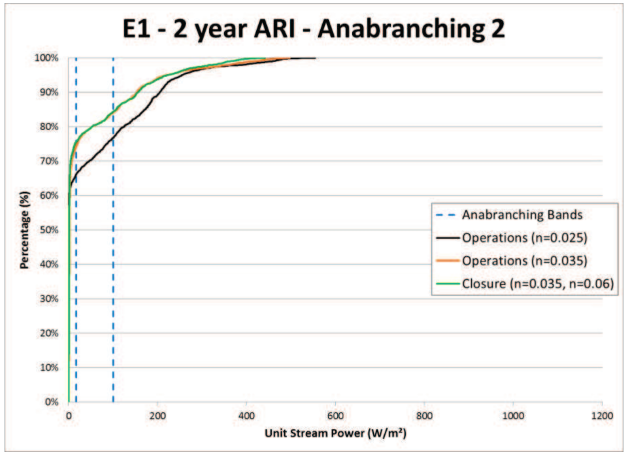


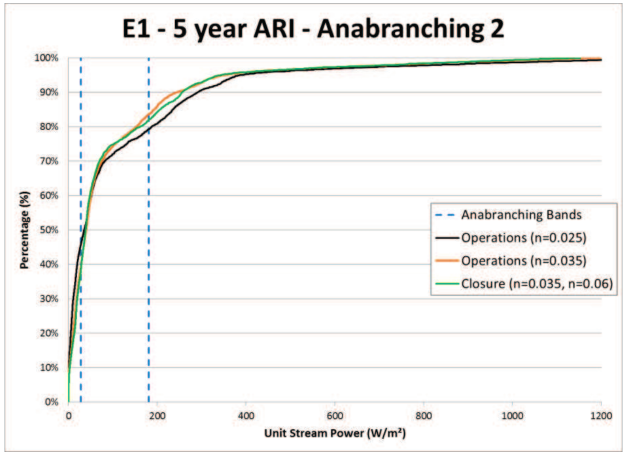


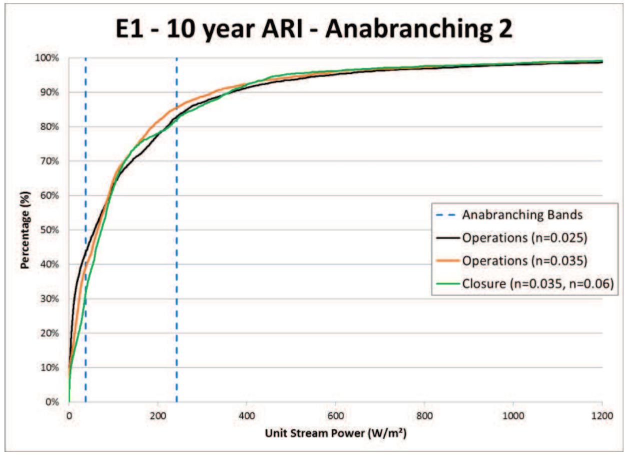
E1 - Anabranching 2: Bed Shear

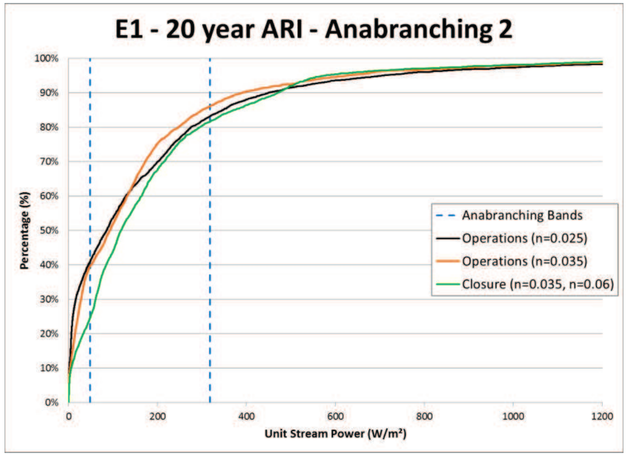


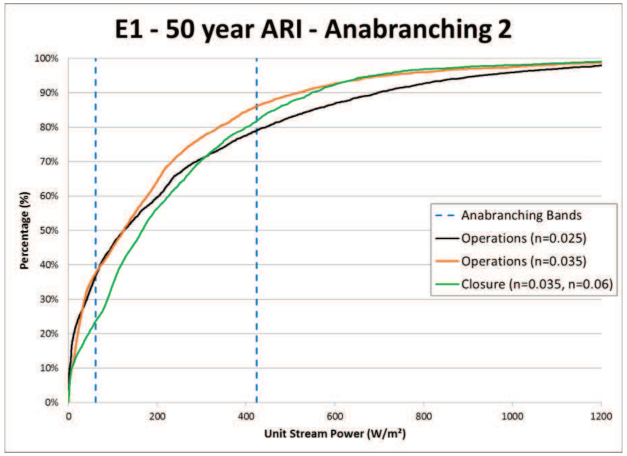
E1 - Anabranching 2: Stream Power

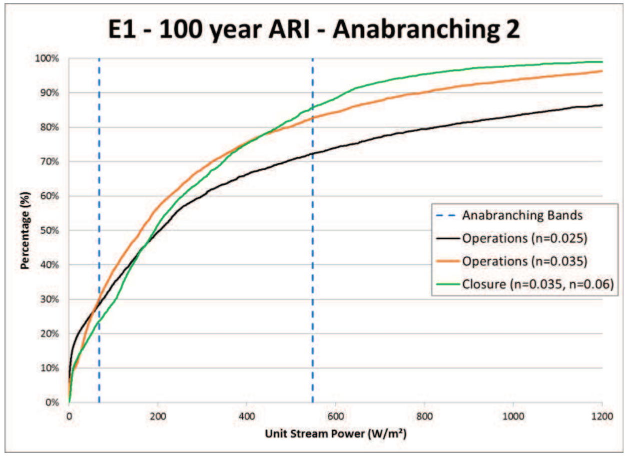


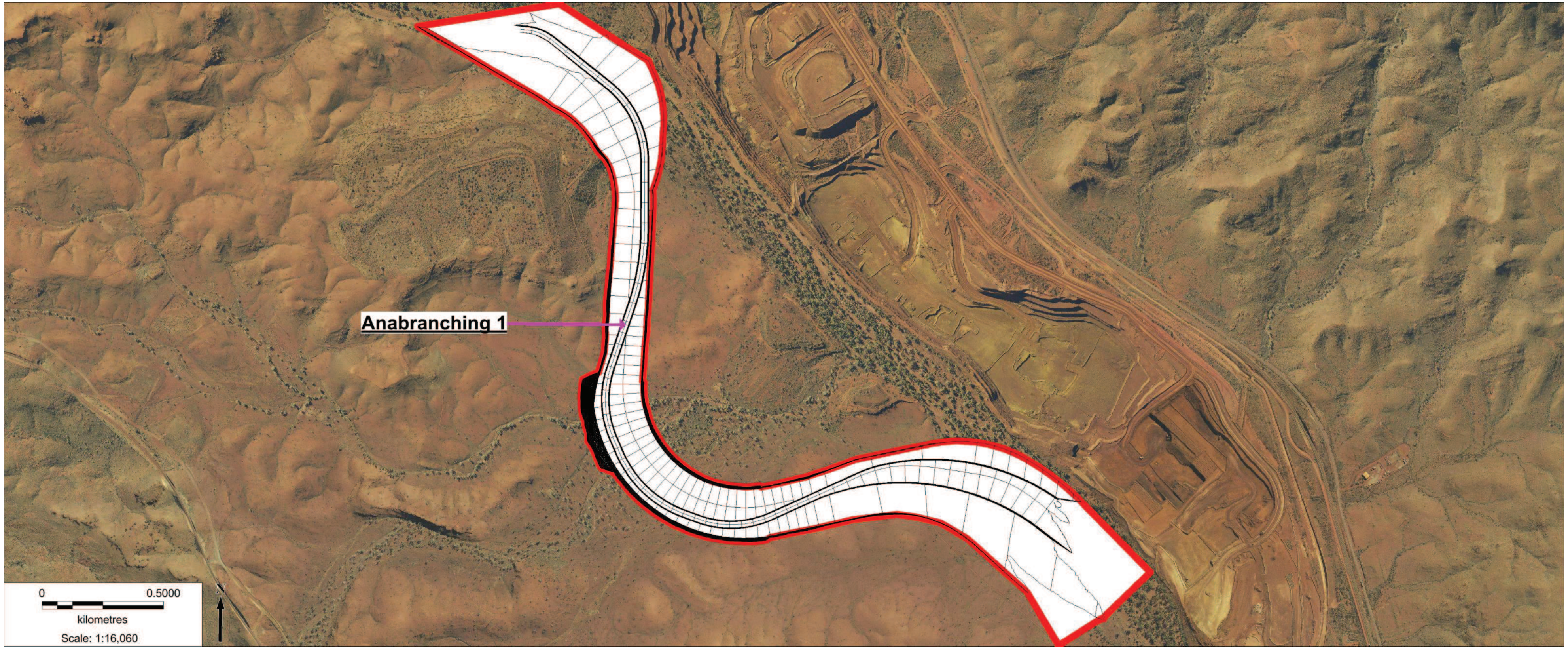






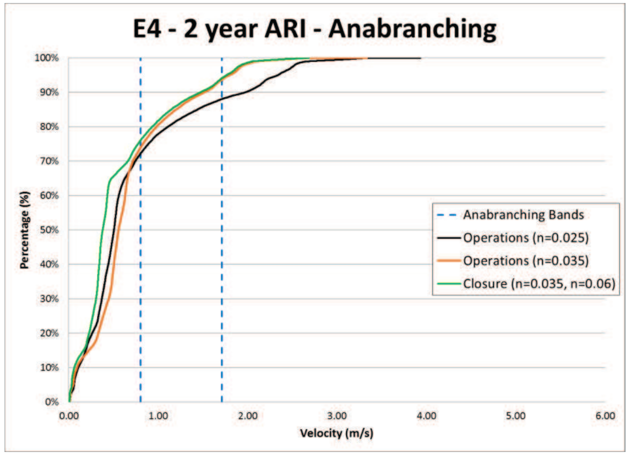


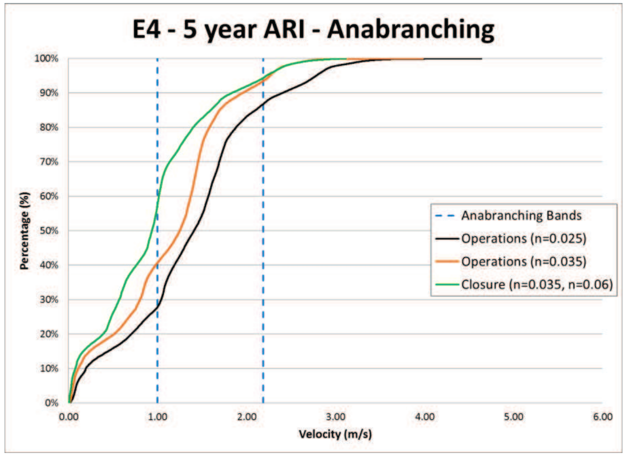


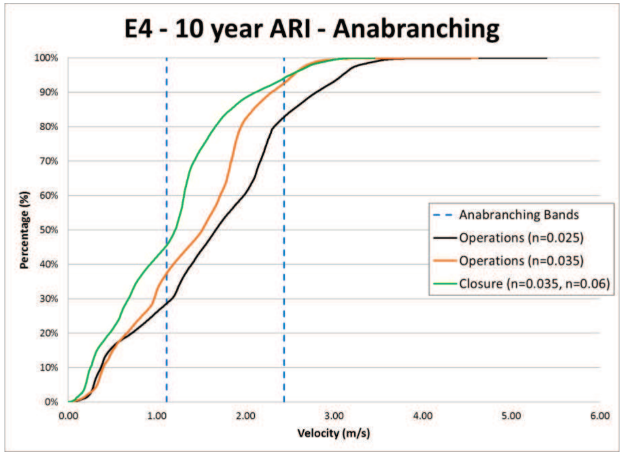


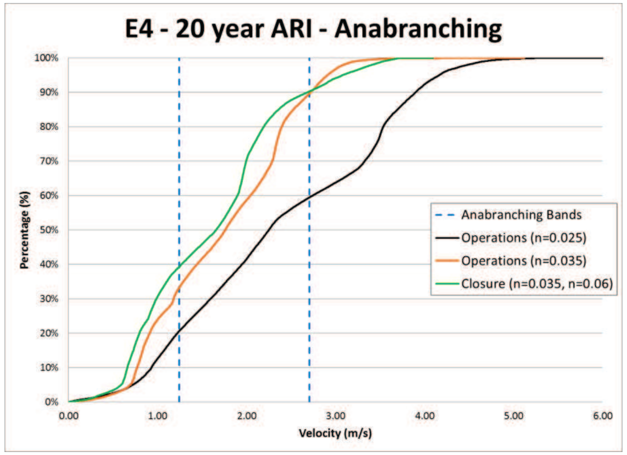
E4 Diversion - Hydraulic Modelling Results

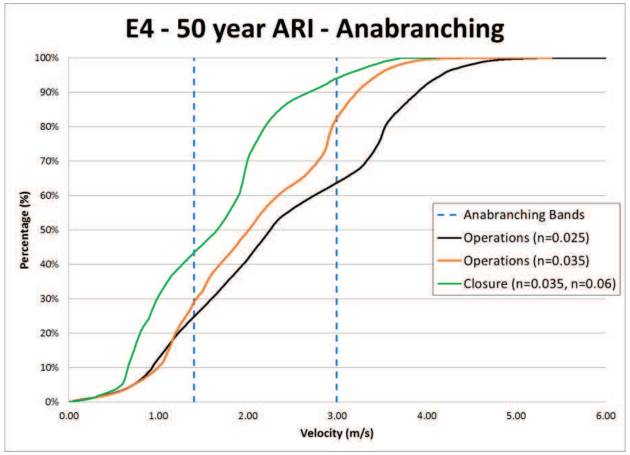
E4 - Anabranching 1: Velocity

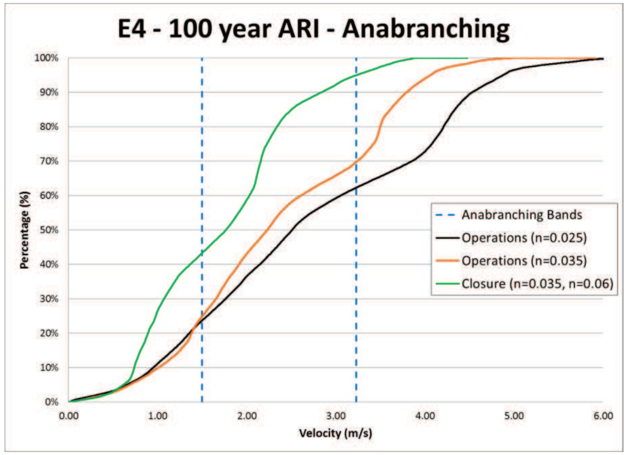




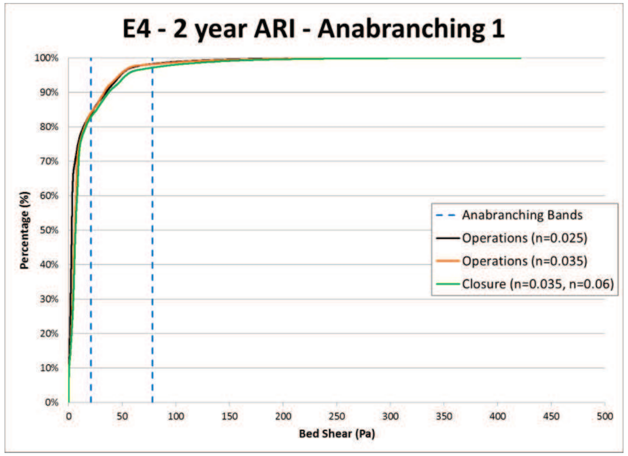


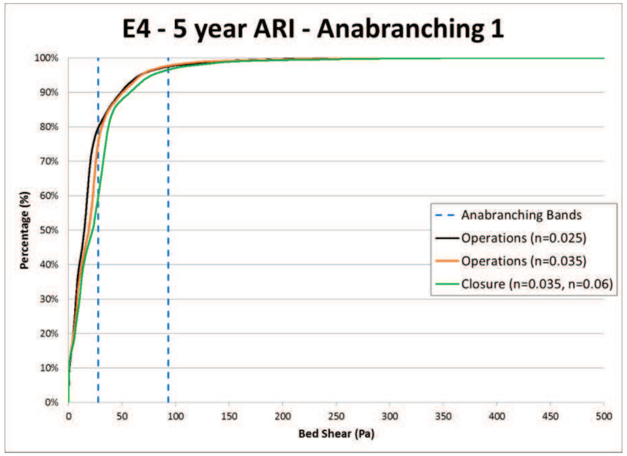


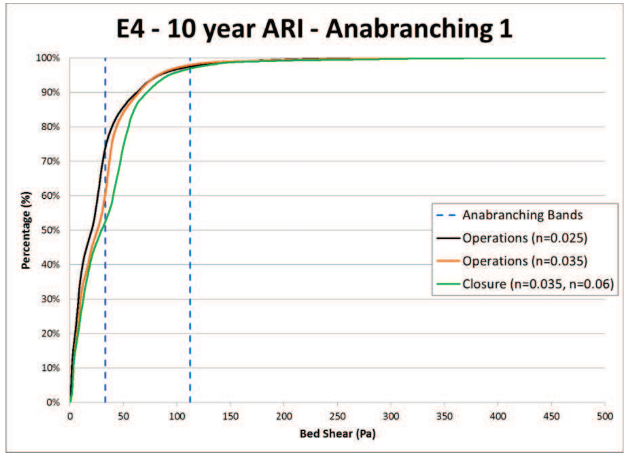


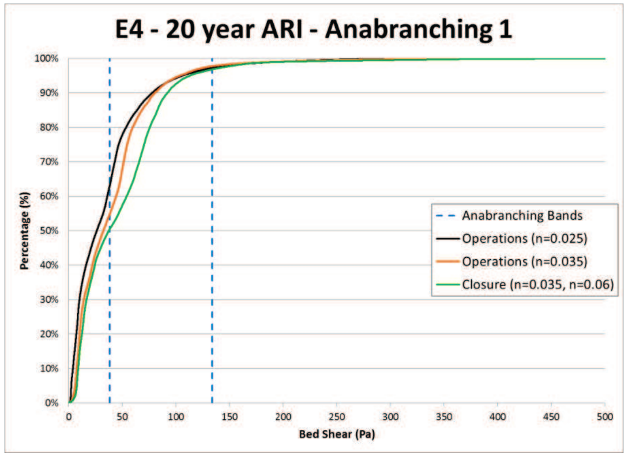


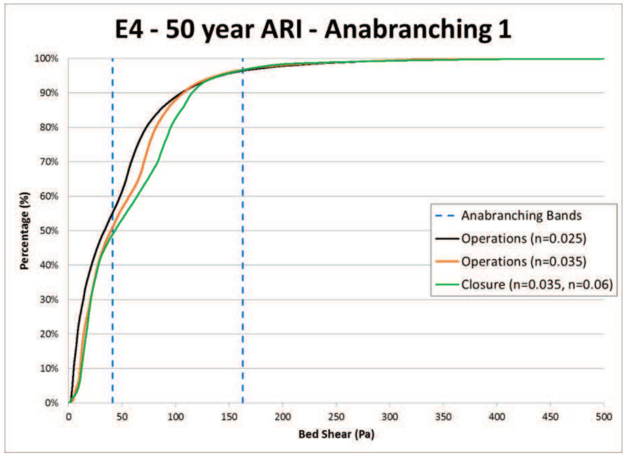
E4 - Anabranching 1: Bed Shear

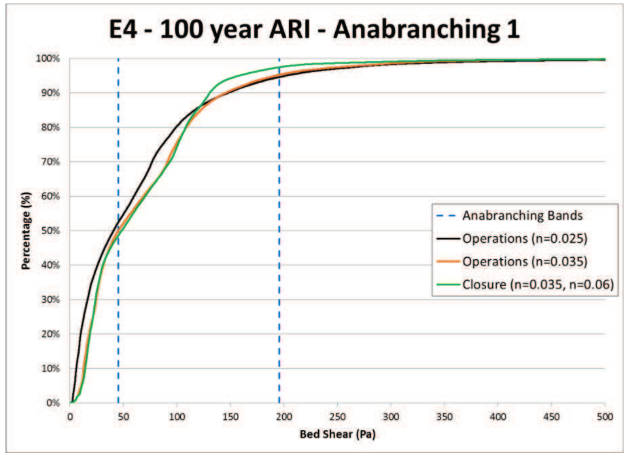




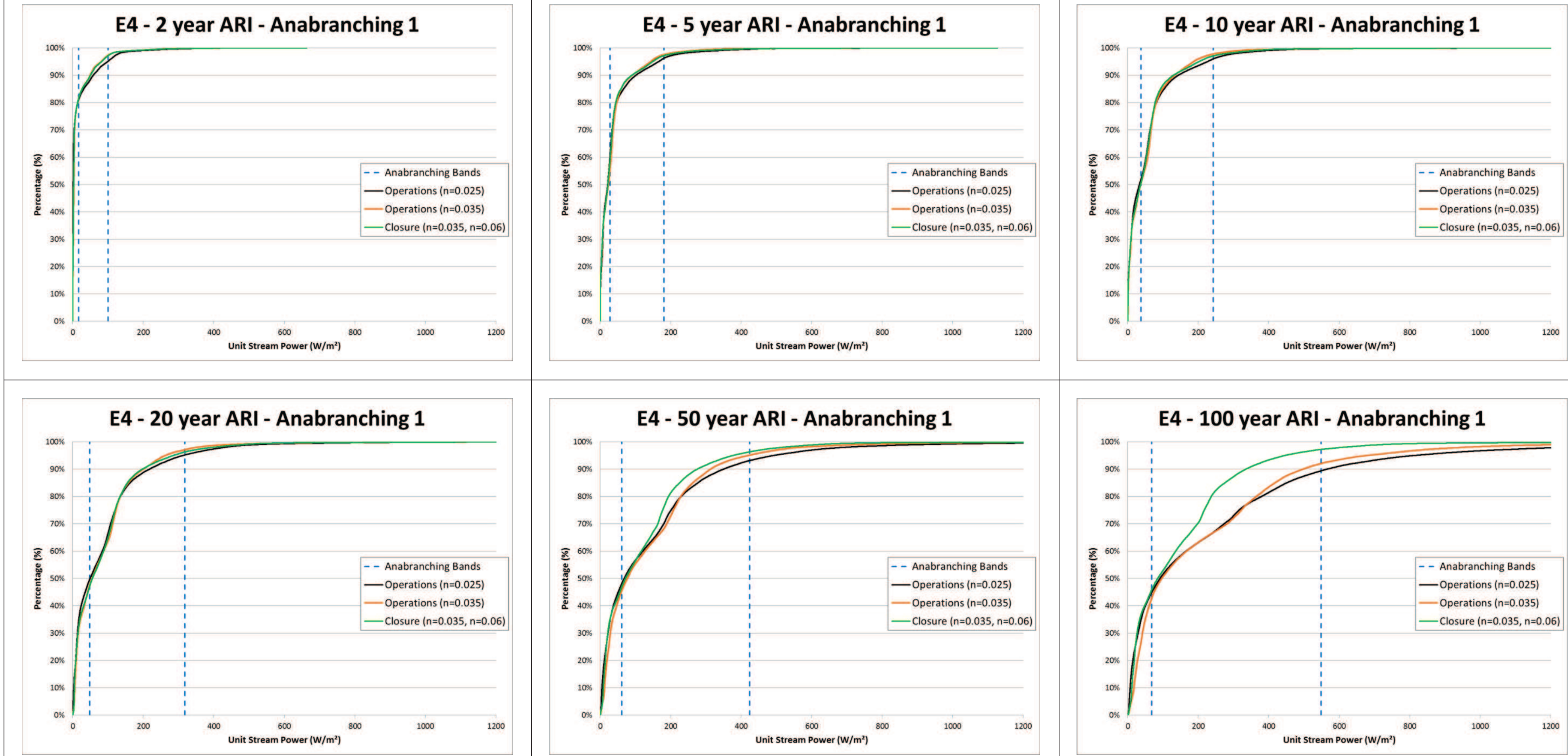




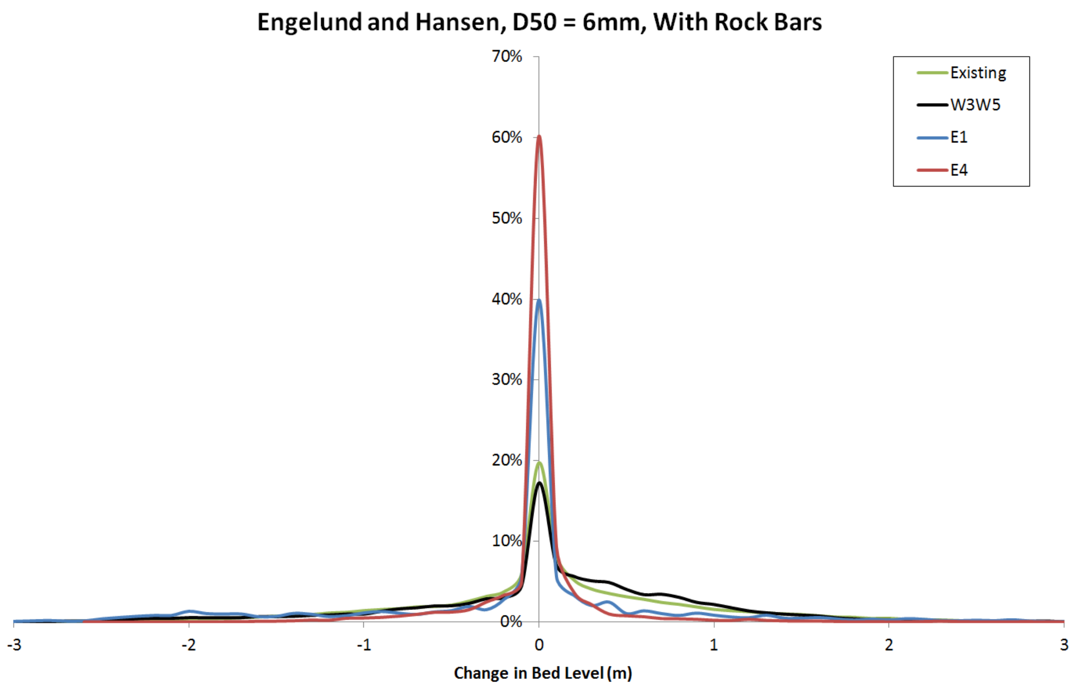




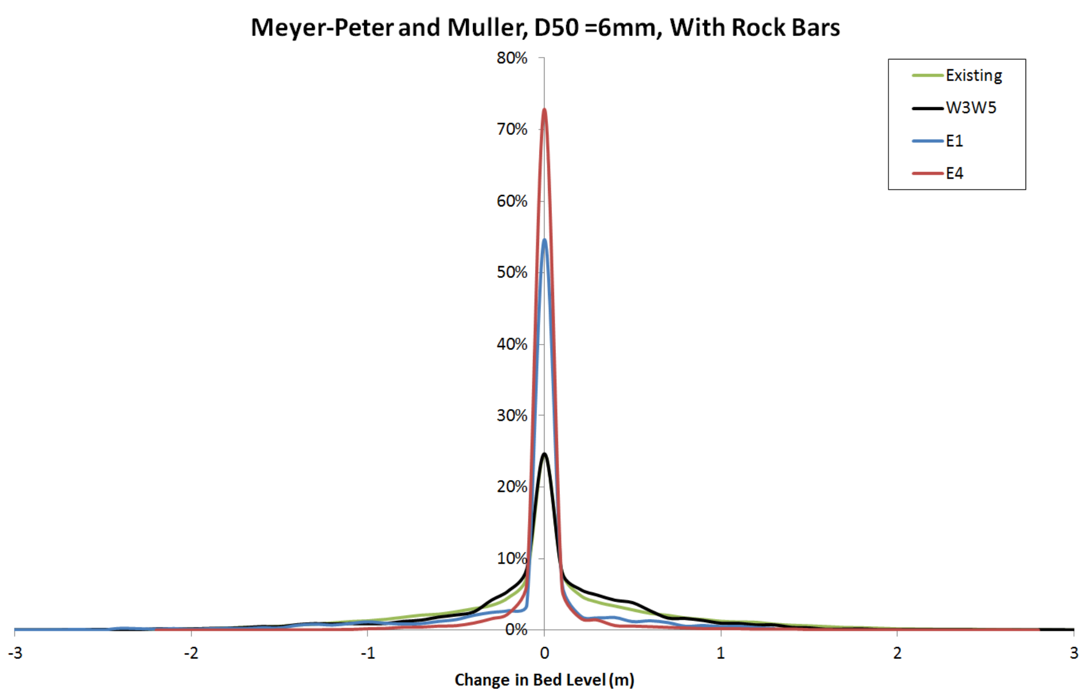
E4 - Anabranching 1: Stream Power



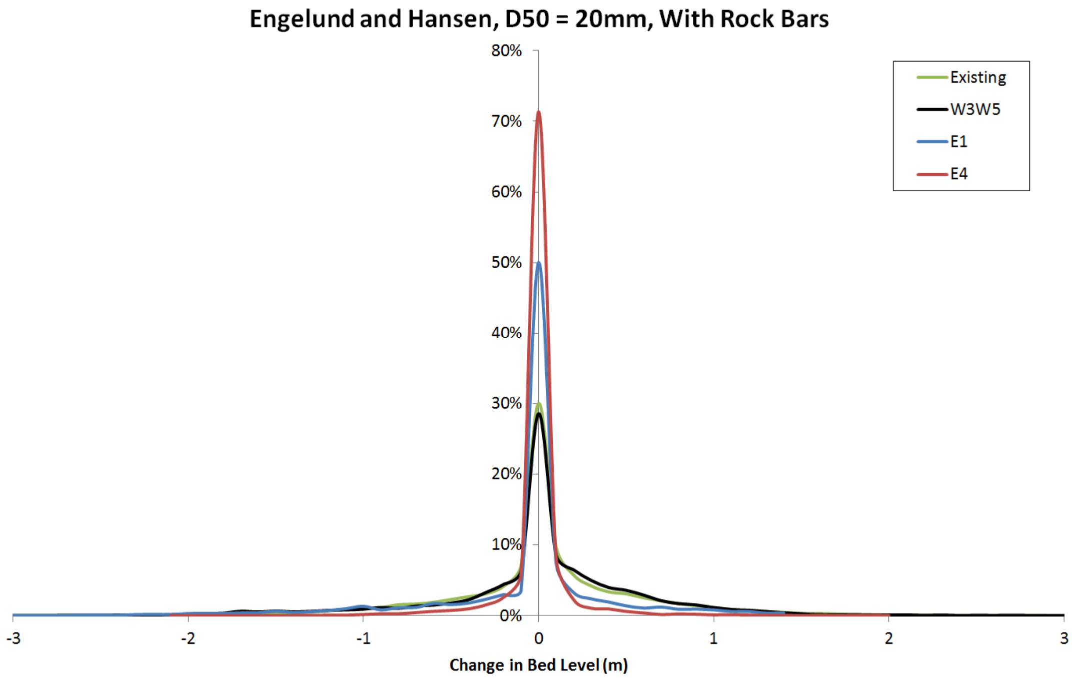
APPENDIX B: Sediment Transport Modelling Results (100 year ARI event)

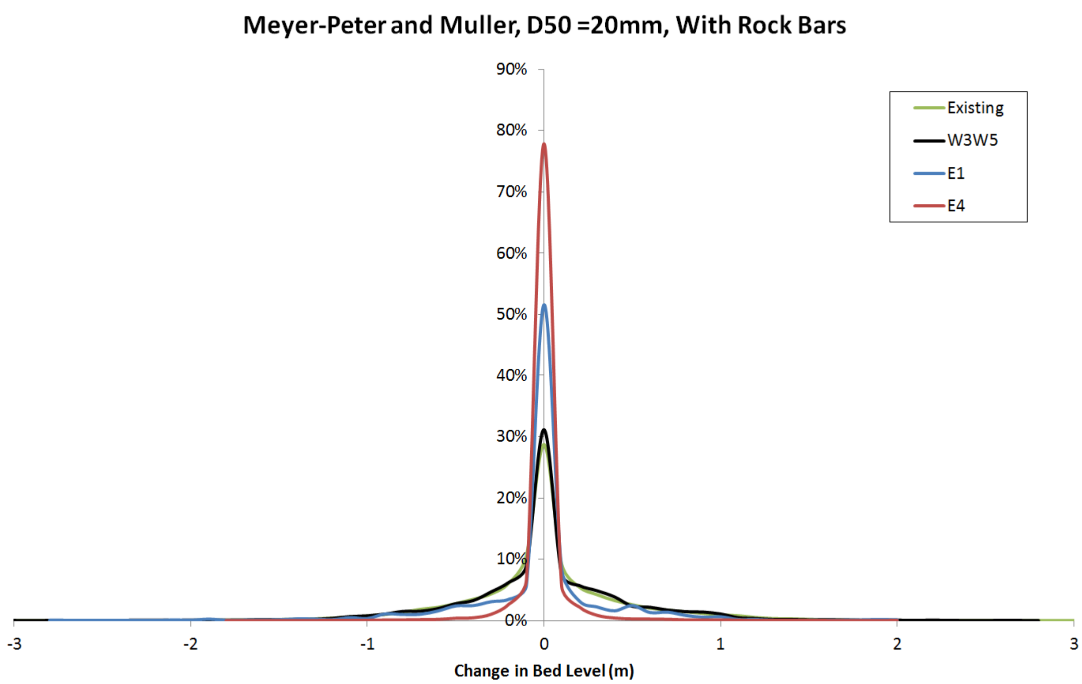


Engelund and Hansen, D50 = 6mm, With Rock Bars
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
Change in Bed Level (m)
Existing
W3W5
E1
E4

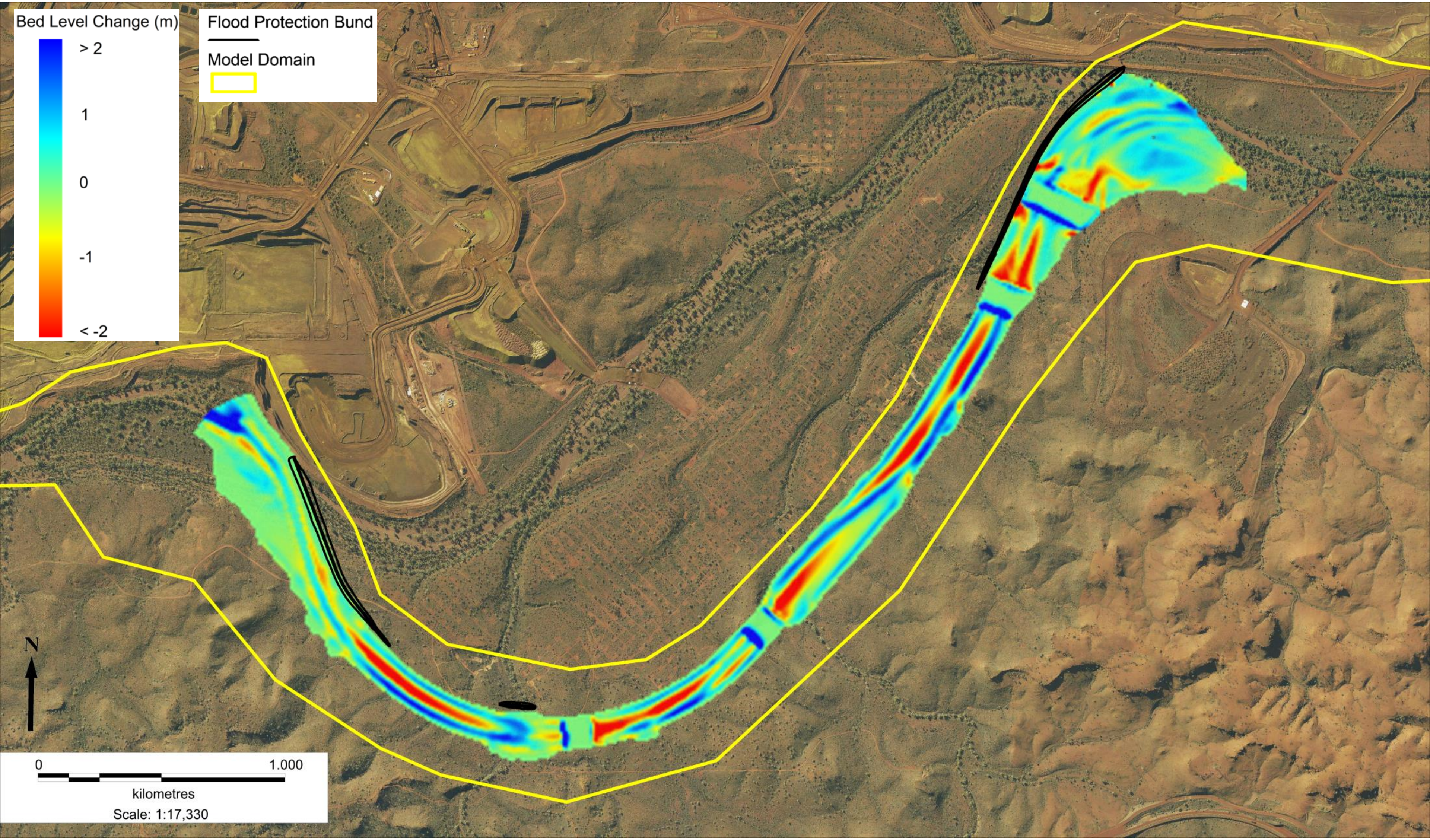


Meyer-Peter and Muller, D50 =6mm, With Rock Bars
80%
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
Change in Bed Level (m)
Existing
W3W5
E1
E4

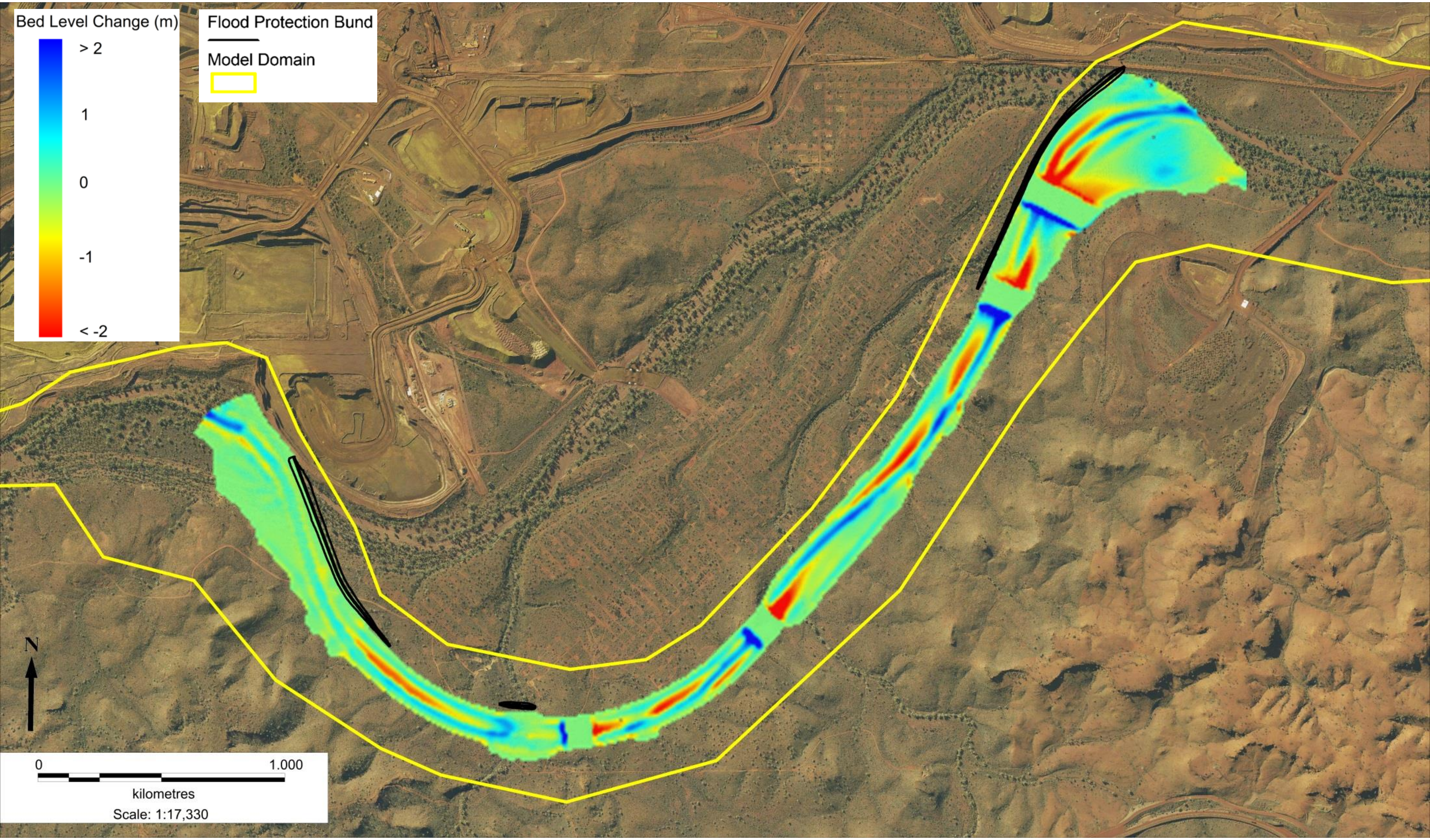

Engelund and Hansen, D50 = 20mm, With Rock Bars
80%
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
Change in Bed Level (m)
Existing
W3W5
E1
E4


Meyer-Peter and Muller, D50 =20mm, With Rock Bars
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
Change in Bed Level (m)
Existing
W3W5
E1
E4

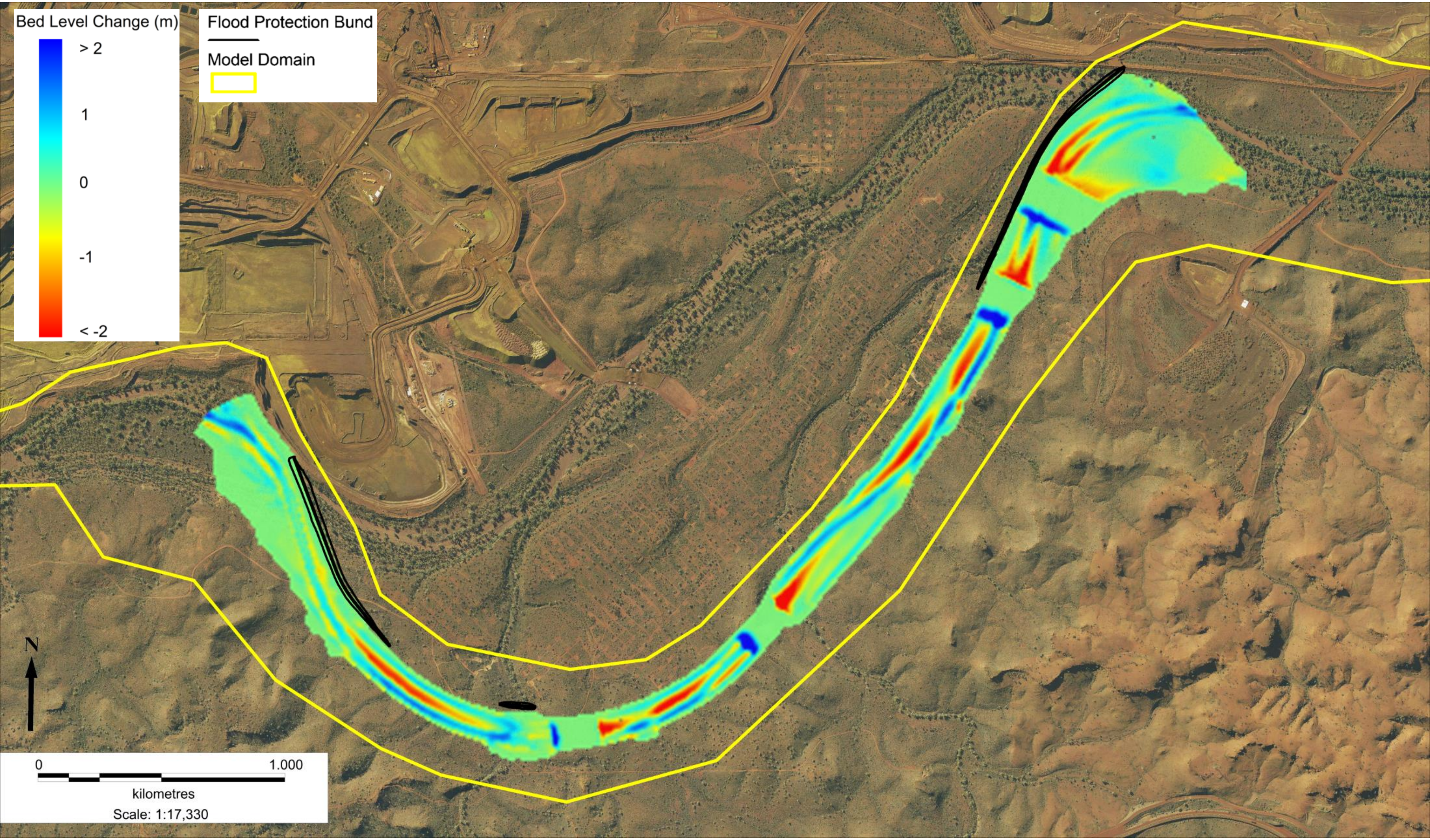
W3W5 - Engelund and Hansen, D50 = 6 mm, With Rock Bars



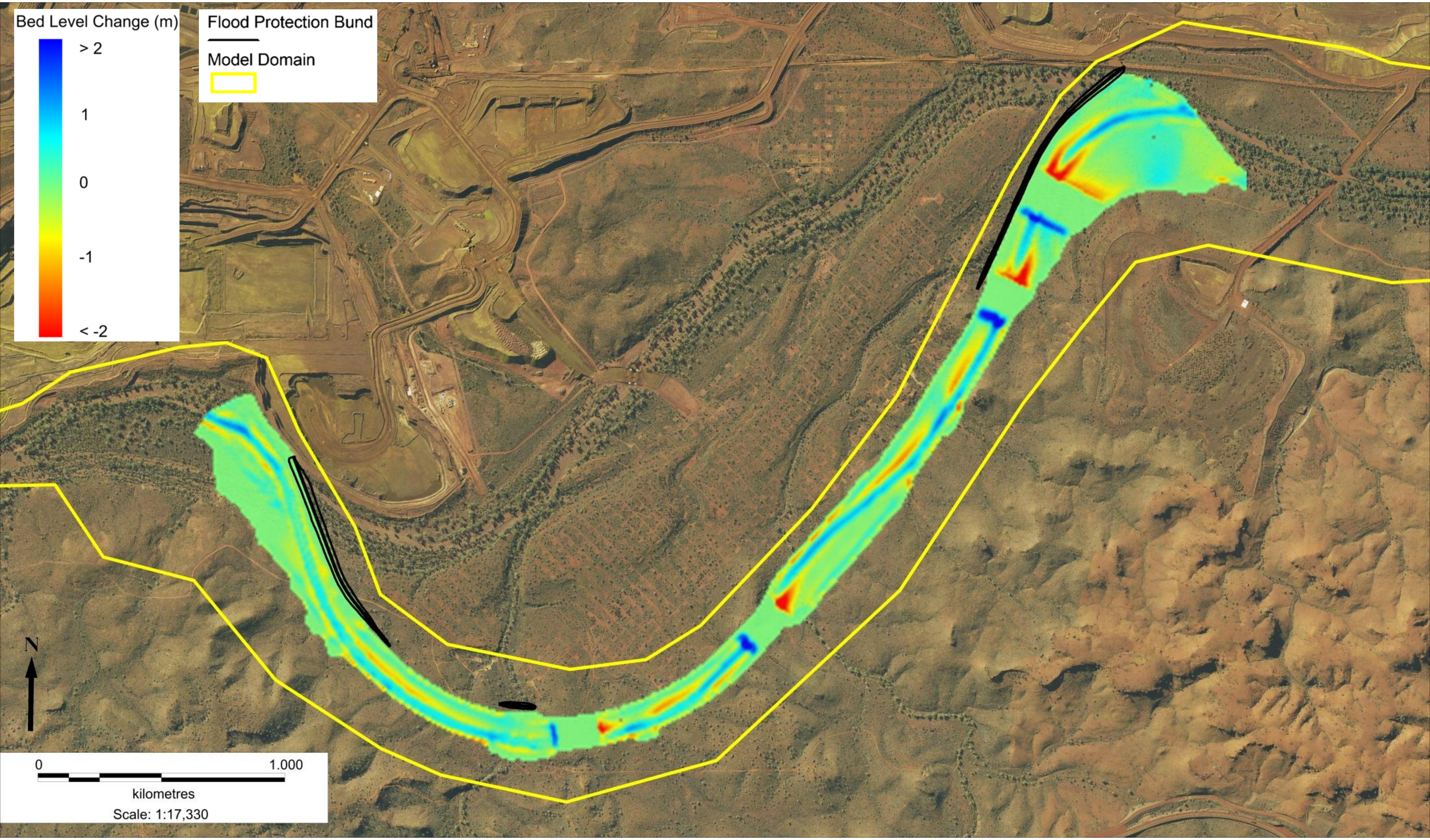
W3W5 – Meyer-Peter and Muller, D50 = 6 mm, With Rock Bars



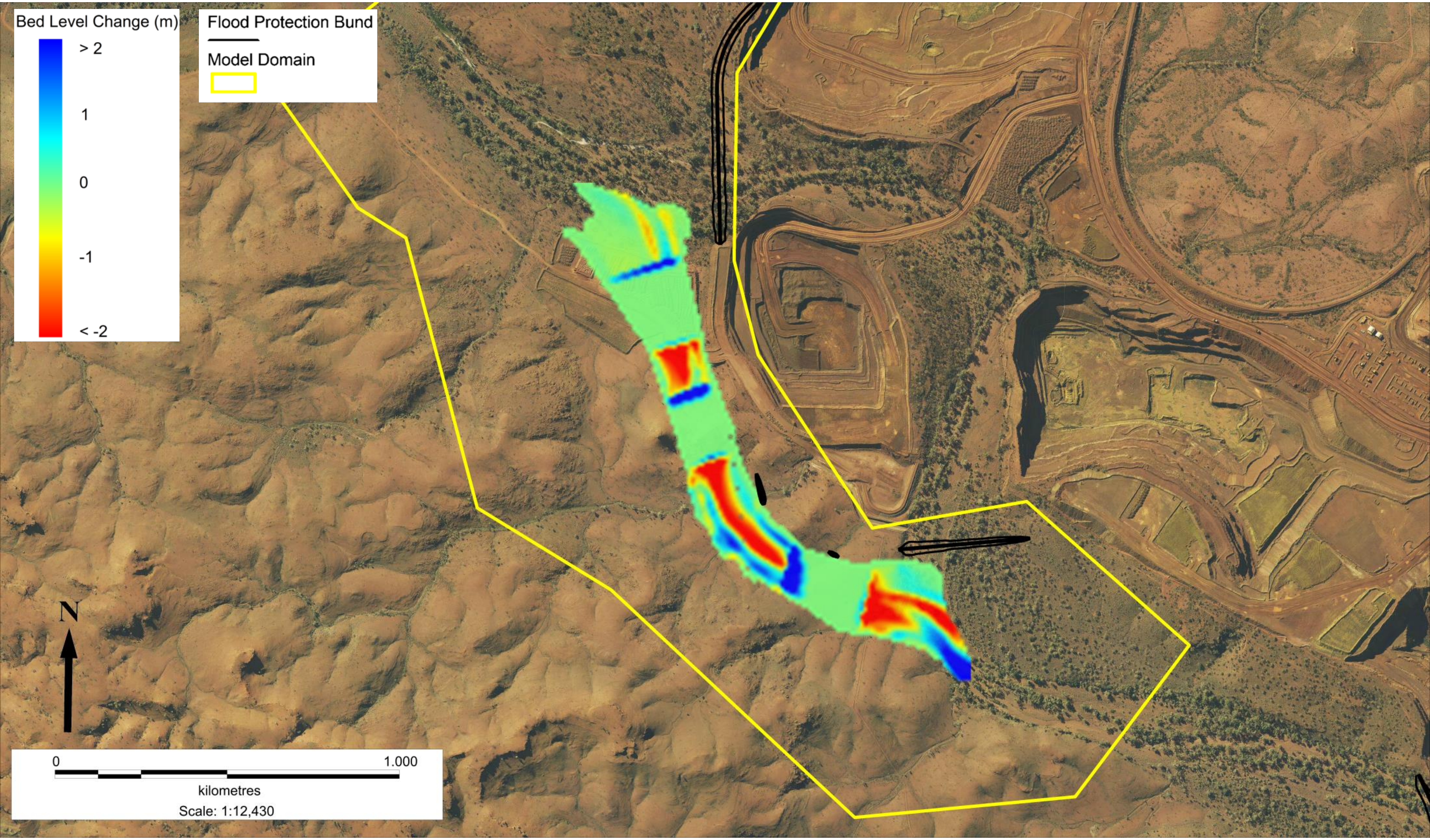
W3W5 - Engelund and Hansen, D50 = 20 mm, With Rock Bars



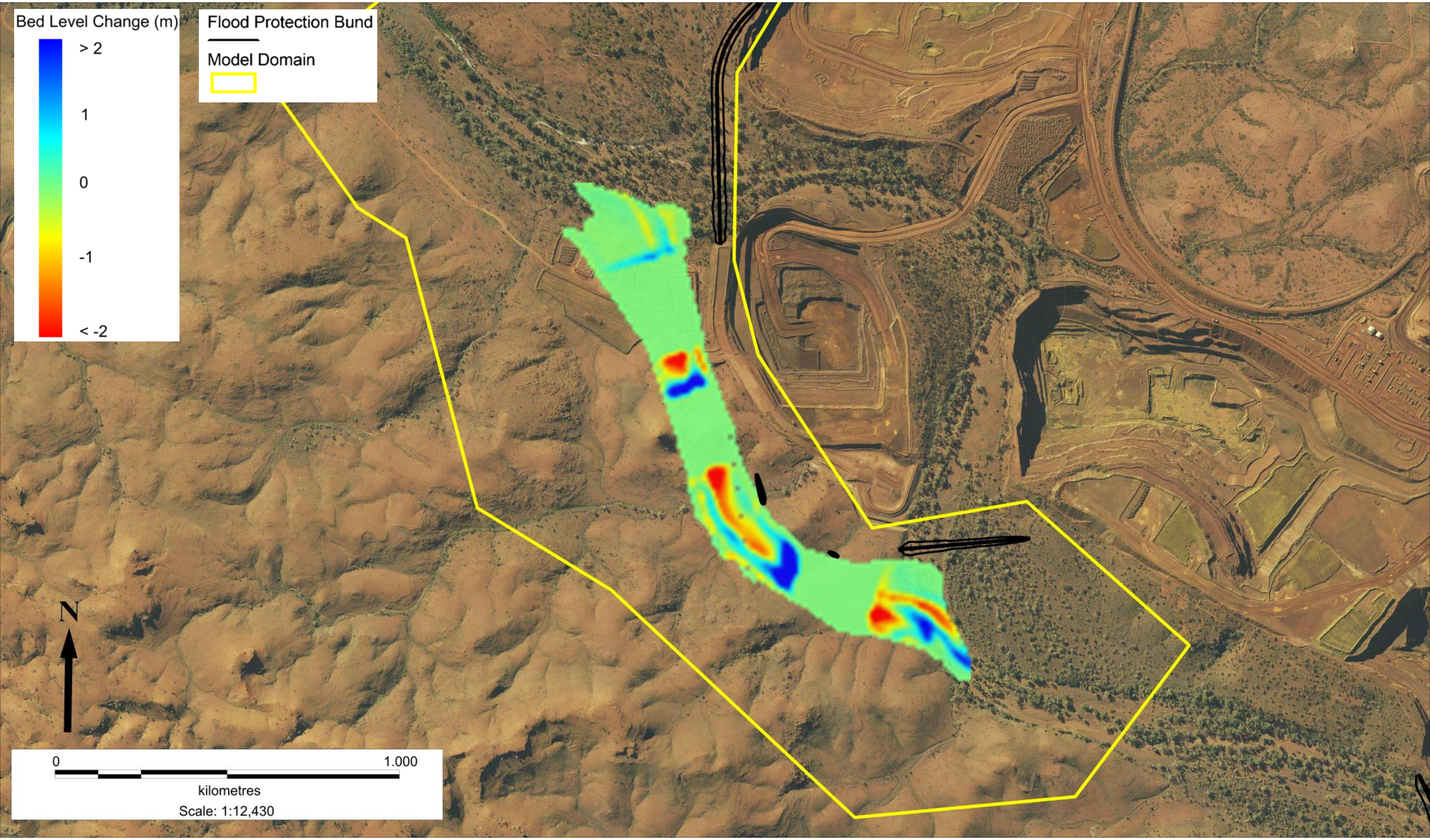
W3W5 – Meyer-Peter and Muller, D50 = 20 mm, With Rock Bars



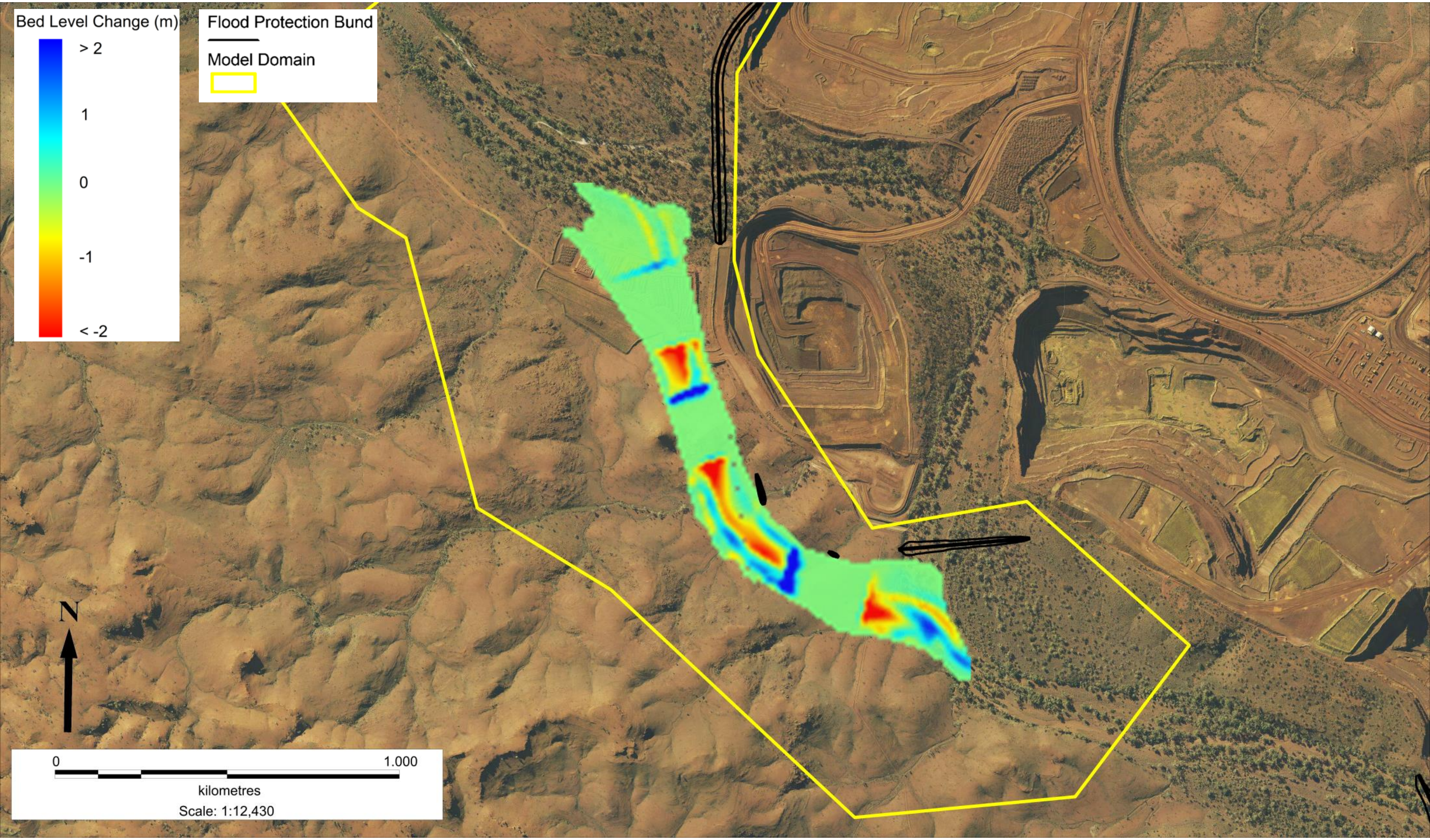
E1 - Engelund and Hansen, D50 = 6 mm, With Rock Bars



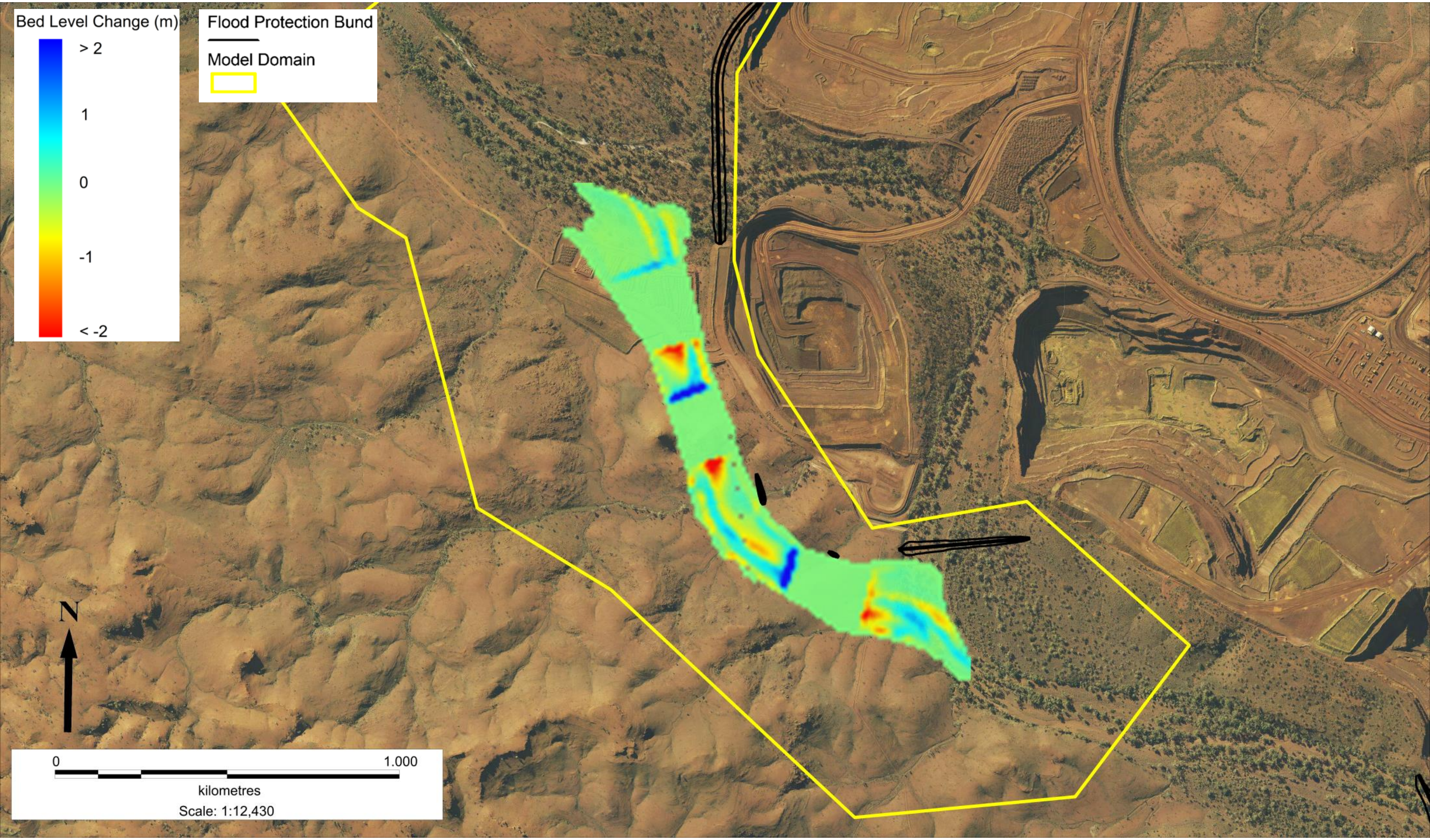
E1 – Meyer-Peter and Muller, D50 = 6 mm, With Rock Bars



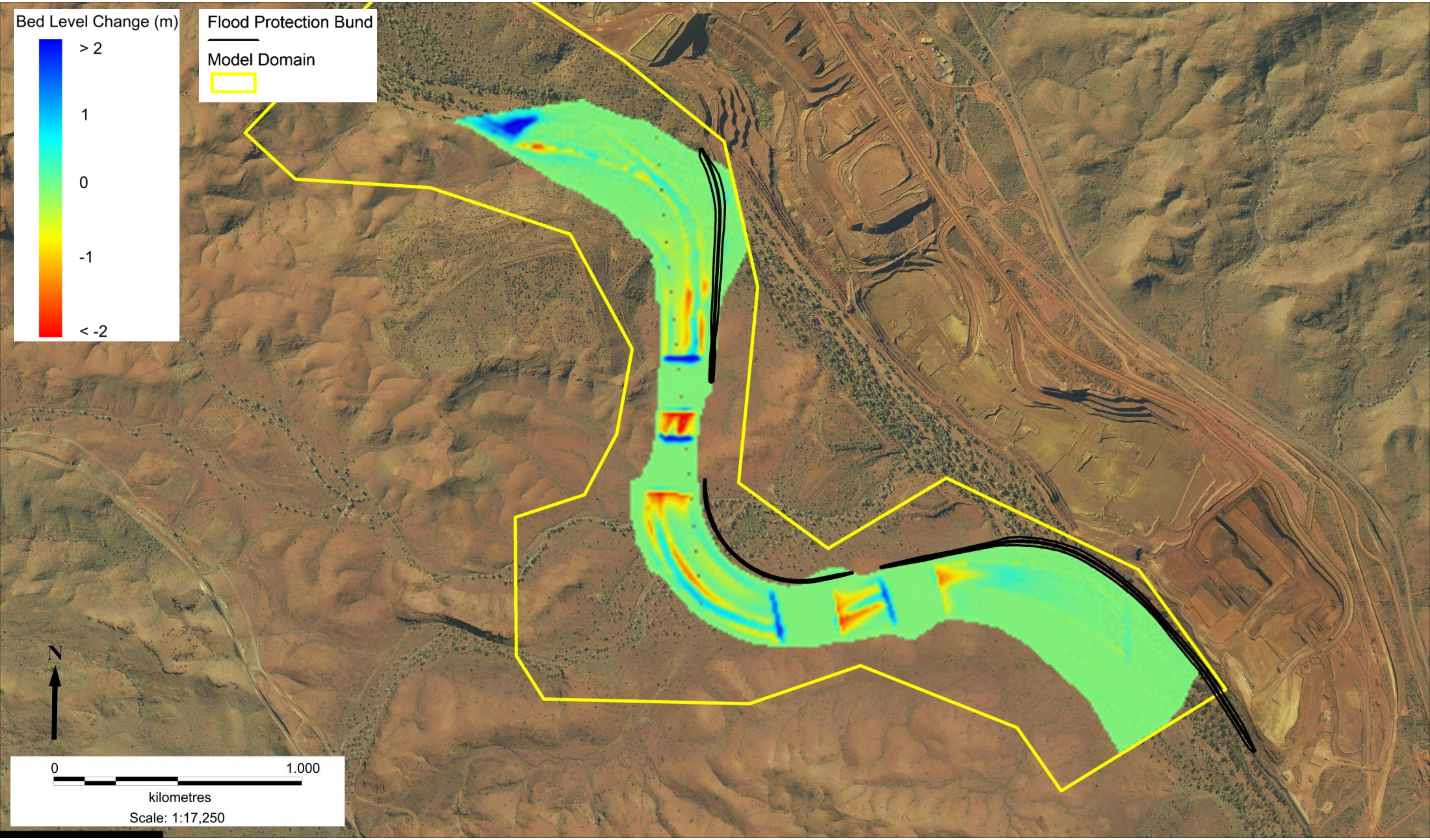
E1 - Engelund and Hansen, D50 = 20 mm, With Rock Bars



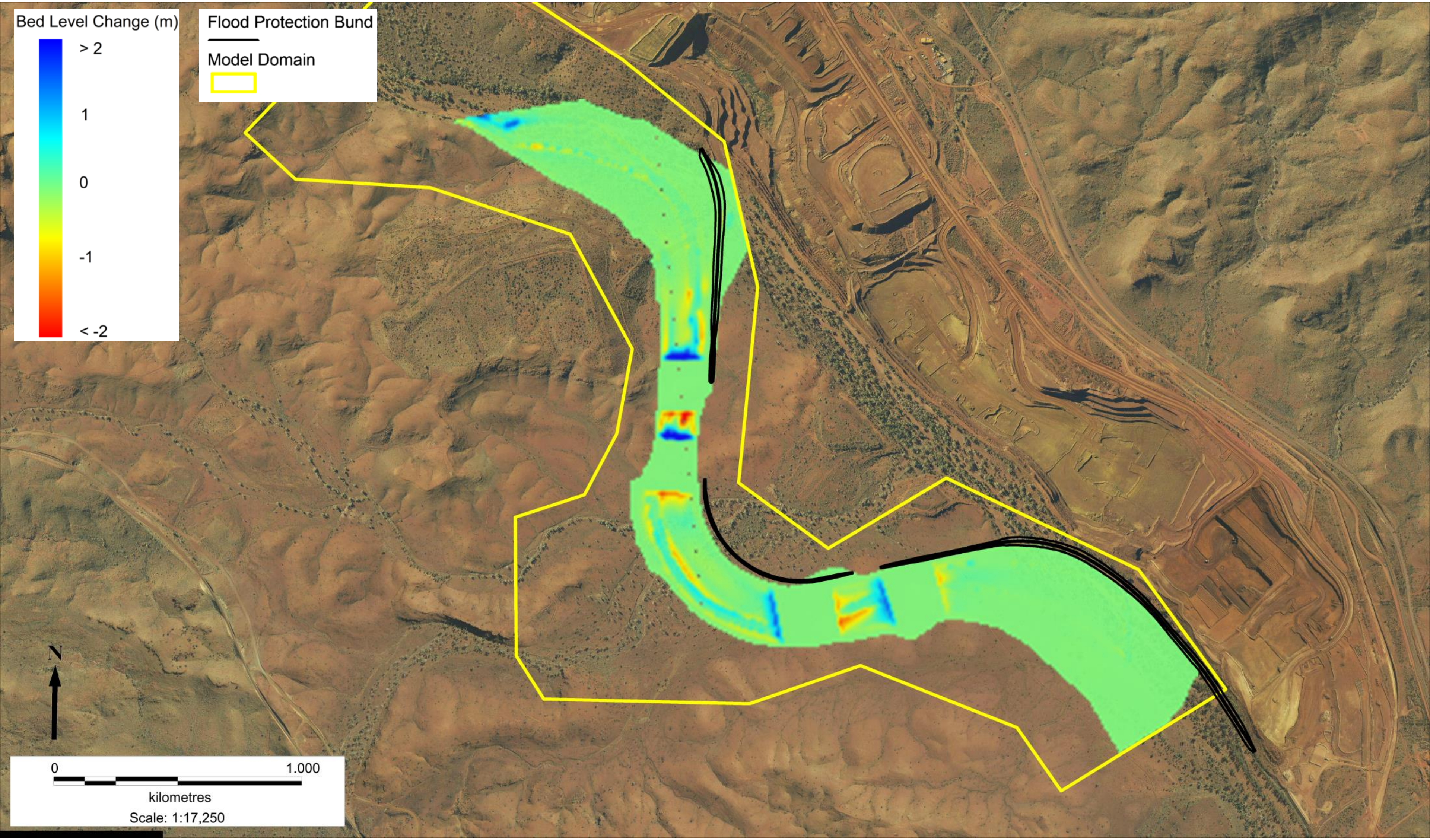
E1 – Meyer-Peter and Muller, D50 = 20 mm, With Rock Bars



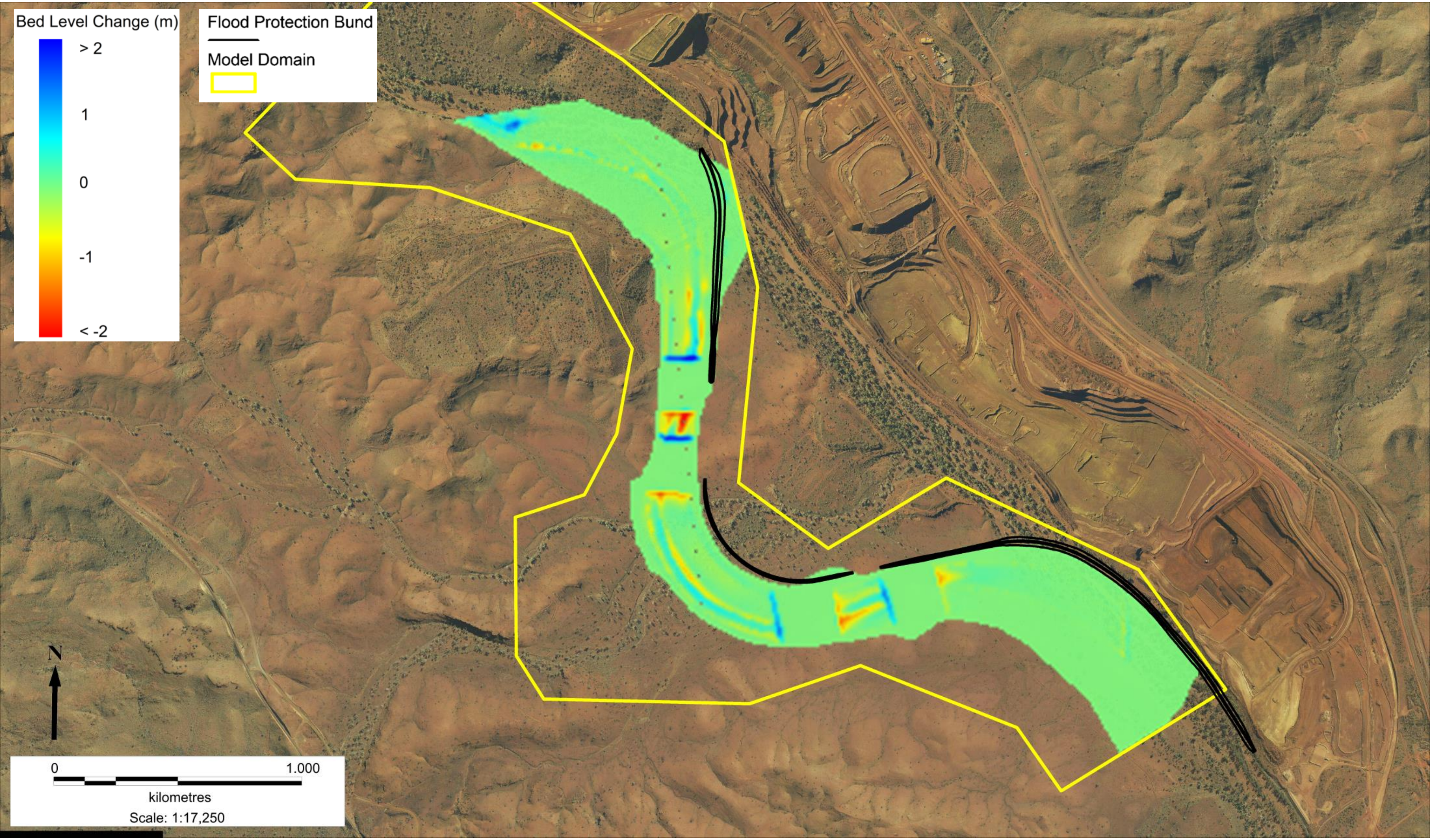
E4 - Engelund and Hansen, D50 = 6 mm, With Rock Bars



E4 – Meyer-Peter and Muller, D50 = 6 mm, With Rock Bars



E4 - Engelund and Hansen, D50 = 20 mm, With Rock Bars



E4 – Meyer-Peter and Muller, D50 = 20 mm, With Rock Bars