A.1. AQ2 vegetation establishment literature review

AQ2 (2020a) conducted a review of scientific literature addressing factors contributing to revegetation success in similar environmental contexts to the Yandi operations in conjunction with site visits to revegetation areas in the Yandi operations area (existing small creek diversions) and Ophthalmia Dam area (upstream and downstream of the reservoir). The results of this review are provided below.

The following key factors affecting seed germination and seedling establishment were identified:

- Favourable weather and climate sequences;
- Substrate characteristics;
- Seed sources / inputs;
- Seed dormancy;
- Seed predation and herbivory; and
- Competition with weeds.

Each of these are further discussed in the following sections. In compiling this information, consideration has been given to the attributes of keystone plant genera that are native to the Yandi locality and anticipated to be prominent in the revegetation of the Yandi mine voids. These include *Eucalyptus* tree species, *Acacia* shrubs and *Triodia* (spinifex) grasses.

Favourable weather and climate sequences

Studies in a variety of arid environments have linked plant germination and recruitment to defined conditions of favourable rainfall and temperature (Lewandrowski, Erickson, Dixon, & Stevens, 2016; Bowers, Turner, & Burgess, 2004). The Pilbara is characterised by a hot, dry climate where annual evaporation greatly exceeds annual rainfall and interannual rainfall variability is high. Vegetation recruitment tends to coincide with conditions that provide sustained moisture for seed germination and seedling development. Such conditions, referred to as 'recruitment windows', occur infrequently.

In a study of *Eucalyptus victrix* recruitment in Pilbara floodplain environments, Fox et al. (2004) found that the emergent seedling stage in this species is critical. Germination occurred readily, however many small plants subsequently died over the next 24 months. The observed mortality was principally attributed to a lack of persistent moisture, with herbivory (by insects and cattle) a secondary factor.

Once newly recruited individuals reached the sapling stage (i.e. 0.6 to 1.0 m in height) mortality rates were much reduced. By this stage, the saplings were presumably able to access more persistent soil moisture at depth and better able to tolerate herbivory. Thus, this species requires a combination of favourable climate sequence / hydrological regime and substrates with adequate water storage capacity to reliably establish. Similar observations have been made for *Eucalyptus camaldulensis* in the eastern states (Dexter, 1967; Roberts & Marston, Water regime of wetland and floodplain plants in the Murray-Darling Basin – A source book of ecological knowledge', Technical Report 30/00, 2000).

In arid zone *Triodia species*, high antecedent rainfall over a protracted period (12 months) is the primary driver of seed set (Wright, Zuur, & Chan, 2014). Lewandrowski et al. (2016) conducted plant establishment experiments using two prominent Pilbara spinifex species (*Triodia. epactia* and *T. wiseana*) involving different seed treatments to overcome dormancy factors and simulated rainfall regimes. A key finding was that recruitment potential, even from non-dormant seeds, was innately limited by rainfall. Even under the highest rainfall frequency and rainfall quantity combination, seedling emergence was limited to about 10%. The authors concluded 'The findings from this study strongly suggest that seedling recruitment in arid ecosystems such as the Pilbara is favoured by a period of continuous rainfall at which recruitment is successfully triggered from larger cyclonic rainfall events'.

The temperature regime during germination, seedling emergence and early growth can also impact on recruitment success. All plants are vulnerable to sublethal thermal effects on photosynthesis and other plant metabolic functions. This can affect growth rates and tolerance to other stressors. Extremes of hot or cold (e.g. in association with frost) can kill young plants. As an example, Roberts and Marston (2000) document seedling mortality in young *E. camaldulensis* seedlings caused by 'heat girdling' (i.e. heat injury caused by high temperatures at the soil surface).

Interactive effects of moisture, temperature and other factors affecting germination and growth (e.g. light, nutrients) are important. For example, many Pilbara species exhibit a temperature preference for germination that corresponds with the warmer summer months when sustained plant available moisture is more probable (Erickson, Seed dormancy and germination traits of 89 arid zone species targeted for mine site restoration in the Pilbara region of Western Australia, 2015). However, species responses to environmental cues may vary considerably even when putatively growing under the same conditions. For this reason, it is preferable to include a mix of species in restoration projects that collectively span a broad 'recruitment window' to maximise the opportunity for overall revegetation success.

Substrate characteristics

Australian arid zone soils including those in the Pilbara are highly weathered and leached, with low levels of available water and nutrients. Native vegetation will often spatially arrange into 'islands of fertility', characterised by heterogenous water accumulation and tight nutrient cycling beneath the canopies of long-lived perennial plants (Tongway & Ludwig, 1994; 2010). Specific vegetation patterns (e.g. clumping, banded vegetation etc) are influenced by surface conditions that affect the redistribution and infiltration of rainfall. Inherent variability across vegetated surfaces creates micro-niches where particular combinations of surface soil texture and structure, nutrient availability, shading and protection from the elements favour new plant recruitment.

Soil development has been recognised as a critical process in mining rehabilitation projects in Australia and elsewhere (Tongway & Ludwig, 2010). In general, mined landscapes create conditions that are sub-optimal for vegetation establishment and persistence without interventions to reinstate soil functional characteristics; including the retention of rainfall and organic matter, and the promotion of nutrient cycling. The presence of soil biota is indicative of highly functional soil, as soil biota contributes to the decomposition of vegetative matter and improved soil structure. In the Pilbara, ants and termites play an important role in this regard (He, Eldridge, & Lambers, 2018).

Actions found to improve the functional behaviour of soil substrates in degraded landscapes include (Tongway & Ludwig, 2010; Lewandrowski, Erickson, Dixon, & Stevens, 2016; Muñoz-Rojas, Erickson, Dixon, & Merritt, 2016; Garcia-Avalos, et al., 2018):

- Importation of non-toxic soil substrate materials (where available) to create a physical medium capable of supporting vegetation, or improve the water and nutrient retention properties of an in-situ medium (e.g. addition of clay to coarse substrates).
- Deep ripping, surface scarification and / or the creation of a network of runoff source and vegetated sink areas (micro-catchments) to facilitate water infiltration and storage in the vegetation root zone.
- Topsoil return, providing a source of seeds and soil biota (e.g. mycorrhizal fungi; biological soil crust taxa) as well as a physical substrate favourable for germination and plant establishment.
- Application of fertilisers and / or other soil amendments to support vegetation establishment and promote nutrient cycling. For example, mulches such as gravel, hay or woodchips have been shown to significantly reduce evaporation from soil surfaces (Tozer & Bradstock, 1997; Yuan, Lei, Mao, Liu, & Wu, 2009; Farzi, Gholami, Baninasab, & Gheysari, 2017; Li, Zhao, Gao, Ren, & Wu, 2018). Organic mulches also have the advantage of ultimately contributing organic matter to the soil. Although unlikely to be practical to apply in large volumes (for cost and logistical reasons), these materials can potentially be used to create 'island' niches for keystone species establishment.

Many native plants have adaptations to low soil fertility, such as the ability to fix atmospheric nitrogen (e.g. some Acacia species) or symbiosis with mycorrhizal fungi to enable soil nutrient uptake. However, in some situations, fertiliser addition may help to 'kick start' nutrient cycling where natural nutrient sources (e.g. topsoil) are lacking on rehabilitation surfaces.

Seed sources / inputs

The plants comprising native vegetation assemblages have a diverse range of seed dispersal mechanisms. Seed may be transported by water flows, wind or biological agents such as insects and vertebrate fauna. In arid landscapes persistent seed banks tend to develop, with germination and emergence not triggered until significant rains or disturbance events such as fire, flood or wind erosion / damage. Different species occupy different ecological niches with respect to seed production (quantity and frequency) and dispersal strategies. As an example, in the case of the riparian tree *Eucalyptus camaldulensis* seed dispersal is aided by the movement of floodwaters (Stefano, 2002).

Laboratory tests indicate that red gum seeds float for up to 36 hours. Consequently, the movement of water may deposit seed many kilometres from the parent tree. In some *Acacia* and *Triodia* species, ants play an important role in seed dispersal by burying the seeds and protecting them from predation (Willson & Traveset, 2000; Wright, Zuur, & Chan, 2014).

In highly disturbed landscapes, natural seed delivery processes may not be adequate for passive revegetation. Where so, these need to be supplemented by the artificial importation of seed or other plant propagules (e.g. seedlings). Particularly in mine site rehabilitation projects, topsoil importation is the primary strategy for simultaneously delivering seeds and a favourable growing medium that includes soil biota. The importance of topsoil for plant establishment, even when applied in diluted form, is well known and has been experimentally determined in Pilbara rehabilitation trials (Kneller, Harris, Bateman, & Muñoz-Rojas, 2018).

However, based on the Yandi topsoil materials balance, it is anticipated that topsoil availability for placement in the mine voids at Yandi will be severely restricted. When topsoil is not available, seed broadcasting either by hand or using purpose machinery is typically employed (Madsen, Davies, Boyd, Kerby, & Svejcar, 2016). Bulking agents (e.g. sand, bentonite, vermiculite) are commonly used to facilitate seed application[1], achieve better areal coverage and improve microsite creation for successful plant establishment. Hydromulching is an interesting technique that incorporates seed into a mulch slurry that can be sprayed directly to the surface using a ground based machine or aerial platform (i.e. a plane or helicopter); it may be particularly useful on steep slopes or rugged terrain that is otherwise difficult to access. Woodchip, sugar cane mulch and recycled paper are common materials used in hydromulches that provide moisture conservation in addition to controlled seed placement.

The use of nursery raised seedlings provides a means of bypassing the vulnerable germination and early establishment phase. This has particular relevance in arid environments with narrow and unpredictable plant establishment windows; highly efficacious seedling deployment systems have been developed for farmland revegetation projects in Western Australia and elsewhere. Seedling propagation also enables highly efficient use of limited seed. In mine site rehabilitation, seedlings are typically used to complement topsoil return and direct seeding methods, particularly for recalcitrant species that are otherwise difficult to establish. Disadvantages of seedlings include cost, the time taken to produce them (typically 6-12 months) and a requirement for additional ground preparation to enable transplanting in the field (e.g. deep ripping or excavation of planting holes).

In cases where seed procurement is necessary, either for direct seeding or the production of nursery seedlings, appropriate methods should be employed to ensure good seed viability and genetic integrity (Millar, Byrne, & Coates, 2008). In their review

[1] Especially for fine seeded species

of this subject, Broadhurst et al (2008) advocated 'capturing high quality and genetically diverse seed to maximise the adaptive potential of restoration efforts to current and future environmental change'. Various industry standards have been developed to guide appropriate seed collecting (for example those of the Revegetation Industry Association of Western Australia[2]).

Seed dormancy

The conversion rate of seed into mature plants, particularly for trees and shrubs, is invariably low in land restoration projects based on seed broadcasting (Yates, Hobbs, & Bell, 1996; Erickson, Seed dormancy and germination traits of 89 arid zone species targeted for mine site restoration in the Pilbara region of Western Australia, 2015; Lewandrowski, Erickson, Dixon, & Stevens, 2016; Setterfield & Andersen, 2018; Turner, et al., 2018). This has been attributed to a range of factors including:

- Constrained availability of suitable microsites or 'niches' for germination, emergence and growth;
- Seed dormancy factors;
- Environmental stresses (e.g. climatic); and
- Biological stresses (e.g. seed predation, competition with other plant species).

For a particular species in any given situation, one factor may have a dominant influence and therefore constitute a 'bottleneck' in the seed to plant conversion process (Turner, et al., 2018). In many cases the prevention of seed germination by physical and / or physiological inhibitors plays an important role.

Many Australian plant species exhibit seed dormancy, an evolutionary adaptation to the irregularity of conditions enabling plant recruitment over much of the continent. Dormancy enables seeds to persist for long periods in the soil, and facilitate emergence during optimal conditions (e.g. moisture and temperature) or following disturbance events that create more favourable establishment windows (Erickson, Seed dormancy and germination traits of 89 arid zone species targeted for mine site restoration in the Pilbara region of Western Australia, 2015). Variable dormancy within a species may also contribute to an expanded recruitment window, by increasing the chances of some individuals establishing under a variety of growing conditions. Failure to alleviate seed dormancy may lead to poor germination even during favourable rainfall seasons (Merritt, Turner, Clarke, & Dixon, 2007).

Fire is a key disturbance that interacts with seed dormancy. In many species, the physical and chemical effects of fire eliminate seed germination inhibitors. By damaging or eliminating extant vegetation, fire also reduces competition for emerging seedlings. The ash bed created by fires can also improve near surface soil water retention and mobilise plant available nutrients (Dexter, 1967; Yates, Hobbs, & Bell, 1996). In revegetation projects, it is often advantageous to accelerate germination and seedling establishment by applying seed treatments that alleviate dormancy (Erickson, Seed dormancy and germination traits of 89 arid zone species targeted for mine site restoration in the Pilbara region of Western Australia, 2015). Fire may also be used as a management tool to manipulate the recruitment trajectory of established vegetation.

Seed predation and herbivory

Seed predation and herbivory of young seedlings are important mortality agents in many revegetation contexts (Bowers, Turner, & Burgess, 2004; Majer, Brennan, & Moir, 2007). Seeds and young emerging seedlings are vulnerable to insects, vertebrate pests and pathogenic fungi. The protection of seed from predators and pathogens is implicit in modern agricultural and horticultural systems based on direct seeding methods.

In Australian tropical savannas, seed predation by ants has been documented to reduce the likelihood of seedling establishment from low to virtually zero (Setterfield & Andersen, 2018). Significant seed predation by insects and vertebrates has been observed in arid zone *Triodia* species (Wright, Zuur, & Chan, 2014).

Cattle, kangaroos, rabbits and other herbivores can significantly damage young plants, and the effects are often exacerbated during drought periods. In a study of regeneration patterns of the floodplain species *Eucalyptus coolabah* in arid South Australia, Roberts (1993) found that recruitment success correlated substrate type (saline vs non-saline) and floodplain topography that conferred protection from herbivores during the floodwater recession period.

Weeds

A weed can simply be defined as 'any unwanted plant'. Weed species typically have ecological attributes that enable them to readily germinate, establish and compete with native species. Consequently, weed species have the potential to prevent the establishment of, or progressively displace, native species in revegetation projects (Dorrough, Oliver, & Wall, 2018). Even with considerable management resources it can be difficult to prevent or reverse the impact of weeds once they encroach onto a restoration site. Detecting weeds in the early stages of invasion is the most cost-effective method of reducing further impact.

Weed species may be favoured by particular sequences of climate and disturbances (e.g. grazing, fire regime) that provide them with a competitive advantage. If these conditions do not arise, it is possible that weeds can occur in low numbers in rehabilitated landscape but remain non-problematic. However, if there is a shift in conditions, they may rapidly expand to the detriment of the

[2] Website http://riawa.com.au

native vegetation. In addition to directly competing with native species, some Pilbara weeds[3] have been linked to increased fuel loads and fire frequency which further contribute to the displacement of native species.

Despite the risk of deleterious effects, weed species can play an important role in the fixation of organic matter and stimulation of nutrient cycling in the early stages of rehabilitation. If managed appropriately in the early stages of rehabilitation, some weeds may therefore help to provide conditions that will ultimately enable a native vegetation assemblage to establish and persist.

Site visits

Site visits to revegetation areas in the Yandi operations area (existing small creek diversions) and Ophthalmia Dam area (upstream and downstream of the reservoir) were completed by Duncan Storey (AQ2) and Dan Huxtable (Equinox) on 2-3 October 2018. The purpose of the site visits was to characterise niche environments and regeneration processes supporting plant recruitment in these areas.

A description of the locations inspected, and key observations made during the site visits is provided in Table M-1.

Table A-1. Key observations made during site visits to the Yandi operation area and Ophthalmia Dam environs

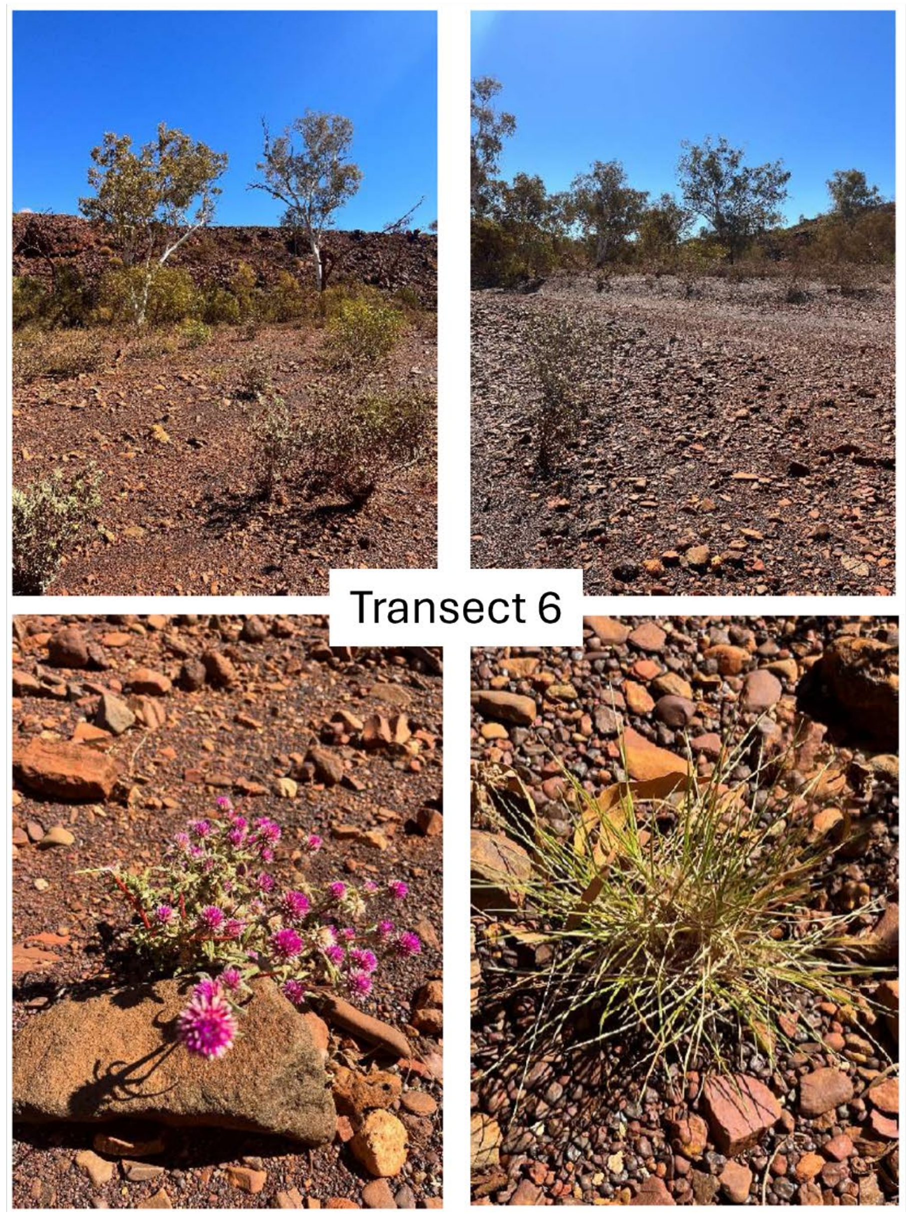
Site Descriptor	Observations
Site 1 Yandi E2 Pit wall	*Eucalyptus camaldulensis* trees (estimated age up to ≈6 years old) have established on a portion of the pit wall where groundwater seepage is occurring. Provides an example of the ability of this species to establish on relatively unfavourable substrates if persistent water is available. Also demonstrates that seed from this species is readily dispersed in the Yandi environment; it is likely that passive recruitment would occur in the Yandi mine voids if a favourable moisture regime were in place.
Site 2 Yandi Slims Creek (C5) Diversion	Passive recruitment of multiple species has occurred in the constructed diversion channel. Plant establishment correlates with micro-niches on the channel fringes and bed, in depressions where fine sediments and organic matter accumulate. The pattern of Eucalypt establishment correlates with flood line seed deposition zones on the channel fringes. These areas may also be less impacted by high energy flows in the channel proper that could kill young seedlings.
Site 3 Yandi W4 Diversion	The downstream portion of this constructed diversion channel was scoured to basement rocks. There was very little vegetation, however a few trees have managed to establish in micro-niches (e.g. cracks) protected from high energy flows where sediment has accumulated. This demonstrates the ability of local, native species to exploit small niches in marginal environments. In upstream areas with a flatter channel gradient, more sediment has accumulated providing a greater number of establishment niches. Multiple species have established in this zone. Larger Eucalypt trees are confined to the channel margins; this is probably a function of seed deposition on flood lines, less exposure to high energy flows and greater soil depth. In particular, it appears that the tree roots extend into the adjacent bank substrates.
Site 4 Yandi E2 rehabilitated overburden storage area	The E2 overburden storage area is a constructed mesa type landform that has been rehabilitated. The vegetation is about 20 years old. Specific rehabilitation methods have not been determined but probably involved topsoil return and possibly included some seed broadcasting. The established vegetation consists of a mixed *Acacia* species overstorey with a spinifex understorey that is structurally similar to adjacent native vegetation. Termite activity was noted, providing an indicator of functional nutrient cycling. A topsoil layer was also noted and provides evidence that natural soil formation processes are operating. The substrates comprising the overburden storage area are probably similar to the anticipated substrates in the mine voids. It is likely that similar a vegetation formation could be established in the mine voids where the groundwater is relatively deep (i.e. >10 mbgl).
Site 5 Ophthalmia North end of reservoir	*Eucalyptus camaldulensis* recruitment is clearly defined by flood line topography, where seeds are deposited. The frequency of flooding is important for enabling this species to establish. The oldest trees are located in the zones of lowest elevation above the permanent water line. This may reflect a climate sequence of less frequent flooding in the past, which suppressed expansion into upgradient areas. Non-waterlogging tolerant species (e.g. spinifex) may also help to prevent expansion upslope due to competition for moisture. Self-thinning of saplings is evident in the Eucalypt stands, as they equilibrate with available water supply and other site resources. As a general rule the older, more established trees outcompete the younger recruits.

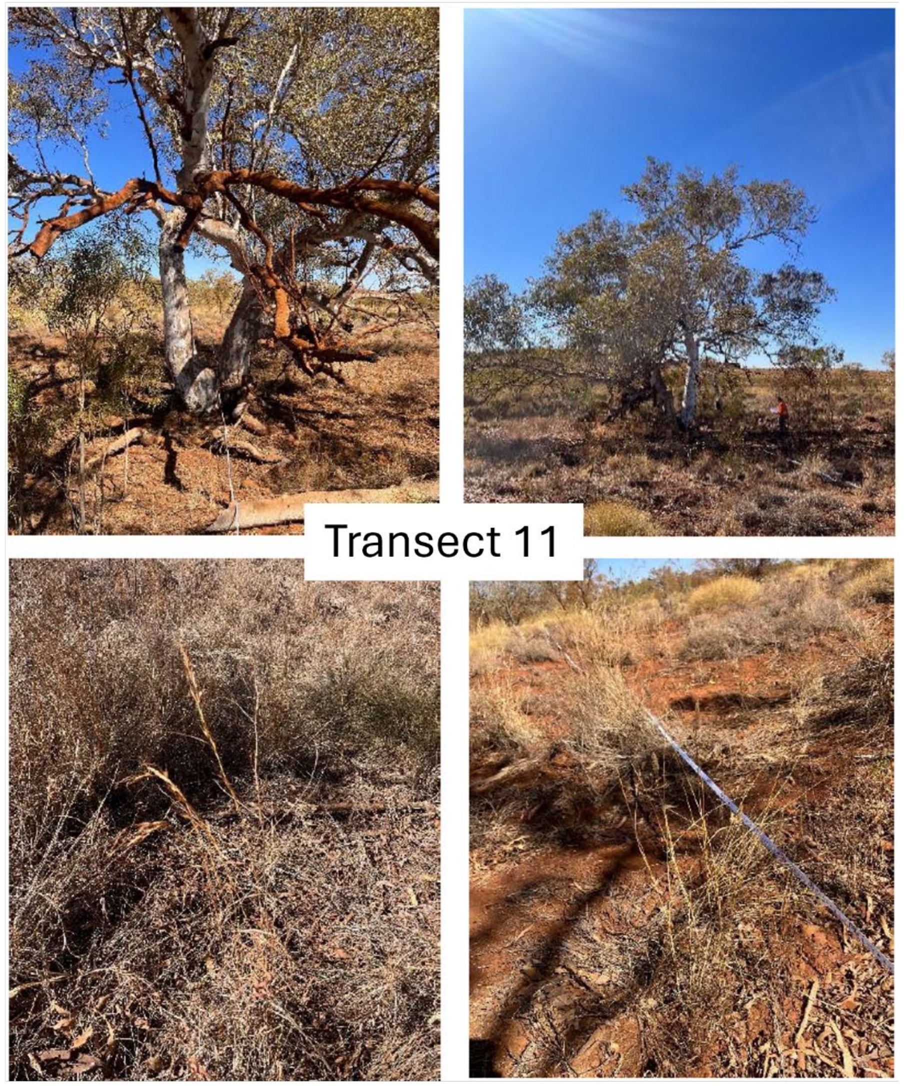
[3] Most notably Buffel Grass (*Cenchrus ciliaris*)

Site Descriptor	Observations
Site 6 Ophthalmia Discharge Outlet	The reservoir waterbody contains numerous dead Eucalypts that have been killed by prolonged flooding. This provides an example of the likely result if the mine voids become flooded for a protracted period. *Typha* reeds are passively colonising at the recently commissioned discharge outlet. This species has a strong propensity to establish at permanent waterbodies in the Pilbara and is probably dispersed by avifauna. If the mine voids include permanent pools it is likely that this species will passively establish; however, it dies out without permanent water. Where flooding is less prolonged (circa months), *E. camaldulensis* can develop adventitious roots (emanating from the stem) that enable it to tolerate waterlogged soils by enabling oxygen uptake. This was observed along the fringes of finger channels entering the reservoir.
Site 7 Ophthalmia – slot channel downstream from reservoir	Passive *Eucalyptus camaldulensis* recruitment has occurred in a constructed channel with a shallow calcrete base. Recruitment niches are associated with sediment traps, but the skeletal soil can only support a low density of trees. Tree roots are adept at proliferating into the available growing media, with larger trees associated with access to the channel bank sediments. Multiple, small dead seedlings were observed; indicating that although favourable germination niches occur in the channel, in many cases there is insufficient soil water holding capacity to enable these trees to persist and grow. Some insect herbivory of seedlings was also observed at this site.

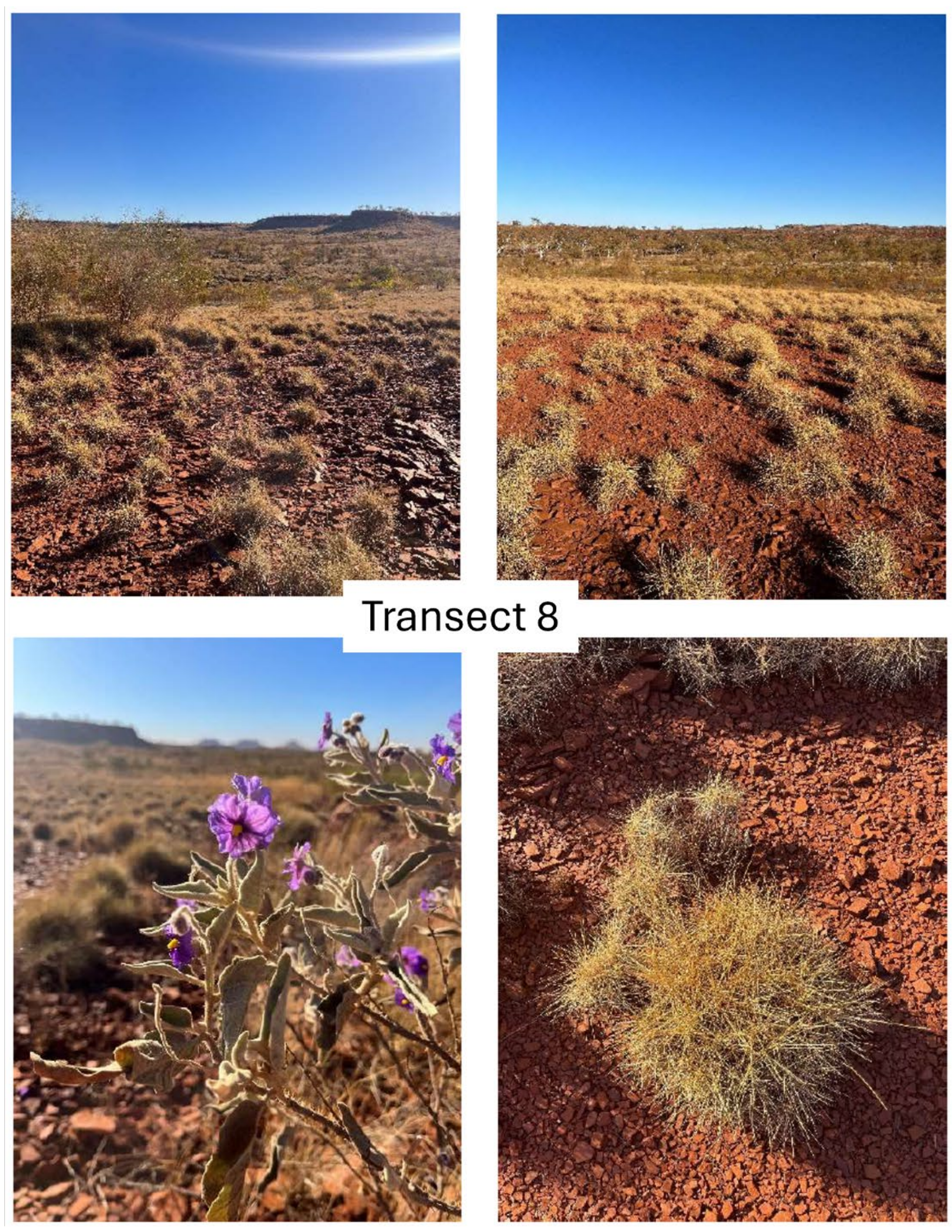
A.2. Representative photographs from 2023 Okane transects

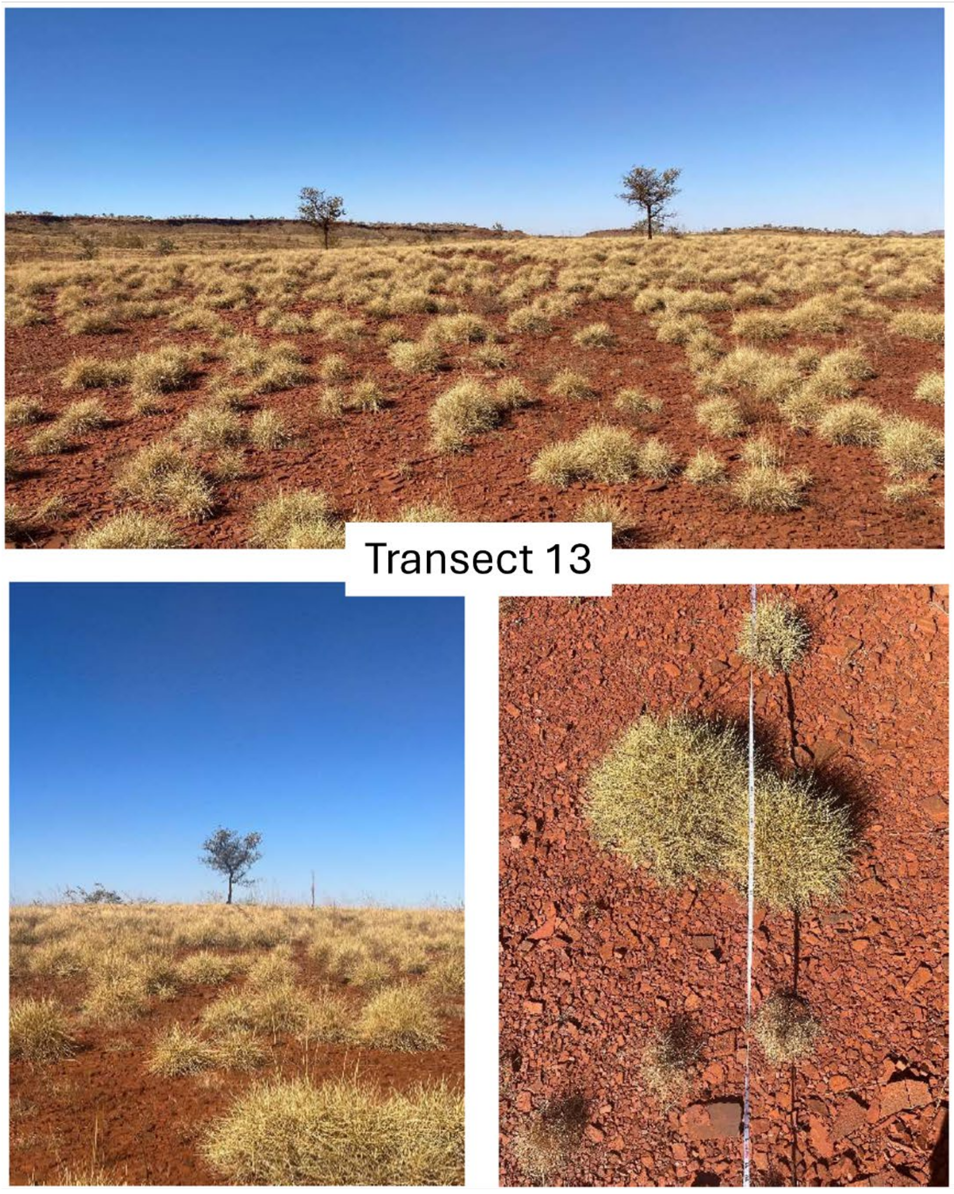
Riparian Zone



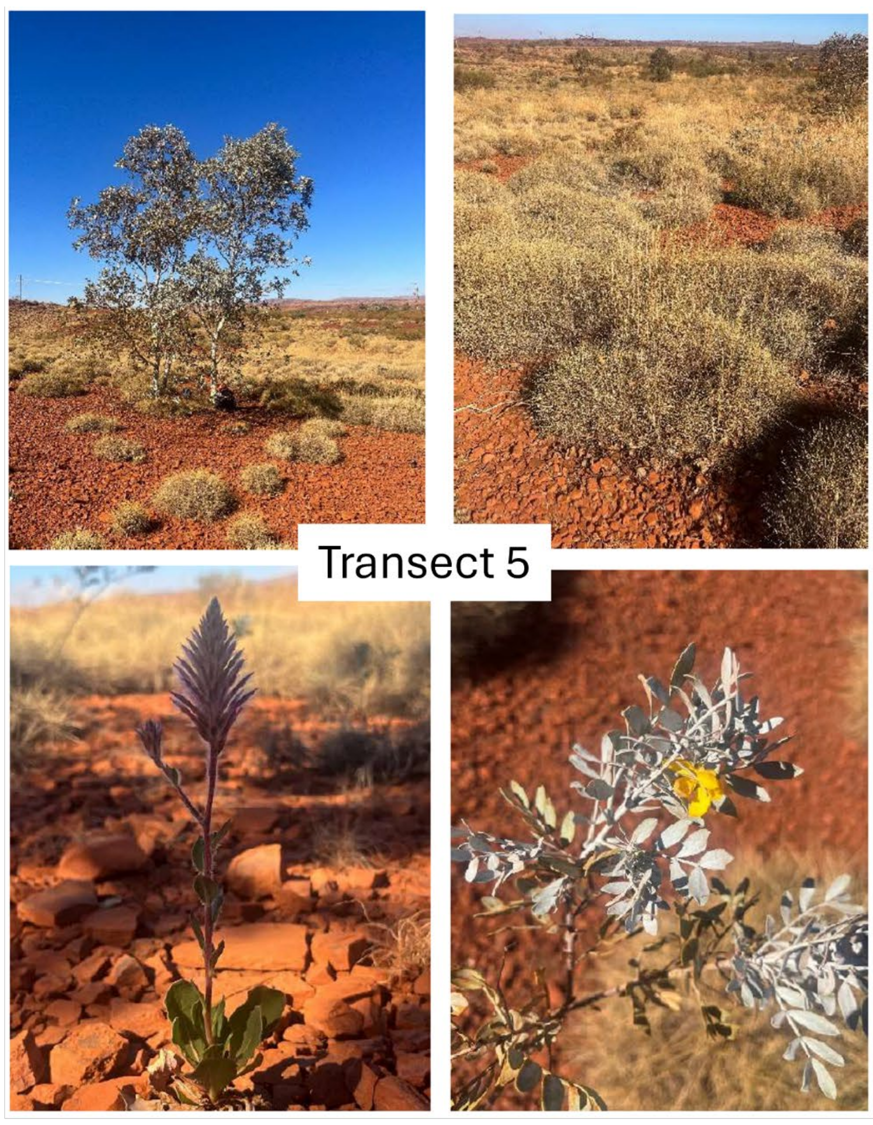


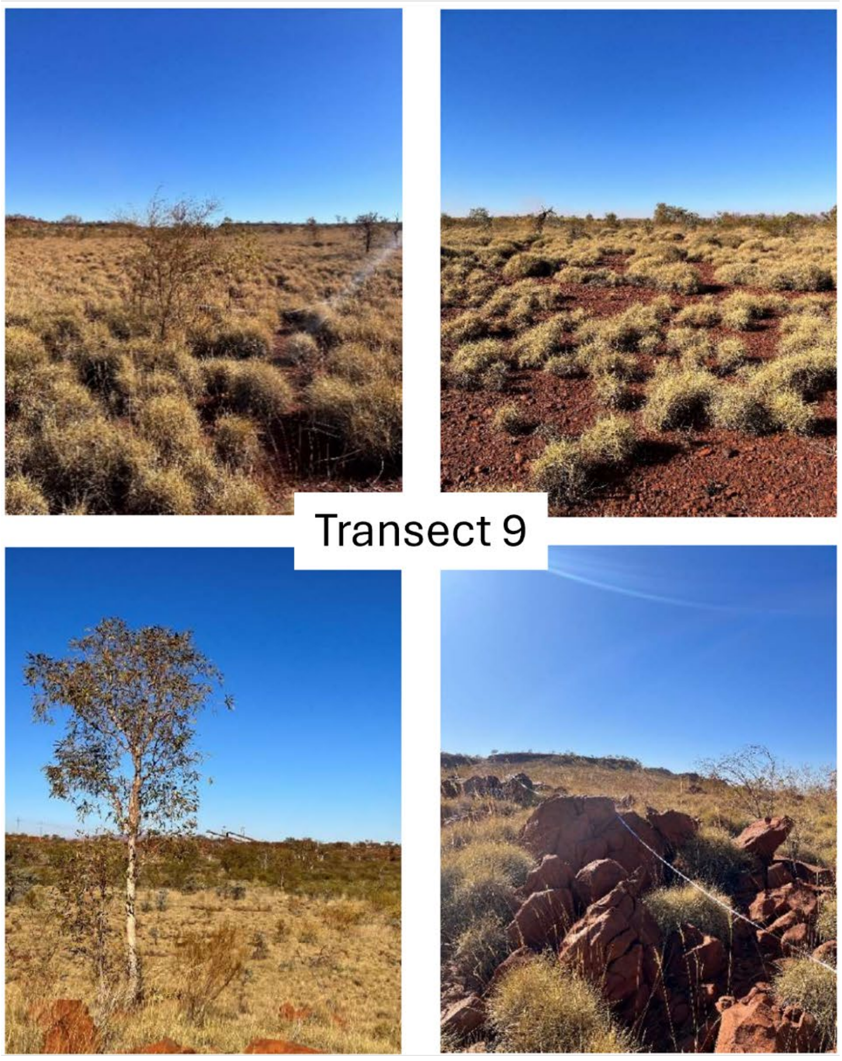
Crest zone



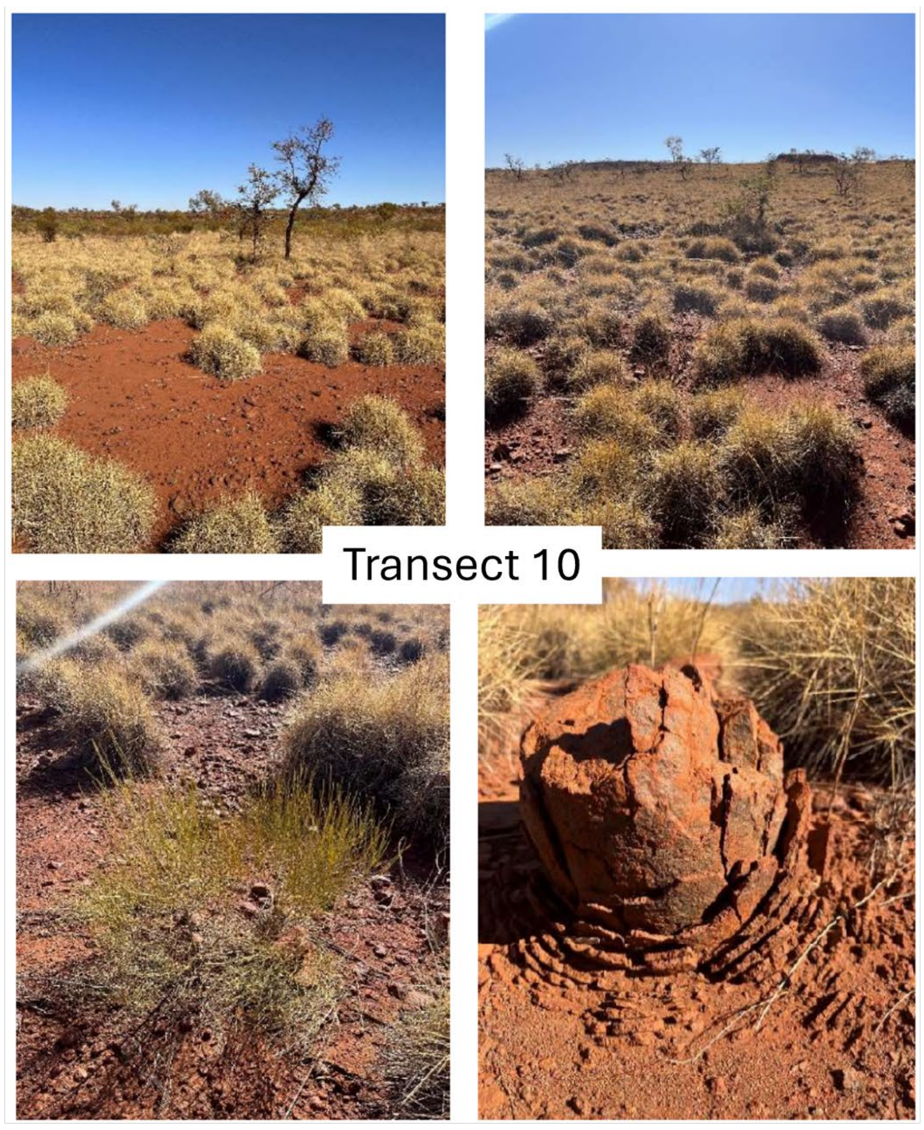


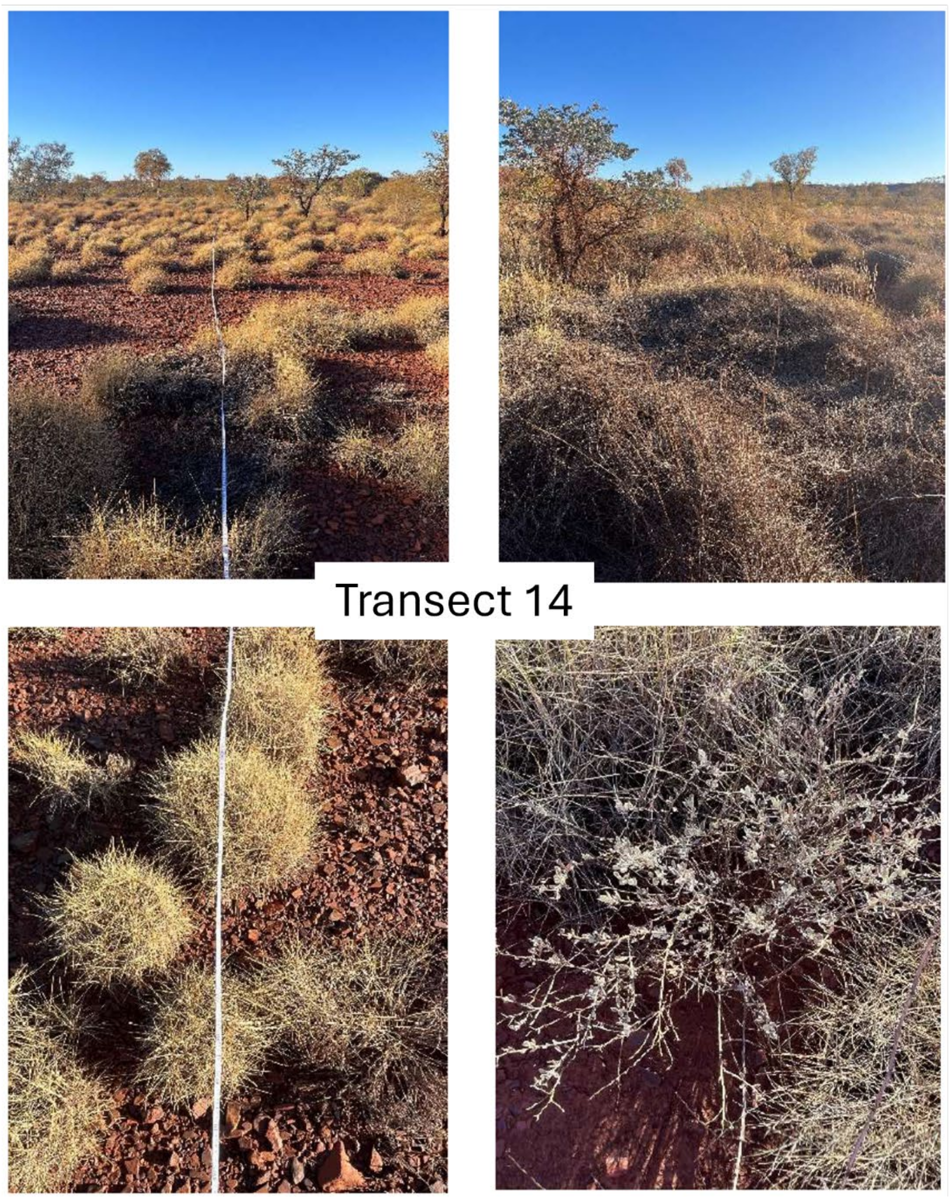
Slope zone

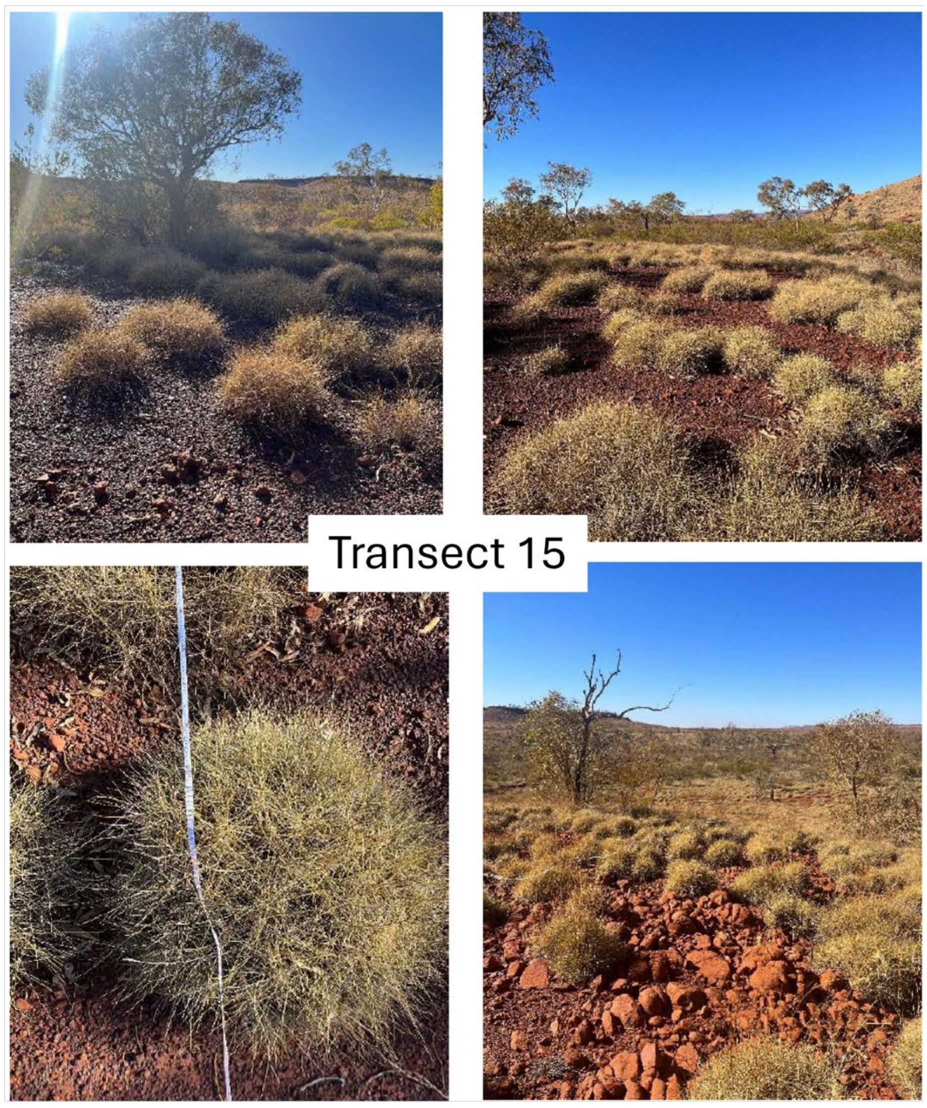




Plains zone







A.3. Indicator species and plant cover criteria

A.3.1 Indicator species for Marillana Creek diversions

Category	Species
Trees	*Eucalyptus victrix.*
	Eucalyptus camaldulensis subsp. *Refulgens.*
	Corymbia hamersleyana.
	Melaleuca argentea.
Lower Trees	*Atalaya hemiglauca.*
	Acacia citrinoviridis.
	Acacia coriacea subsp. *Pendens.*
	Acacia pruinocarpa.
	Acacia ampliceps.
Shrubs	*Melaleuca glomerate.*
	Gossypium robinsonii.
	Acacia pyrifolia.
	Acacia tumida var. pilbarensis.
	Acacia bivenosa.
	Acacia ancistrocarpa.
	Acacia monticola.
	Petalostylis labicheoides.
	Grevillea wickhamii.
Low Shrubs	*Corchorus crozophorifolius.*
	Tephrosia rosea var. Fortescue creeks (M.I.H. Brooker 2186).
Grasses	*Eulalia aurea.*
	Themeda triandra.
	Triodia longiceps.
	Triodia pungens.
	Eriachne tenuiculmis.

A.3.2 Current indicator species and cover targets for pastoral grazing land uses

Target Vegetation Types			**Grass Steppe**	**Shrub Steppe**	**Low Tree Steppe**	**Low Woodland**	**Riparian Woodland**
Indicator Species	Presence of dominant and common species from each Target Vegetation Type *Note, if more than one type is applicable, choose the most representative for each rehabilitated area*	At least one dominant species from each strata present >50% of common species present	Dominant Trees -	Dominant Trees *Corymbia hamersleyana*	Dominant Trees *Corymbia hamersleyana* *Eucalyptus leucophloia subsp.leucophloia* *Eucalyptus gamophylla*	Dominant Trees* *Acacia aneura* *Acacia ayersiana* *Acacia minyura* *Acacia paraneura* *Corymbia hamersleyana* *Eucalyptus leucophloia subsp. leucophloia*	Dominant Trees *Eucalyptus camaldulensis var. obtusa* *Eucalyptus victrix* *Melaleuca glomerata* *Melaleuca argentea*
			Dominant shrubs *Acacia tumida var. pilbarensis* *Acacia eriopoda* *Acacia ptychophylla* *Grevillea wickhamii*	Dominant Shrubs *Acacia bivenosa* *Acacia aneura* *Acacia inaequilatera* *Acacia pyrifolia* *Grevillea pyramidalis subsp. leucadendron* *Grevillea wickhamii* *Hybanthus aurantiacus* *Senna notabilis* *Senna glutinosa subsp. glutinosa*	Dominant Shrubs *Acacia ancistrocarpa* *Acacia atkinsiana* *Acacia bivenosa* *Acacia aneura* *Acacia hiliana* *Hakea chordophylla* *Hakea lorea* *Senna artemisioides* *Senna glutinosa subsp. glutinosa* *Senna pleurocarpa var. pleurocarpa* *Solanum lasiophyllum*	Dominant Shrubs *Acacia adoxa var. adoxa* *Acacia pruinocarpa* *Acacia tenuissima* *Eremophila spp.* *Grevillea wickhamii* *Hakea chordophylla* *Hybanthus aurantiacus* *Indigofera monophylla* *Senna artemisioides subsp. oligophylla* *Senna glutinosa subsp. glutinosa*	Dominant Shrubs *Acacia ampliceps* *Acacia pyrifolia var. pyrifolia* *Atalaya hemiglauca* *Crotalaria novae-hollandiae subsp. novae-hollandiae* *Cymbopogon ambiguus* *Cyperus vaginatus* *Gossypium robinsonii* *Indigofera monophylla* *Petalostylis labicheoides*
			Dominant Grasses: *Triodia basedowii* *Triodia epactia* *Triodia pungens* *Triodia schinzii*	Dominant Grasses: *Triodia wiseana* *Triodia basedowii* *Triodia pungens* *Triodia vanleeuwenii* *Triodia epactia*	Dominant Grasses: *Triodia wiseana* *Triodia basedowii* *Triodia schinzii* *Triodia vanleeuwenii* *Eriachne pulchella subsp. pulchella*	Dominant Grasses: *Triodia basedowii* *Triodia pungens* *Triodia wiseana* *Aristida spp.* *Cymbopogon spp.* *Eriachne pulchella subsp. Pulchella*	Dominant Grasses/Sedges: *Aristida spp.* *Enneapogon spp.* *Eragrostis spp.* *Eriachne mucronata* *Eriachne tenuiculmis* *Themeda triandra*
Plant Cover	% cover for each strata and each Vegetation Type to be > Q1 for relevant reference sites	Trees	>0	>1	>1	>2	>10
		Shrubs	>0.1	>3	>2	>2.6	>2
		Hummock grasses	>15	>19	>20	>17	>2
		Other grasses	>0.01	>0.02	>0.04	>0.2	>2
		Herbs	>0.1	>0.1	>0.05	>0.06	>2
Species richness	Perennial native species richness to be >Q1	No. perennial species recorded in aggregated 50 x 50 m plots	>8	>15	>16	>28	>14

*Note: the mulga group (*Acacia aneura* group) are classed as trees only in the Low Woodland Vegetation Group.

Appendix B Existing rehabilitation

B.1. Marillana Creek E1 & E4 diversion design study

The Marillana Creek diversion design objectives were documented in the Marillana Creek Diversion Management Plan (BHP Billiton, 2016) and are outlined in Table N-1. These objectives have been incorporated into the MCP objectives and completion criteria.

Table B-1. Marillana Creek diversion design objectives

Category	Objective
Hydrology	Surface water flow volumes are sustained 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

Source: BHP Billiton (2016)

The Marillana Creek Diversion Management Plan (BHP Billiton, 2016) outlined the concept designs for the creek diversions. A series of studies (Advisian, 2017a; 2017b; 2017c; 2019; AQ2, 2017) then followed to guide the development of detailed designs for the diversion. Key aspects considered in the studies were the impact of the diversion designs on the hydraulic regime in Marillana Creek and the diversions themselves, sediment transport, geomorphology (refer to Appendices N.1.2 to N.1.10) and factors affecting shallow aquifer design (alluvium characteristics and vegetation). The studies considered both operational and closure conditions.

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.

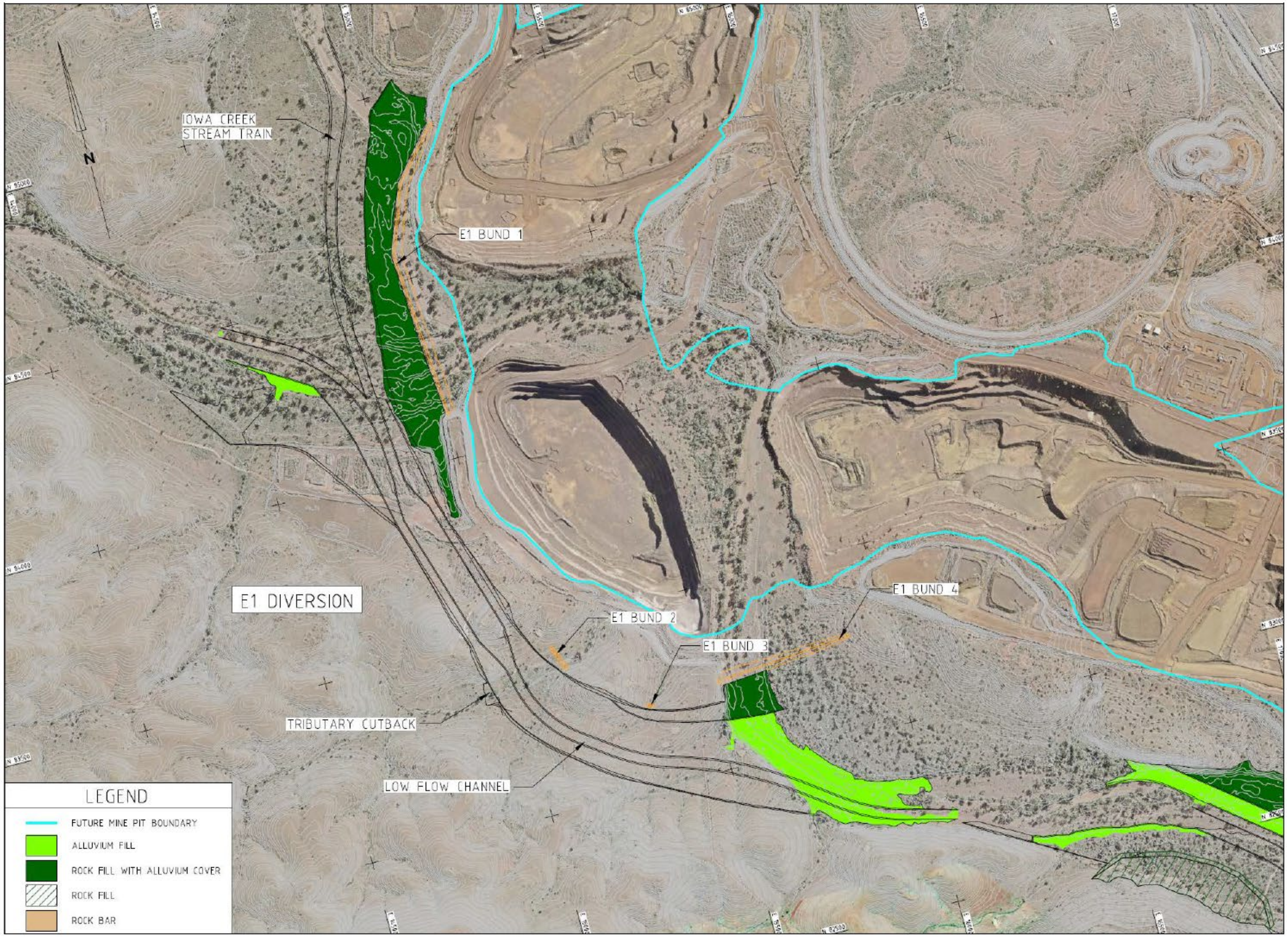
The overarching design approach was to reference the form and function of Marillana Creek in the diversions as far as practicable. Key attributes specified as a basis of design included planform type, width, depth, slope, sediment depth and roughness. While it did not attempt to exactly replicate the existing creek, the design aimed to achieve ranges seen in the natural system (i.e. similar hydraulic and sediment-transport characteristics) (BHP Billiton, 2016).

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 (Alluvium, 2016).

The final design of the Marillana Creek diversions is described in Advisian (2017e). Key elements of the design are outlined in the sections below. Figure N-1 and Figure N-2 show the layout of the diversions.

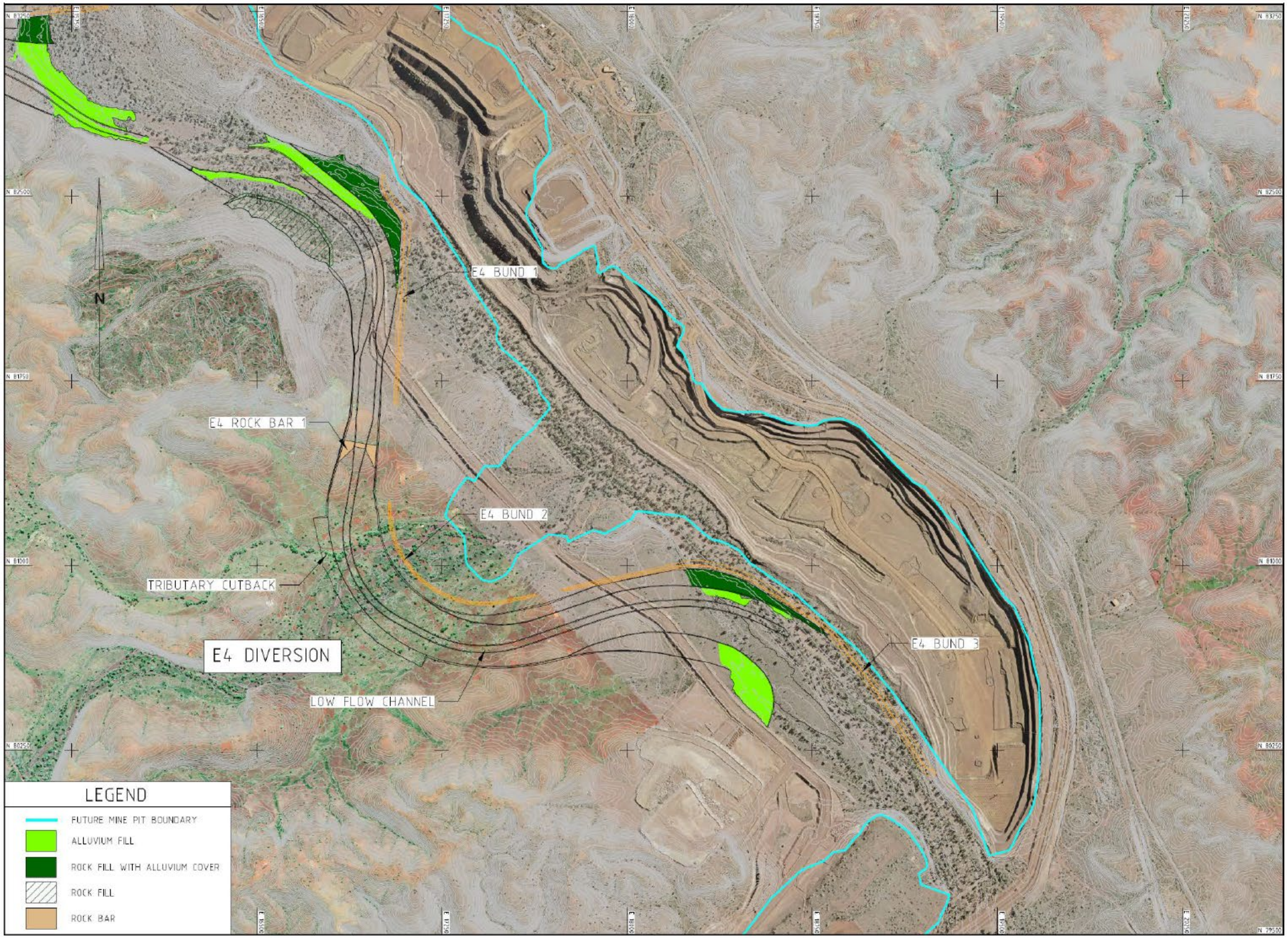
B.1.1 Location and alignment

The alignment of the diversion designs was based on seeking the shortest route around the closure pit setbacks whilst maintaining similar channel curvature and alignment to the existing Marillana Creek system. The alignments were checked against environment and heritage registers and no significant issues / conflicts were identified.



Source: Advisian (2017e)

Figure B-1. E1 creek diversion layout

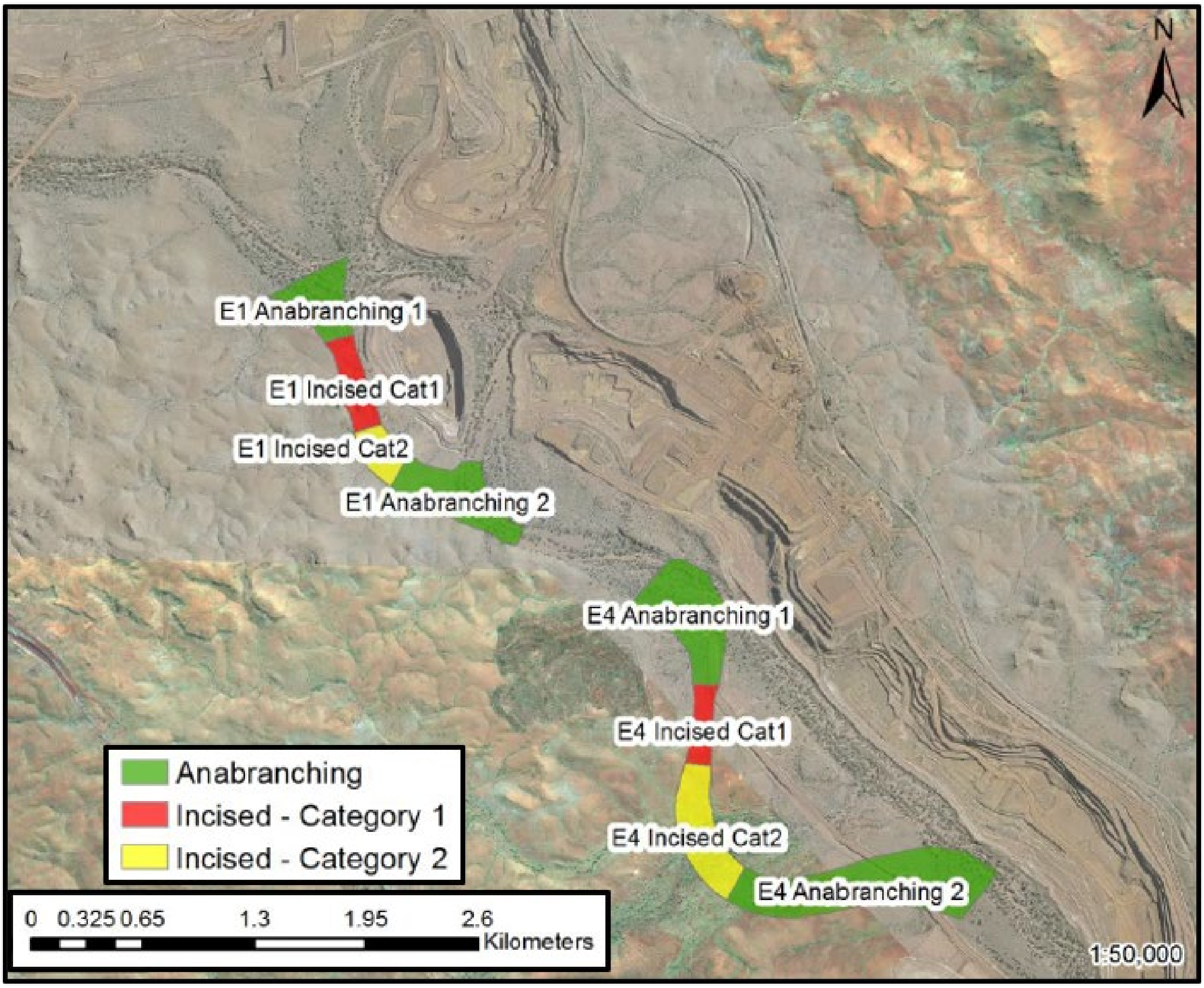


Source: Advisian (2017e)

Figure B-2. E4 creek diversion layout

B.1.2 Geomorphology

The length of 'anabranching' and 'incised' reaches were selected to achieve similar proportions observed in the existing Marillana Creek system (Figure N-3). 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 (BHP Billiton, 2016).



Source: Advisian (2017a)

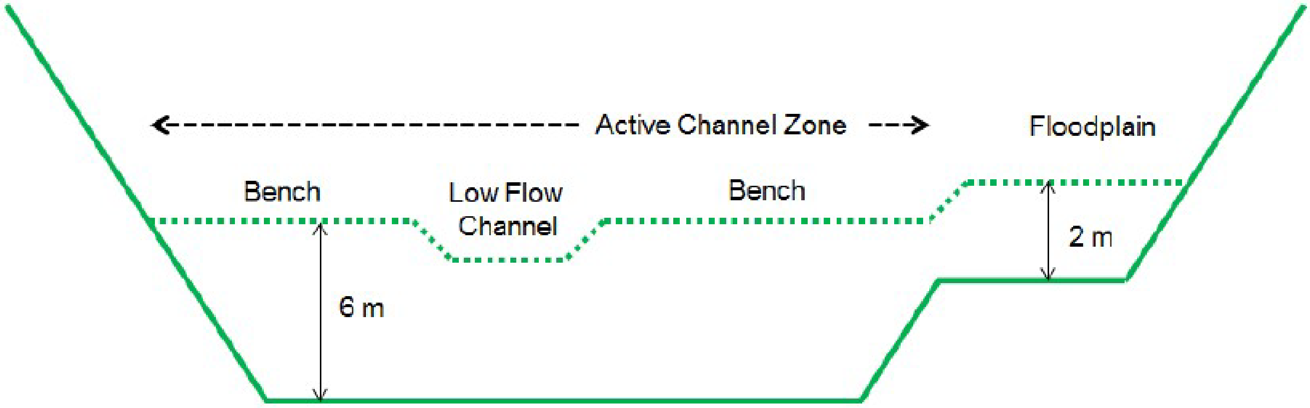
Figure B-3. E1 & E4 creek diversion reach types

The diversion channel geometry adopted for the 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. 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 (BHP Billiton, 2016). Anabranching reaches consist of a primary channel situated within an 'active channel zone' and at least one elevated floodplain (Figure N-4). Incised category 1 reaches consist of a flat, wide central channel and elevated benches at both margins of the channel (Figure N-5), and incised category 2 reaches consist of a primary channel situated within an active channel zone only (Figure N-6) (Advisian, 2017e).

The active channel in anabranching reaches is the area over which multiple channels and vegetated ridges are expected to form over time and is generally inundated by the 2-year ARI flood. The active channel zone was designed to have a minimum width of 120 m based on the analysis of the existing Marillana Creek system.

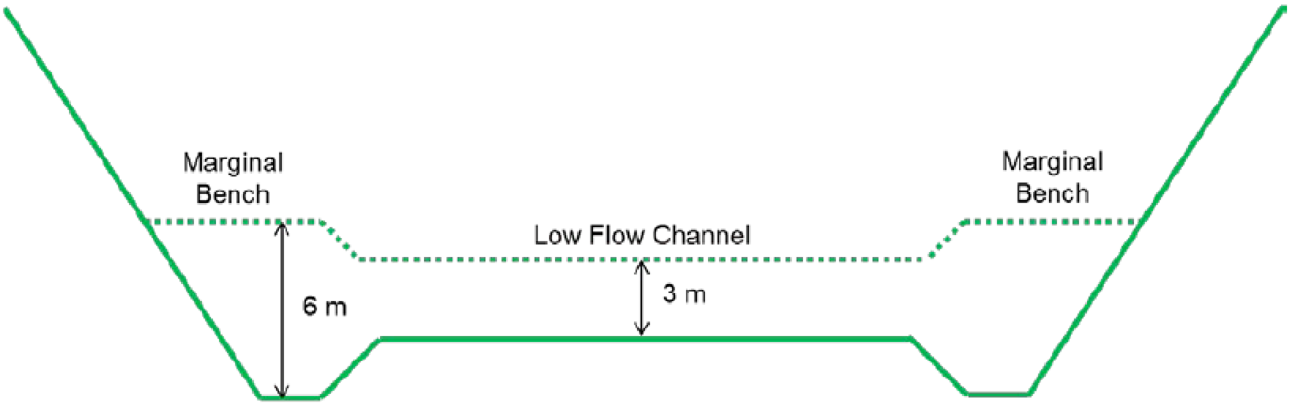
Incised category 1 reaches include elevated benches at both margins of the diversion. The width of these benches was set to 20 m based on analysis of the existing creek system. They are included to provide a suitable medium in which trees can be sustained (Advisian, 2017e).

A low flow 'seed' channel was included in the diversion designs to replicate the form of the primary low flow channel in the existing Marillana Creek. The dimensions, sinuosity and curvature of the seed channel design were based on the geomorphological characteristics of the primary low flow channel in the existing Marillana Creek. The width of the seed channel is 25 m with a nominal depth of 1 m, except in incised category 1 reaches where it is 60 to 80 m wide. The seed channels for each diversion tie-in with the primary low flow channel in Marillana Creek.



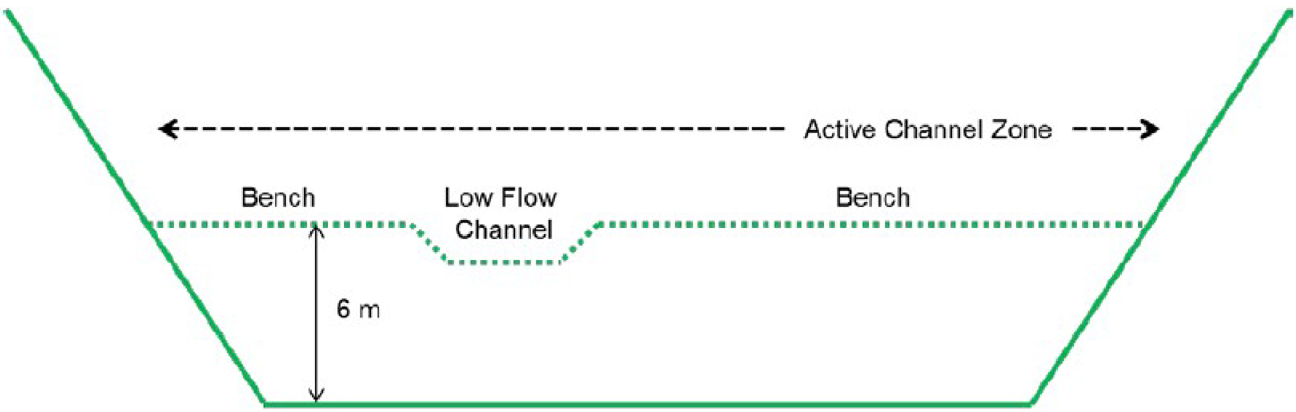
Notes: dotted green line represents the surface of alluvial material placed within the excavated channel (refer to Section N.1.8 for discussion)
Source: Advisian (2017e)

Figure B-4. Anabranching reach geometry and engineered aquifer cross section



Notes: dotted green line represents the surface of alluvial material placed within the excavated channel (refer to Section N.1.8 for discussion)
Source: Advisian (2017e)

Figure B-5. Incised category 1 reach geometry and engineered aquifer cross section



Notes: dotted green line represents the surface of alluvial material placed within the excavated channel (refer to Section N.1.8 for discussion)
Source: Advisian (2017e)

Figure B-6. Incised category 2 reach geometry and engineered aquifer cross section

The optimised reach widths and gradients are summarised in Table N-2. The first anabranching reach of the E1 diversion was designed to be slightly steeper than the average gradient to reduce the backwater effect caused by the narrower incised category 1 reach immediately downstream (Advisian, 2017e).

Table B-2. Marillana Creek diversion reach widths and gradients

Diversion	Reach	Width	Gradient
E1	Anabranching	> 120 m	0.30%
	Incised - Category 1	120 m	0.23%
	Incised - Category 2	180 m	0.23%
	Anabranching	> 180 m	0.23%
E4	Anabranching	> 110 m	0.14%
	Incised - Category 1	110 m	0.14%
	Incised - Category 2	200 m	0.19%
	Anabranching	> 200 m	0.19%

Source: Advisian (2017e)

To avoid the risk of slope failure partially blocking the diversion, cut slopes were generally designed to achieve a FoS of 1.5 for static conditions. However, they were also designed to be sufficiently steep such that, over the long term, localised failures (slip surfaces <1.5 m deep) occur, which will be beneficial for the fluvial system. A FoS of 1.0 to 1.2 was targeted for local stability to allow some localised failures to occur over time.

Potential for lateral migration of the main channel

Advisian (2017b) assessed the risk of lateral erosion in areas of cut leading to connection of the Marillana Creek diversions and pit and concluded that:

- The distances between the walls of the diversions and the pits and estimated lateral erosion rates are such that there is a low risk of lateral erosion leading to connection of the diversion and pit.
- The mechanism most likely to cause connection of the diversions and pits is the collapse of a pit wall rather than erosion of in-situ rock by diversion channel migration or widening. To address this risk, pit setback distances, defining the safe distance between the diversion and final expected mine voids, have been calculated, and the diversion designs developed to ensure they sit outside the pit setbacks.
- The very narrow width of the existing walls of in-situ rock between Marillana Creek and the pits presents a greater risk than the wider walls of in-situ rock between the E1 and E4 diversions. These areas have been found to have a FoS > 1.5.

Advisian (2017b) assessed the mobility of anabranches and low flow channels and concluded that some readjustment of the channel form is inevitable (which is intended and desirable), but large-scale change was considered unlikely given the behaviour of the low flow channel in the natural creek. One of the functions of induced roughness in the design is to constrain the lateral movement of the low flow.

The residual risks associated with the flood bunds and lateral migration of the creek are addressed by the geotechnical design of the flood bunds. In addition, the diversion reaches are designed to be wide anabranching reaches with low velocities / shear / stream power in the vicinity of the flood bunds, and the bunds are designed to located outside pit setbacks (or pit walls to be buttressed) to mitigate risks associated with pit wall failure (Advisian, 2017b).

Potential for erosion / deposition in transition zones

The transition zones (tie-in points where the diversions intersect Marillana Creek) are locations where the morphology of the channel and associated hydraulics change rapidly. Therefore, there is a potential risk of accelerated erosion (specifically head cutting) and / or deposition. Head cutting typically occurs where there is a sudden discontinuity in energy gradient or sediment supply which drives an erosion front in an upstream direction (Advisian, 2017b).

Upstream progressing head cutting was considered to be a low risk for the E1 diversion due to the fact there are no sharp bed gradient changes in the transition zone, however, the hydraulic conditions in this area suggest that modest morphological adjustment is likely to occur. This may manifest as scour and downstream deposition. To reduce these risks, all rock bars were removed from the design (Figure N-1) and modifications to channel widths and bed gradients were made to further reduce hydraulics at transition zones (Advisian, 2017b).

While upstream progressing head cutting was considered to be a low to moderate risk at the entry to the downstream bend of the E4 diversion (due to the fact there are no sharp bed gradient changes), the concentration of high hydraulic values in this area suggested that morphological adjustment is likely to occur. This may manifest as localised scour and downstream deposition, and the rapid migration of the core of maximum velocity / stress / power to the outside of the bend. The results of 2D modelling showed a maximum scour ‘hotspot’ at the downstream end of the transition where there is a localised bed depression that follows the existing topography. It is possible that a localised head cut may form at this location, but it was considered likely that replenishment of the scour pocket by transported sediment would limit the extent of head cutting. For the final E4 diversion design (Figure N-2), the first (most upstream) rock bar was removed, and modifications to channel widths and bed gradients were made to further reduce hydraulics at transition zones and mitigate the risks associated with head cutting and erosion (Advisian, 2017b).

B.1.3 Rock bars

Rock bars were included in the E4 diversion (Figure N-2) to manage the risks posed by high hydraulic forces during large flood events and to provide grade control in areas with head-cutting risk (Advisian, 2017e). To support the detailed design of rock bars, a literature review was conducted by Advisian (2017a). The review concluded that the most appropriate design geometry for application at Yandi is a U-shaped cross vane. Cross vanes are typically constructed using imported rock; however, the rock bars at Yandi were cut into in-situ rock material (dolerite or BIF), as the use of imported rock is expected to have a higher risk of failure. Consequently, the final rock bar design for Yandi is a modified U-shaped cross vane. The downstream longitudinal grade of the rock bar is 4% to allow fish passage upstream (feeding, reproducing etc.) (Advisian, 2017e).

In accordance with recommendations from the literature review, rock bars have been located so that they are a minimum of two times the channel width upstream of critical infrastructure such as flood protection bunds. The downstream face of the rock bars has been buried beneath imported alluvium and is expected to be partially exposed as scour holes form downstream during flood events. Based on the sediment transport modelling results (Section N.1.10), the rock bars have been situated such that scour holes will not pose a significant risk to infrastructure such as flood protection bunds (Advisian, 2017e).

The rock bars may result in the formation of ephemeral pools in the scour holes on the downstream faces, which may be beneficial to the Marillana Creek fluvial system (Advisian, 2017e).

B.1.4 Rock fill

At the upstream and downstream transitions of each diversion with Marillana Creek, there are ‘rock fill’ areas that have been included in the design to create a smooth transition to the existing creek (Advisian, 2017e) (Figure N-1 and Figure N-2):

- At the entrance to the E1 diversion, the rock fill area was designed to reduce the risk of the re-aligned primary channel of Iowa Creek rapidly migrating directly against the flood protection bund.
- At the upstream transition section of the E4 diversion, there are sections of rock fill designed to constrict the channel cross section to increase the velocity of the water and thereby reduce the risk of sediment deposition, which could eventually result in overtopping of flood protection bunds during extreme flood events, or a higher frequency of flow over the closure spillways than intended.

The rock fill areas have been filled with blasted BIF material from the diversion excavations and, where the rock fill areas will be inundated by regular flooding (nominally >5-year ARI), 1 m of alluvium has been placed over the blasted BIF. Alluvium topsoil has also been spread over the surface to provide a seed bank that will allow for vegetation to establish on these areas (Advisian, 2017e).

B.1.5 Tributary transitions

There are a number of tributaries that intersect the E1 and E4 diversions from the southern side, and a railway owned by Rio Tinto Iron Ore that crosses four of the tributaries at distances upstream that vary between approximately 1 and 4 km (Figure N-7) (Advisian, 2017b).

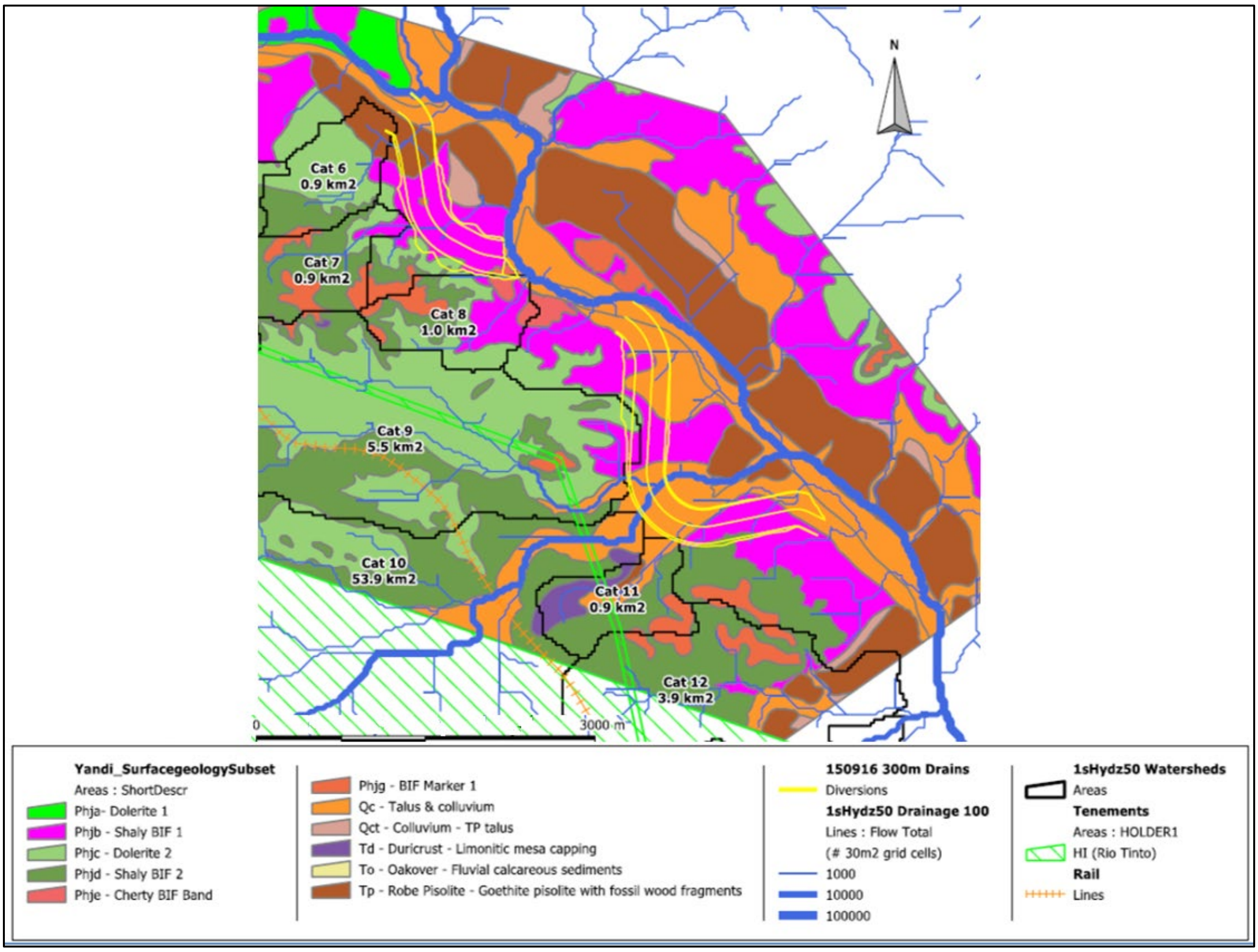
Tributary transitions have been cut back to a 15% grade (Advisian, 2017e) in accordance with the recommendations of the Advisian (2017b) geomorphology study (Table N-3). Figure N-1 and Figure N-2 show the locations of cutbacks.

As the diversions will intersect the tributaries upstream from the normal confluence point with Marillana Creek, the tributaries will be perched above the bed as they enter the steep outer bank of each diversion. Estimates of the ‘drop height’ at the entry points range between 1 and 17 m. Such a sudden change of elevation means that there is a risk that head cutting will progress along the tributaries during flow events and that this erosion front could potentially affect the infrastructure further upstream. The rate of progression of any erosion will depend upon the magnitude and duration of the hydraulic forces of the flow event, and the resistance of the bed material (Advisian, 2017b).

The management options for each tributary intersection were:

- Do nothing and allow the tributary to cut back to an equilibrium slope as a natural process. This is an appropriate action for tributaries where the magnitude and consequences of head cutting were considered to be low. Monitoring of tributaries for the do-nothing case will be undertaken.
- Cut back to a flatter grade. This option reduces the risk of major erosion occurring, particularly during the first few flow events after construction. The engineered cutback would be relatively stable compared to a natural head cut and would reduce the risk of debris blockages from the bed erosion and widening process occurring in both the tributary channels and at the confluence points with the diversions, which would create the potential for local scour and further erosion to occur. This action was appropriate for tributaries where the magnitude and consequences of erosion were higher.

Table N-3 provides a summary of the potential risk associated with each of the tributaries intersecting the diversions and the measures incorporated into the design to mitigate them.



Source: adapted from Advisian (2017b)

Figure B-7. Tributaries intersecting E1 and E4 diversions

Table B-3. Tributary risk assessment and design mitigations

Catchment ID	Catchment Area (km²)	Hanging Height (m above diversion bed level)	Geology at Confluence with Diversion	Existing Bed Grades (%)			Design Risk Mitigations
				Upstream of Diversion	Between Diversion and Marillana Ck	Ramp to Marillana Ck	
6	0.90	1 m	Pisolite	1.7%	1.1%	3.6%	Leave as is. The hanging height is negligible and catchment area is small.
7	0.90	6 m	3 m alluvial and colluvial material over competent shale	2.0%	1.5%	2.9%	Cut back alluvials at 15% grade. The catchment is of small size so flows over the short 3v:1h slope would not pose a scour risk to alluvials in diversion.
9	5.50	7 m	Alluvial / colluvial material over weathered and weak calcrete and ferricrete	0.7%	0.7%	1.1%	Cut back alluvial / colluvial material at 15% grade. The catchment is of moderate size so erosion is expected to occur through the existing material towards the underlying resistant material.

Catchment ID	Catchment Area (km²)	Hanging Height (m above diversion bed level)	Geology at Confluence with Diversion	Existing Bed Grades (%)			Design Risk Mitigations
				Upstream of Diversion	Between Diversion and Marillana Ck	Ramp to Marillana Ck	
10	53.90	8 m	Alluvial / colluvial material over weathered and weak calcrete and ferricrete	0.7%	0.7%	1.1%	Cut back alluvial / colluvial material at 15% grade. The catchment is large so erosion is expected to occur through the existing material towards the underlying resistant material.
11	0.90	8 m	No drill hole in exact area, likely to be similar to ID 9 and ID 10.	0.9%	0.7%	6.6%	Cut back alluvial / colluvial material at 15% grade. The catchment is small so erosion is not expected to be significant.

Source: Advisian (2017b)

B.1.6 Channel roughness

The diversions include 'roughness features' that are intended to serve two purposes:

- Promote and accelerate the development of morphological features in the diversions (such as vegetated anabranch ridges and channels) to achieve the performance criteria within a shorter period of time; and
- Reduce the risk that a significant volume of alluvium will erode and emergent vegetation be destroyed, should a moderate to large flood event occur shortly after construction.

The roughness features consist of a mixture of:

- Logs embedded into the sediment with the root plate exposed and facing upstream;
- Single placed boulders of 2 m diameter;
- Boulder clusters of three to four boulders up to 1 m diameter each to achieve a rock cluster height of 2 m; and
- Dumped boulder piles of particles with a median size of 0.55 m diameter, shaped into an elongated cone of 2 m height.

B.1.7 Revegetation

Techniques to establish vegetation in the creek diversions included:

- Segregating topsoil stripped from the original creek alignment based on whether it was removed from the stream habitat zone (bed, banks and floodplain) or that of a terrestrial environment (slopes and uplands), and replacement of soil within corresponding habitat areas within the creek diversions.
- Spreading topsoil onto newly created diversion landforms at much the same depth as it was collected, and preferentially allocating it to the floodplains and upper banks where flooding is less frequent, to minimise potential loss downstream from flood events.
- Control of weeds in topsoil prior to stripping. Previous studies and experience have shown that topsoils in the areas stripped are likely to contain weeds given their prevalence in drainage lines across the region.
- Encouraging natural processes to regenerate vegetation through a succession of communities from colonisers to a stable climax community over a 15 plus year timeframe. Natural recruitment will occur with seasonal flows. Channel roughness elements tend to promote natural colonisation of plants as they slow down water flows which encourages deposition, not only of finer alluvium, but also seed being dispersed by water. Natural regeneration is likely to be the most successful revegetation approach. However, seeding with relatively high densities of native grasses (both annual and perennial) was used for areas where rapid stabilisation was required, and in revegetation zones where such species are typically dominant (e.g. floodplains).
- Direct seeding was concentrated on floodplains and upper banks where flooding and surface water flows are uncommon. Some tube stock planting was also implemented on the benches in 2021 - 2022.

B.1.8 Shallow aquifer

Ministerial conditions require diverted sections of the creek to function in a similar manner to the existing creek and the re-establishment of riparian vegetation is an important factor. The riparian vegetation in Marillana Creek interacts with a shallow alluvial aquifer, and the establishment of a shallow aquifer within the diversions is important for the development of a functionally similar vegetation community. AQ2 (2017) conducted a study to develop a shallow aquifer design for the E1 and E4 creek diversions. This included a literature review of factors affecting establishment and survival of riparian vegetation, and a review of the natural ecohydrological system associated with Marillana Creek. Following the reviews, the following performance objectives for the shallow aquifer were defined:

- Have comparable saturated and unsaturated hydraulic properties to the natural alluvium.
- Be of sufficient depth to replicate a seasonal water level change of 2 to 3 m and contain sufficient plant-available water to support the riparian vegetation.

- Aquifer to receive sufficient infiltration (recharge) so it can retain adequate plant-available water over its depth to support riparian vegetation as horizontal flow of groundwater in the shallow aquifer is small (due to limited saturated thickness) and cannot be relied on as a source of recharge.
- Support vegetation at similar densities observed in the existing Marillana Creek System.
- Areas of high-density trees should be inundated by the 2-year ARI flood events.

The design of the shallow aquifer is different for each of the three reach types / categories:

- **Anabranching:** the aquifer must support trees at a similar density to the existing creek over the full width of the active channel zone, and support scattered trees, shrubs, spinifex and other grass species on the floodplain areas.
- **Incised – Category 1:** the aquifer must support trees at similar density to the existing creek on the marginal benches of the channel, with no vegetation expected to be permanently established in the centre of the channel.
- **Incised – Category 2:** the aquifer must support trees at a similar density to the existing creek over the full width of the active channel zone.

AQ2 (2017) conducted ecohydrological water balance modelling to determine the appropriate depth of alluvium for creek diversions to enable them to support riparian vegetation at currently observed tree densities over periods between recharge events of up to 6 years. A drought length of six years was adopted as this represents the longest recorded period of time between significant recharge events, based on analysis of streamflow data from the Flat Rocks gauging station since 1968.

The modelling concluded that an aquifer thickness of 6 m (beneath the zone supporting vegetation) would provide a soil moisture content between 3% and 18% and the soil matric potential would remain above -4,500 kPa, to allow the survival of some tree species in drought conditions; specifically *Eucalyptus victrix*. A depth of 6 m is consistent with the minimum depth of alluvium observed in the natural system where significant riparian vegetation is preserved (Advisian, 2017e).

The aquifer design for the diversions, therefore, incorporated the full depth of alluvium (6 m) throughout the active channel area of the anabranching and incised category 2 reaches to account for future low flow channel lateral migration (Figure N-4 and Figure N-6). Reducing the aquifer depth away from the primary channel may not initially have a significant effect on vegetation in the diversion, however, should the primary channel migrate laterally to this area at some point in the future, it could result in a section of the diversion without both of the preconditions required to support trees. This could result in a loss of longitudinal continuity of vegetation and failure to meet the performance criteria (Advisian, 2017e).

The floodplain features within the anabranching reaches have an aquifer depth of 2 m (Figure N-4) because these areas are not expected to support trees due to their less frequent inundation by flood events. Given that there will not be sufficient water to sustain trees, the aquifer depth was reduced to 2 m to provide sufficient soil moisture needed to support spinifex and other grass species, as well as scattered trees and shrubs (Advisian, 2017e).

Similarly, the aquifer depth in the centre of the incised category 1 reaches was reduced because no vegetation is expected to be sustained in these areas due to the high hydraulic forces during flooding. The aquifer depth in these locations was set to 3 m to avoid exposed rock due to scour during flood events (refer to Section N.1.10). The marginal benches of the incised category 1 reaches are intended to sustain trees and other vegetation, therefore, these areas include a 6 m deep aquifer (Figure N-5) (Advisian, 2017e).

Over-blast material was identified as a suitable substitute for imported alluvium within the shallow aquifer in terms of moisture retention capacity. However, the particle size distribution of the blasted rock is different to the alluvium and has different sediment transport characteristics. Additionally, there is a risk that exposed blasted rock could negatively affect the ecology of the hyporheic zone, which influences important in-stream processes such as primary productivity and nutrient cycling. The sediments in the hyporheic zone also provide habitat for important microbes and invertebrates (Advisian, 2017e).

To mitigate these risks, the design of the engineered aquifer included blasted rock at the bottom of the aquifer with alluvium placed on top, with the interface between the two layers set to 0.5 m below the maximum scour depth estimated by sediment transport modelling during a 100 year ARI flood event (Advisian, 2017e).

B.1.9 Hydraulic performance

The approach to evaluating the hydraulic performance of the E1 and E4 creek diversions was based on that outlined in ACARP (2014), however, the threshold values used to inform the design were based on hydraulic modelling of Marillana Creek and, therefore, were different to those adopted by ACARP (Advisian, 2020).

2D hydraulic modelling conducted by Advisian (2017a), to assess the performance of the E1 and E4 creek diversion detailed design, concluded that the diversions would be expected to function as a fluvial system in a similar manner to Marillana Creek (Table N-4). Subsequent modelling following the optimisation of the spillways (Advisian, 2019) concluded that the hydraulic conditions within the diversions would remain similar to those modelled in 2017 (see Figure N-8 to Figure N-11 for S-Curves) and, therefore, would be similar to those of the existing Marillana Creek system up to a 100 year ARI event. There were some minor exceedances of the S-curve bands, however there were no reaches where this was considered to pose a significant risk. In some reaches, the hydraulics improved as a result of the optimised spillway configuration.

The results of the hydraulic modelling were used to inform the placement of rock bars in the E1 and E4 creek diversions (Figure N-2 and Section N.1.3) and the required height of, and erosion protection required for, flood bunds. Hydraulic modelling of rock bar performance confirmed that they direct velocity vectors towards the centre of the channel and away from the cut slopes (Advisian, 2017a).

Sensitivity analysis

Sensitivity analyses were conducted to assess the impact of the E1 or E4 creek diversion channel roughness being higher or lower than expected, and the formation of multiple low flow channels.

The 2D hydraulic model predicted that there would be an increase in velocities within all creek diversion reaches for the low roughness scenario, but shear and stream power values in some scenarios would be reduced due to the lower depths of flow associated with the change in roughness. The results indicated that the hydraulics within the majority of diversion reaches would be similar to, or only slightly in excess of, the range of values associated with the existing Marillana Creek. Increases were localised and minor, and the diversions would therefore still function in a similar manner to the existing creek. For the high roughness scenario, there would be increased flood levels, but not sufficient for the flood bunds to over-top (Advisian, 2017a).

Formation of multiple low flow channels within the diversions is expected to occur over time and has the potential to change the diversion's hydraulic performance. Modelling of additional low flow channels in the E1 diversion was, therefore, conducted and the results compared to those from a single low flow channel. The number, depth and width of additional low flow channels were selected to match natural analogues within Marillana Creek. Comparison of S-Curves developed from the modelling suggested that the hydraulic behaviour of the diversions is not sensitive to the number of low flow channels that form over time. It is, therefore, appropriate to assess the long term performance of the diversion designs on the hydraulic performance of the design that will be constructed, even though it is intended and expected that the morphology of the diversions will evolve over time (Advisian, 2017a).

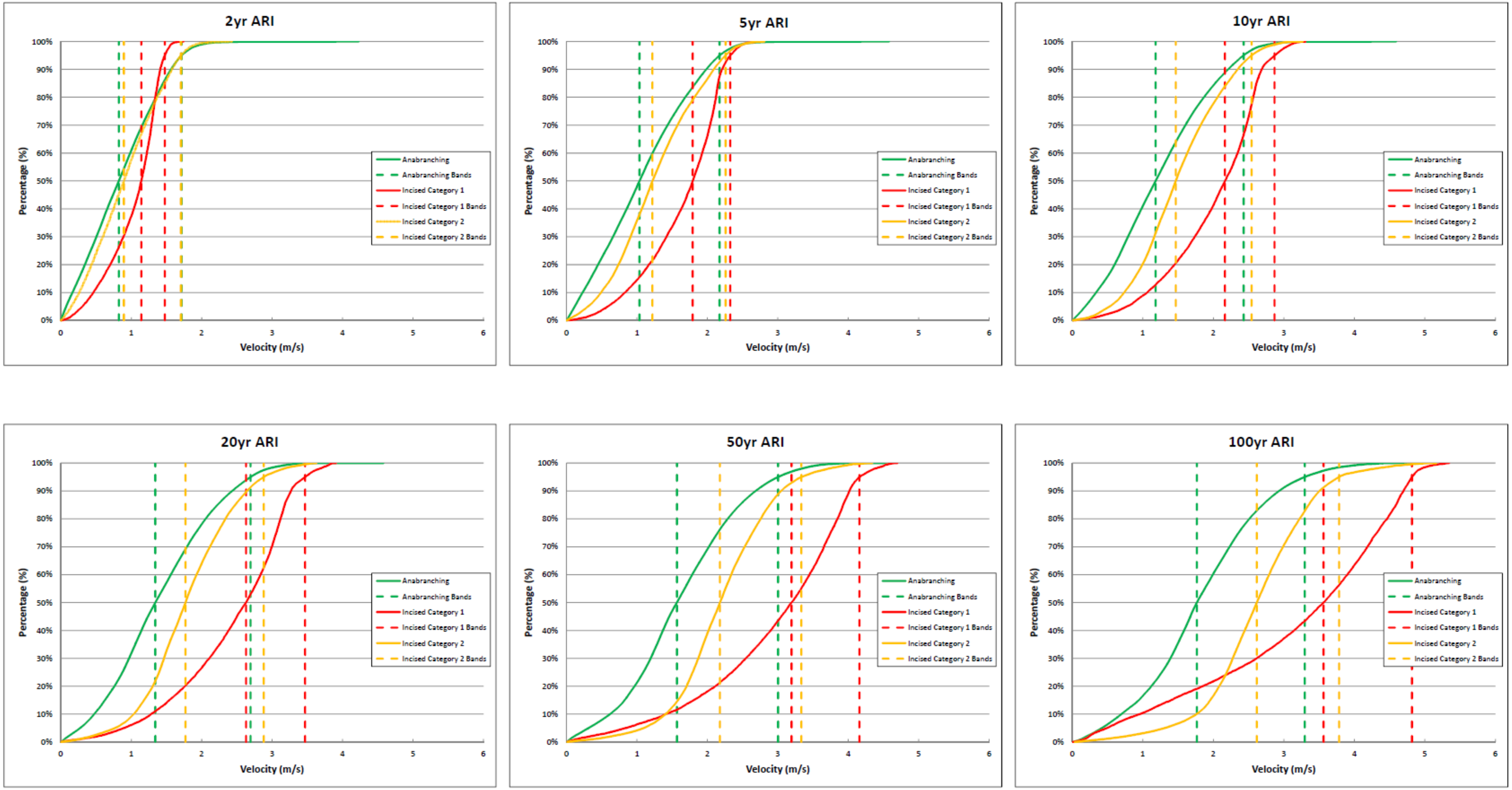
Table B-4. 2D modelling hydraulic performance (closure) assessment results

Diversion	Section #	Type	2yr	5yr	10yr	20yr	50yr	100yr
Velocity								
E1	1	Anabranching						
E1	2	Incised - Category 1						
E1	3	Incised - Category 2						
E1	4	Anabranching						
E4	1	Anabranching						
E4	2	Incised - Category 1						
E4	3	Incised - Category 2						
E4	4	Anabranching						
Shear Stress								
E1	1	Anabranching						
E1	2	Incised - Category 1						
E1	3	Incised - Category 2						
E1	4	Anabranching						
E4	1	Anabranching						
E4	2	Incised - Category 1						
E4	3	Incised - Category 2						
E4	4	Anabranching						
Stream Power								
E1	1	Anabranching						
E1	2	Incised - Category 1						
E1	3	Incised - Category 2						
E1	4	Anabranching						
E4	1	Anabranching						
E4	2	Incised - Category 1						
E4	3	Incised - Category 2						
E4	4	Anabranching						

Source: Advisian (2017a)

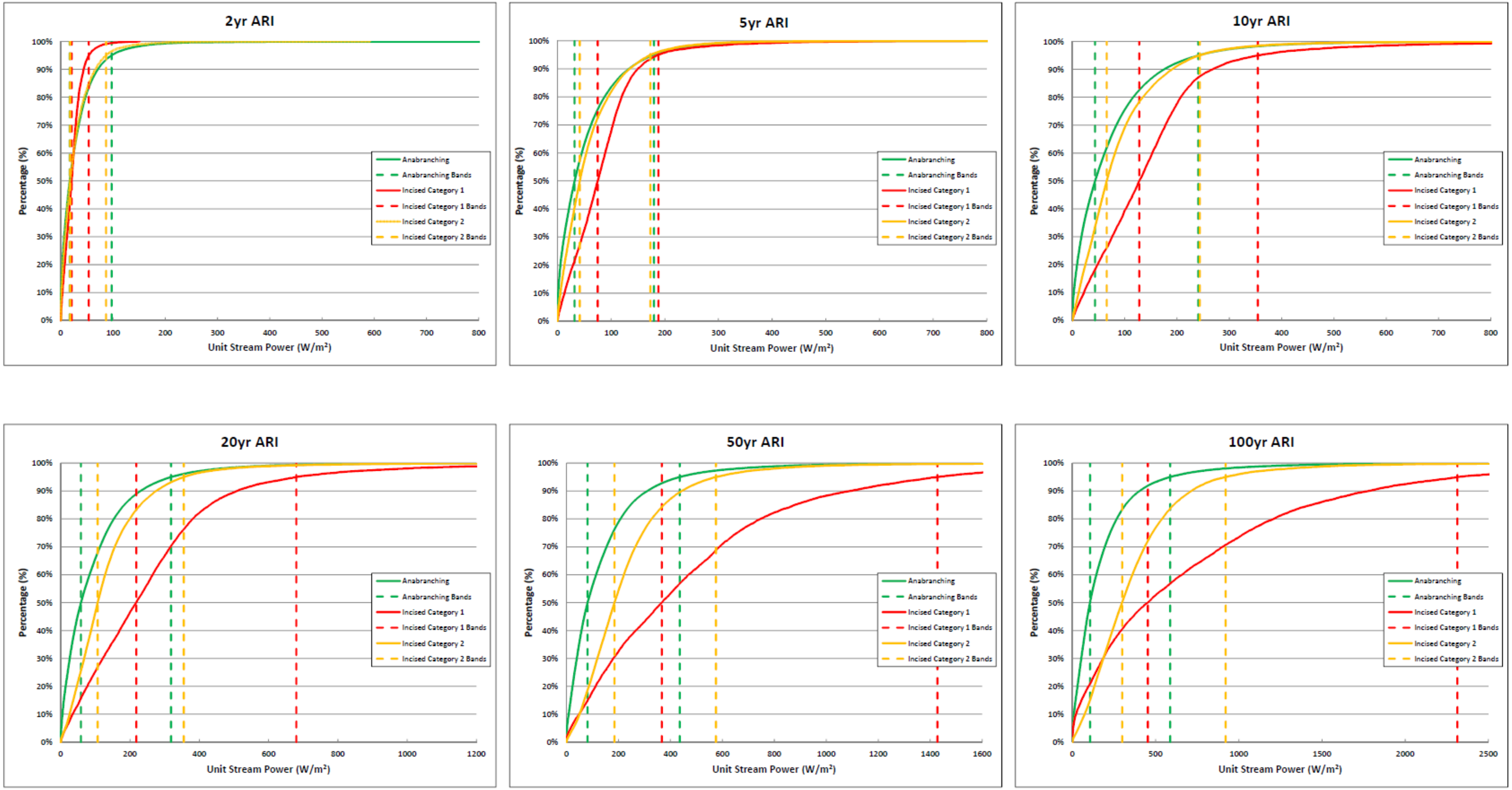
	Within range
	Slightly outside range but considered acceptable
	Outside range but can be managed (e.g. through placement of rock bars)
	Design improvements required

Figure B-8. Existing conditions – velocity S-curves



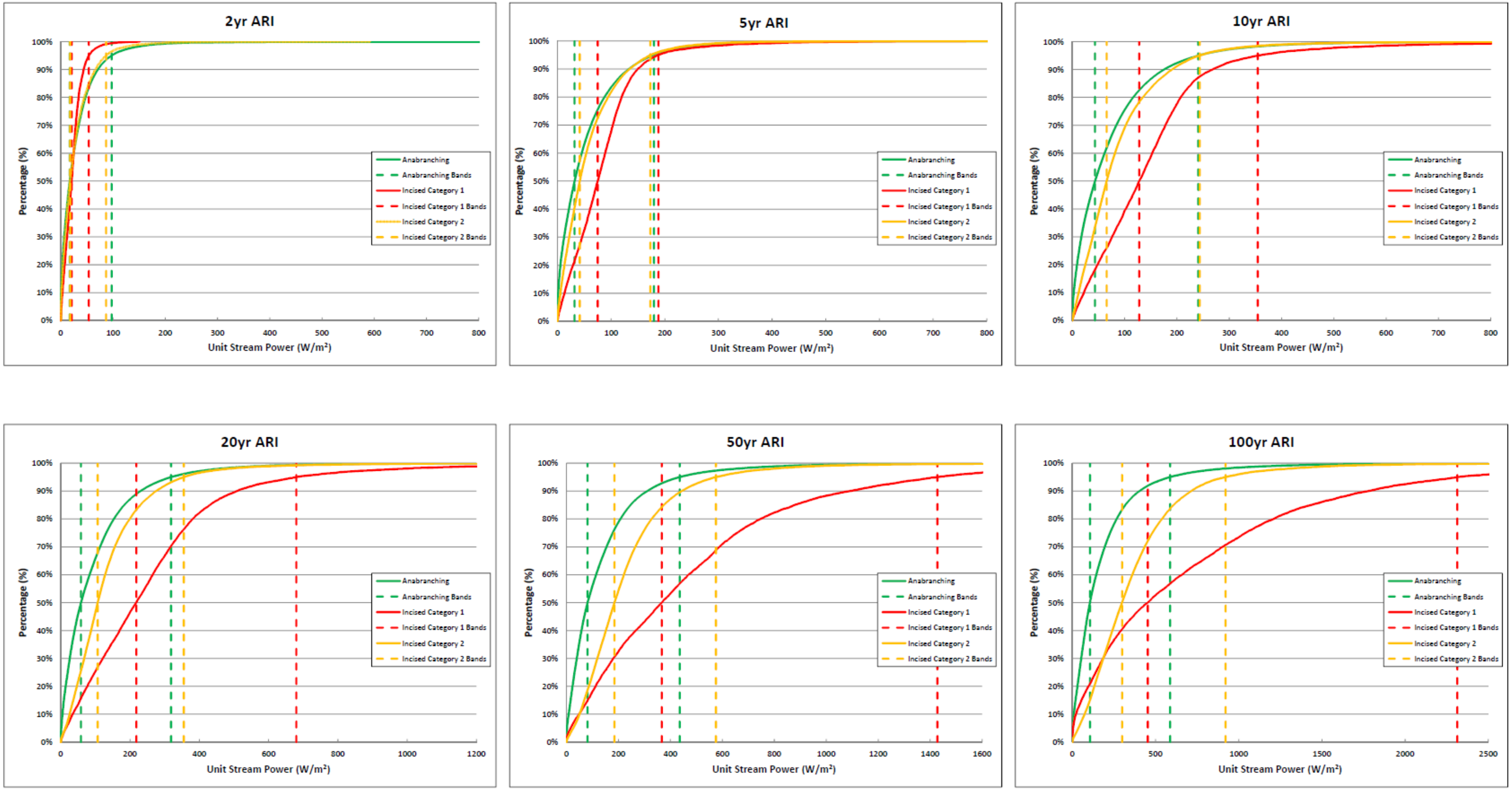
Source: Advisian (2017a)

Figure B-9. Existing conditions – bed shear S-curves



Source: Advisian (2017a)

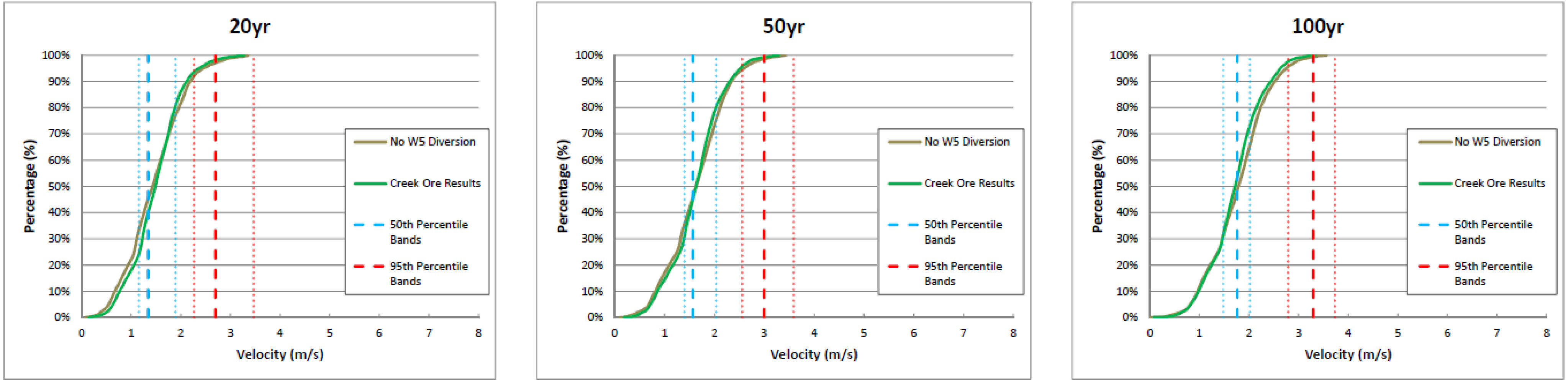
Figure B-10. Existing conditions unit stream power S-curves



Source: Advisian (2017a)

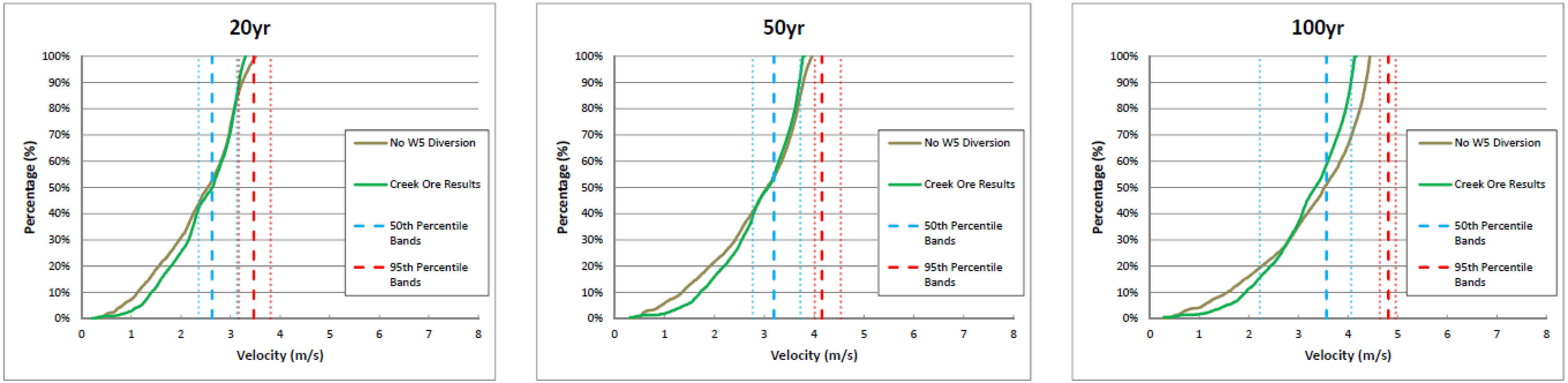
Figure B-11. Closure - velocity S-curves

E1 reach anabranching



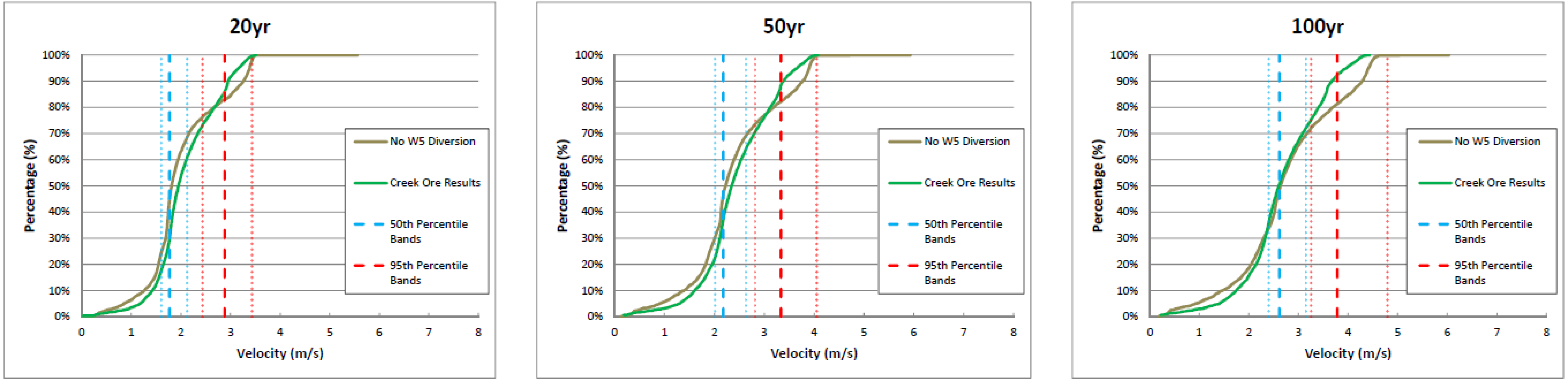
Source: Advisian (2019)

E1 Reach 2 – incised category 1



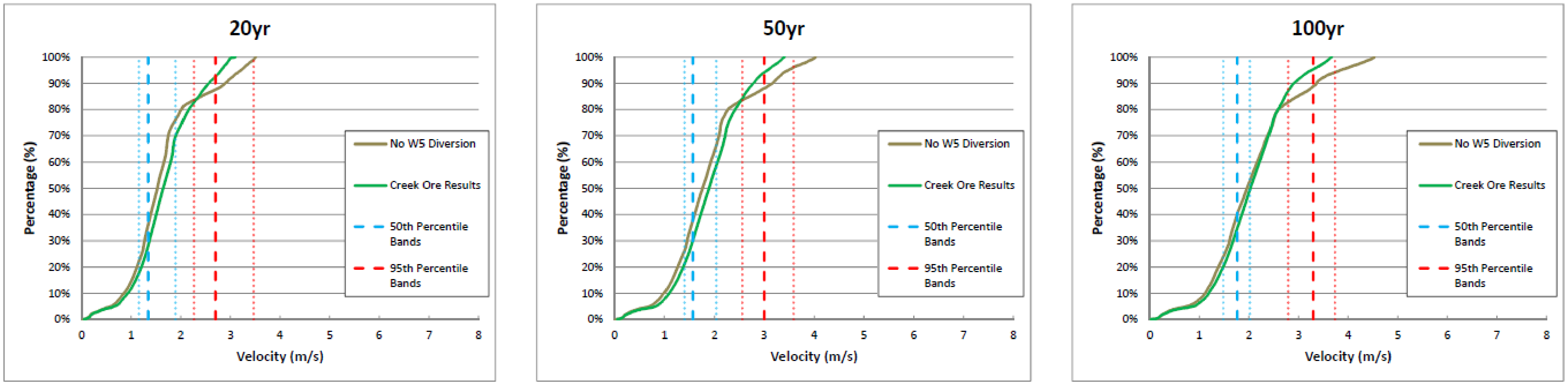
Source: Advisian (2019)

E1 Reach 3 – incised category 2



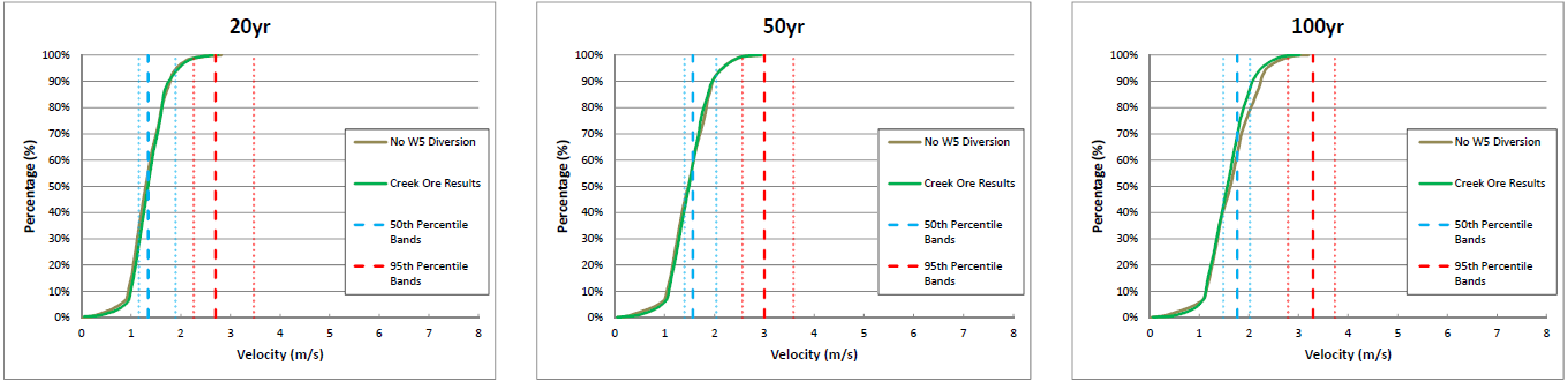
Source: Advisian (2019)

E1 Reach 4 - anabranching



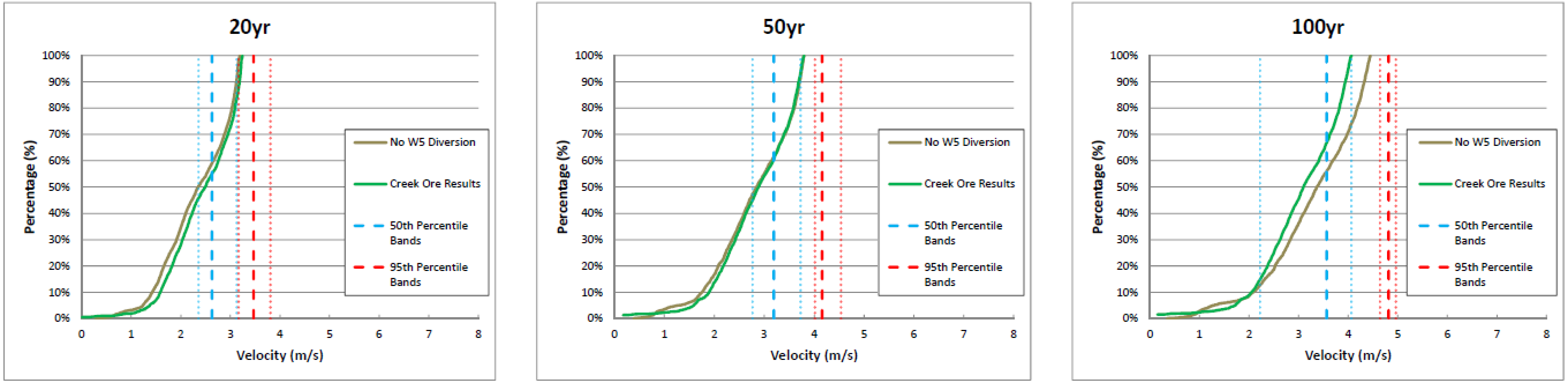
Source: Advisian (2019)

E4 Reach 1 – anabranching



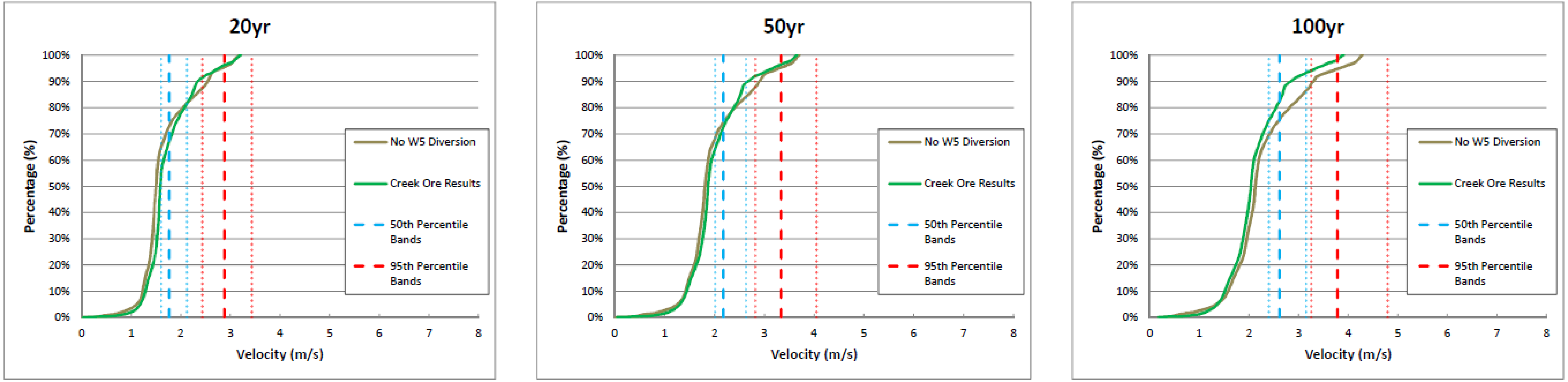
Source: Advisian (2019)

E4 Reach 2 – incised category 1



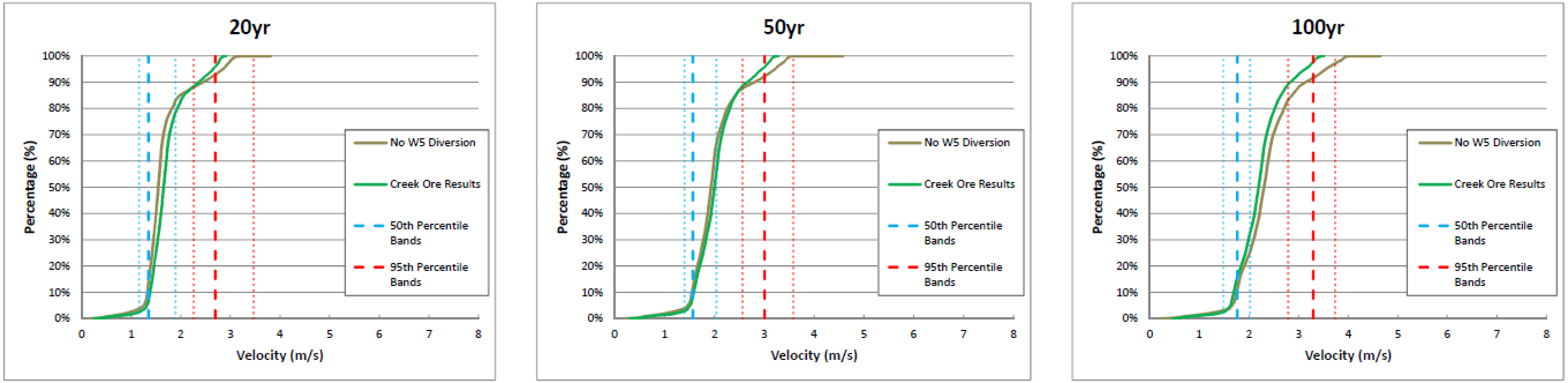
Source: Advisian (2019)

E4 Reach 3 – incised category 2



Source: Advisian (2019)

E4 Reach 4 – anabranching



Source: Advisian (2019)

B.1.10 Sediment transport modelling

Sediment transport modelling was conducted by Advisian (2017c) for closure conditions within E1 and E4 creek diversions to:

- Simulate sediment transport and changes in bed level for the 10 and 100-year AEP flood events.
- Assess long term changes in bed elevations in the vicinity of spillways and flood bunds and the impact this may have on the risk of overtopping bunds and the magnitude and frequency of spillway flows.
- Assess the risk of losing alluvium to inform the design of the shallow aquifer.
- Assess the risk that the scour holes pose to flood bunds downstream.

Bed elevation changes

The range of bed elevation changes predicted by the models for the 10 and 100-year AEP events for existing conditions and closure were similar[4]. Indicative changes in the average bed elevations predicted for the 100-year AEP event are shown in Table N-5. Comparison of the 2D bed elevation maps and bell curves indicated that the range of bed elevation changes for the E1 and E4 diversions under closure conditions would be similar to existing conditions. The maximum bed elevation changes within the diversions range between +/-1.8 m, with 99 % of the cells having bed elevation changes of less than 1.8 m. The bell curves were symmetrical and centred on a zero change in bed elevation (Advisian, 2017c).

Table B-5. 100 year AEP net changes in bed elevation

ID	Average Width (m)	Length (m)	Average Change in Bed Elevation (m)
Existing Conditions	180	25,500	-0.03
E1	170	2,061	0.02
E4	210	4,437	-0.01

Source: Advisian (2017c)

Modelling was conducted over 2,000 years to gain an understanding of the long-term sediment transport conditions. An event representative of a 10,000-year AEP flood event was included in the modelling to understand the impact of these flows. The results of the long-term modelling indicated that the sediment transport trends for existing and closure conditions were generally similar, with aggradation in the upstream reaches and degradation in the downstream reaches of Marillana Creek. The cumulative mass change for both scenarios was relatively minor throughout the model domains for the first 100 years of simulation (Figure N-12 and Figure N-13) and relatively low at the outlet (i.e. at the Yandi lease boundary - 0 Chainage) in the first 500 years of simulation for both existing and closure conditions. However, the last 1,000 years of simulation contains the largest flood event and there is a significant spike in cumulative mass change around year 1,450 when the maximum flood event of 5,080 m^3/s occurs. During this event, spillway flows into pits do not return to the creek system in the sediment transport model, so the major flood flows are significantly greater for the existing conditions and have a higher transport capacity. The existing conditions scenario also has deeper erosion without rock bars and the mass balance shows greater erosion than the closure scenario, particularly in the downstream reaches (Advisian, 2017c).

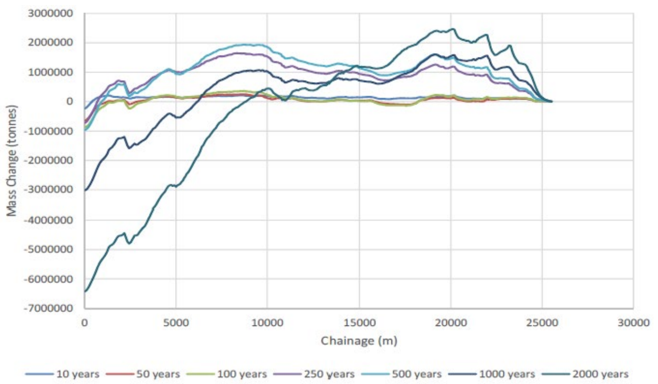


Figure B-12. Cumulative mass change - existing conditions

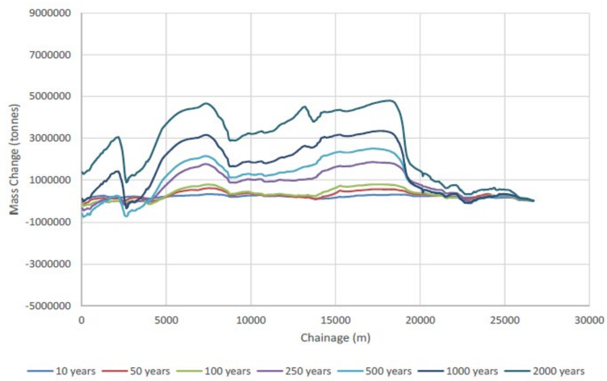


Figure B-13. Cumulative mass change - closure

4 The sediment transport assessment makes relative comparisons of bed elevation changes rather than predicting absolute values due to the limitations of sediment transport modelling.

Note: A positive change indicates aggradation while a negative change indicates degradation

Indicative estimates of long term (average) bed elevation change and trends in aggradation and degradation within the diversions suggested that (Advisian, 2017c):

- Only minor change in average bed elevations would occur within both diversions over the first 100 years of simulation (up to +/- 0.35 m) and less than 0.65 m after 2,000 years (Table N-6).
- There is the potential for long-term degradation throughout the E1 diversion.
- There is the potential for long-term aggradation in the upstream third of the E4 diversion (Chainage 0 to 1,225 m) so some additional freeboard could be considered at the upstream flood bund as a contingency measure for closure. Elsewhere long-term degradation would be expected.

Table B-6. Representative average change in bed elevation over 2,000 year simulation

Year	Cumulative Mass Change (1,000 tonnes)		Estimated Average Change in Bed Elevation(m)	
	E1	E4	E1	E4
10	-25	-95	-0.04	-0.06
50	18	-379	0.03	-0.23
100	54	-528	0.09	-0.32
250	-36	-892	-0.06	-0.55
500	-85	-1039	-0.14	-0.64
1000	-147	-831	-0.24	-0.51
2000	-378	-722	-0.62	-0.44

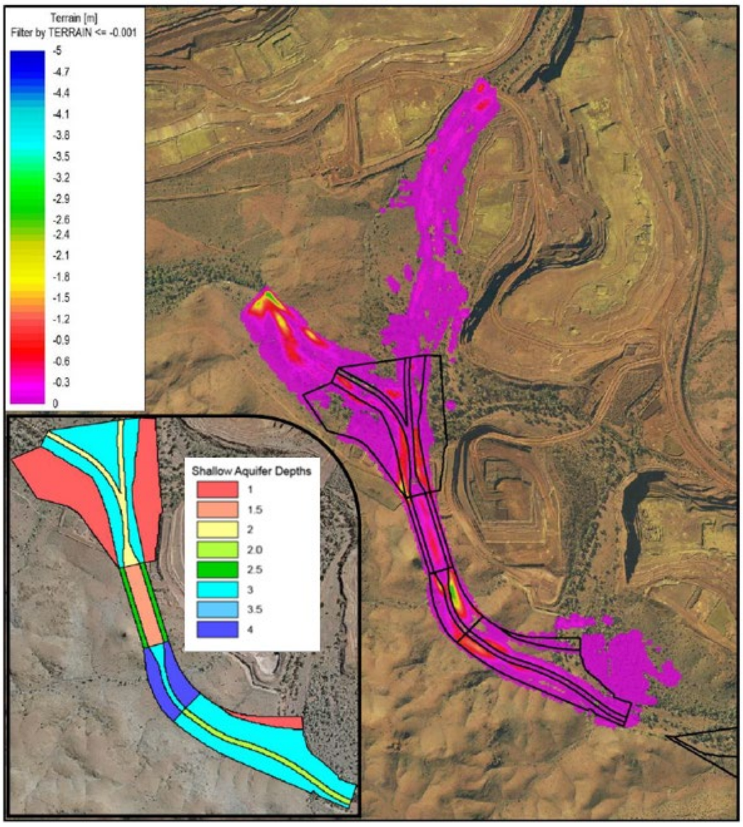
Source: Advisian (2017c)

Risk to spillways

Advisian (2017b; 2017c) investigated the risk of water loss over spillways during flows in excess of the 20-year AEP flow leading to a reduction in sediment transport capacity and subsequent sediment deposition at spillways to determine if this could lead to diversion of more water over the spillway and progressive loss of diversion capacity. Modelling indicated that sediment aggradation due to spillways was not expected to result in a significant long-term increase in the magnitude and frequency of spillway flows or increase in the risk of overtopping flood bunds, particularly over the first 100 years. Although accretion may occur in the creek adjacent to spillways during large floods, the more frequent low-flow events scour the active channels sufficiently so that significant long-term increases in floodwater levels and spillway flows do not occur (Advisian, 2017b; 2017c).

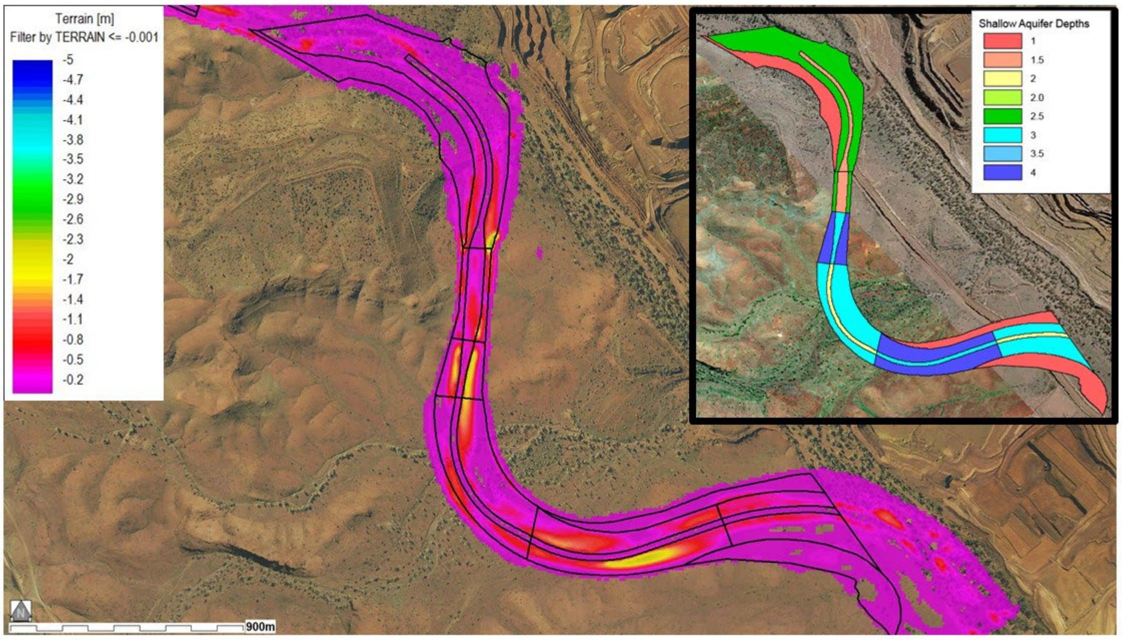
Risk to shallow alluvium aquifer

2D sediment transport modelling was used to validate the depth of alluvium used as the upper layer in the shallow aquifer design for the Marillana Creek diversions (see Section N.1.8). The maximum scour depths predicted by the model are overlain by the design alluvium depths in Figure N-14 and Figure N-15. The results suggest that the adopted alluvium depths for the upper layer of the shallow aquifer are at least 0.5 m deeper than the estimated maximum depths of scour predicted by the 2D sediment transport model (Advisian, 2017c).



Source: Advisian (2017c)

Figure B-14. E1 diversion - maximum predicted scour depths and imported alluvium depths



Source: Advisian (2017c)

Figure B-15. E4 diversion - maximum predicted scour depths and imported alluvium depths

Risk of scour to flood bunds

Rock bars present a physical partial barrier to sediment transport during flow events, and therefore lessen the risk of depletion of alluvium to some degree. However, scour areas are likely to form downstream of the rock bars during flow events. These are likely to be relatively limited in extent and to provide some remnant pool benefits for aquatic habitats (Advisian, 2017b). The results of 2D sediment transport modelling (Advisian, 2017c) suggested that scour holes could be approximately 3 m deep at the toe of the rock bar, and extend at shallower depth up to approximately 200 m downstream for the 100-year ARI event. Modelling showed that the rock bar scour holes were located at a sufficient distance upstream of flood bunds to minimise the risk of the scour holes impacting on the structural integrity of the bunds (Advisian, 2017c).

B.1.11 Geotechnical stability analysis

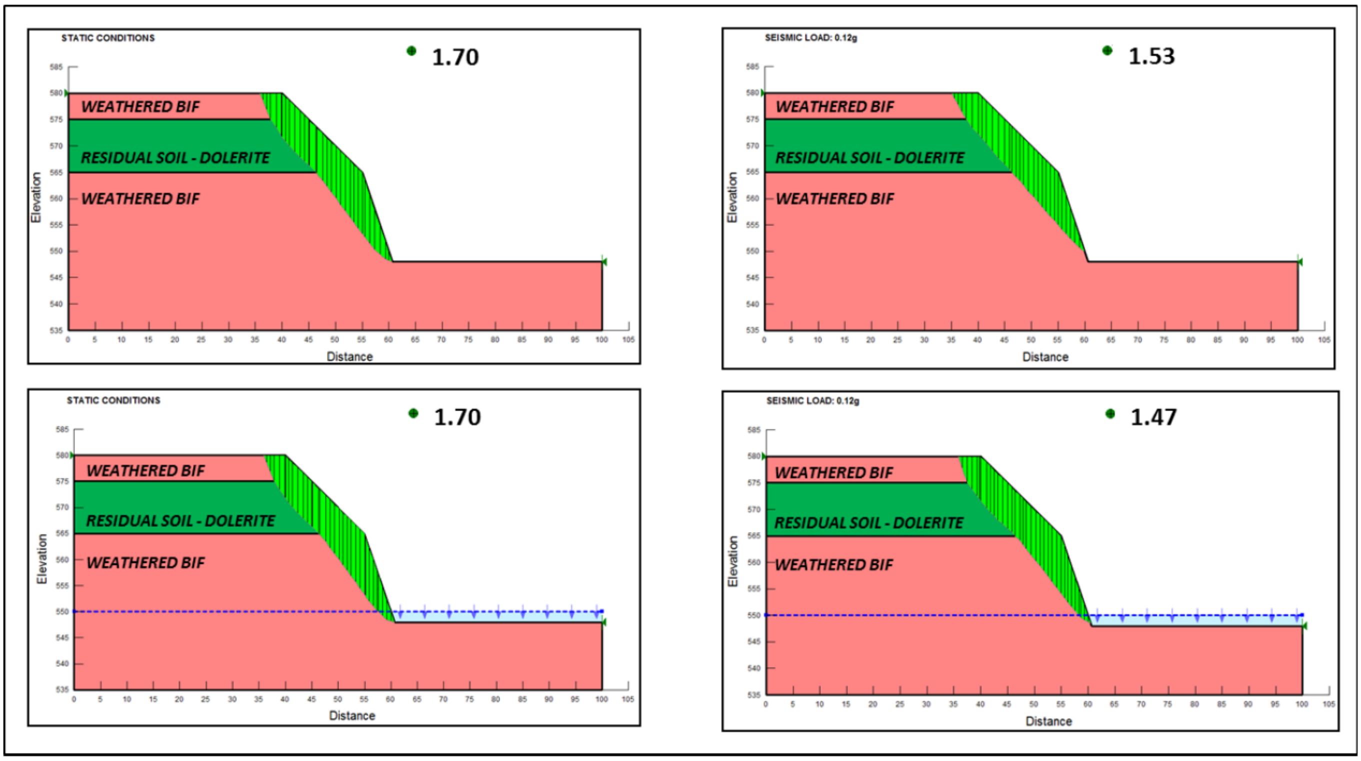
Advisian (2017d) conducted a limit equilibrium slope stability analysis for the highest cut along the Marillana Creek diversion (32 m), using the software package SLOPE/W. The analysis considered:

- Normal steady state and seismic scenarios (earthquake horizontal acceleration 0.12 g).
- Dry and wet (flood) conditions. For wet conditions, a phreatic surface simulating the flood flow was included above the floor of the diversion channel.

Geological profiles were developed from the results of drilling and the mapping. Given the possible variability of materials, a conservative approach was adopted when assigning the geotechnical parameters, considering weathered rock along the entire profile for both cuts, regardless of the presence of fresh rock (Advisian, 2017d).

A minimum slip circle depth of 1.5 m was adopted during the analyses. Localised failures may occur during both the short and long term, and are deemed beneficial for the diversion as they will provide additional material to the engineered Alluvium in the diversion floor (Advisian, 2017d).

The analyses show that the general stability of the cuts is satisfactory under both static and seismic scenarios in both wet (flood) and dry conditions (Figure N-16) (Advisian, 2017d).



Source: Advisian (2017d)

Figure B-16. Cut slope stability analysis

The global stability of the cuts along the E1 and E4 creek diversions was also assessed by kinematic methods using geological data obtained from the drilling and surface mapping. Approximately 2,300 geological structures (bedding, joints, faults, veins, decomposed zones and shear zones) measured in all three diversions were used during the kinematic analyses.

Each diversion was divided into a number of internal and external sectors by assessing the average orientation of the cuts and the interpreted geology. Cuts excavated only in common materials, massive materials like Calcrete / Ferricrete or with less than 4 m of rock were not analysed.

Structural data was assigned to each sector and the kinematic analyses were undertaken for planar and wedge failures only. It is expected that toppling failures will occur at localised locations only and will be beneficial in that such localised failures will provide additional material to the placed Alluvium in the base of the diversion cuts.

Friction angles for the discontinuities were determined by assessing the thickness, roughness, shape and nature of the discontinuity infill. The friction angles used in the analyses vary from 27° to 45° and are considered to be moderately conservative.

Kinematic analyses were conducted using a number of different slope angles until the steepest, stable slope was achieved. Table N-7 and Table N-8 present summaries of the analyses and the final diversion cut slope design for E1 and E4, respectively.

Table B-7. Summary of Cut Slope Characteristics and Geometries - E1

Sector	Chainage		Length (m)	Cut height (m)		Slope Geometry		Slope Design	
	from	to		Max.	Min.	Azimuth	Dip Direction	Common	Rock
E1-IN-01	50	350	300	9.0	1.3	169	259	1V:1H	1V:1H
E1-IN-02	350	900	550	32.1	5.8	162	252	1V:1H	3V:1H
E1-IN-03	900	1100	200	26.3	4.7	136	226	1V:1H	2V:1H
E1-IN-04	1100	1300	200	25.3	6.9	116	206	1V:1H	3V:1H
E1-IN-05	1300	1480	180	12.6	0.5	96	186	1V:1H	3V:1H
E1-OUT-01	-60	80	140	6.5	5.6	128	38	1V:1H	N/A
E1-OUT-02	80	350	270	9.1	6.8	144	54	1V:1H	N/A
E1-OUT-03	350	580	500	23.2	9.1	163	73	1V:1H	3V:1H
E1-OUT-04	580	720	640	28.9	18.0	162	72	1V:1H	3V:1H
E1-OUT-05	720	850	770	20.1	6.8	164	74	1V:1H	3V:1H
E1-OUT-06	850	980	900	10.0	6.8	152	62	1V:1H	3V:1H
E1-OUT-07	980	1300	1220	18.5	7.1	128	38	1V:1H	3V:1H
E1-OUT-08	1300	1675	1595	12.4	5.1	118	28	1V:1H	3V:1H

Source: Advisian (2017d)

Table B-8. Summary of Cut Slope Characteristics and Geometries - E4

Sector	Chainage		Length (m)	Cut height (m)		Slope Geometry		Slope Design	
	from	to		Max.	Min.	Azimuth	Dip	Common	Rock
E4-IN-01	50	250	200	N/A	N/A	130	220	1V:1H	N/A
E4-IN-02	250	480	230	1.5	0.0	151	241	1V:1H	N/A
E4-IN-03	480	800	320	3.3	0.8	181	271	1V:1H	1V:1H
E4-IN-04	800	1000	200	7.2	3.3	188	278	1V:1H	3V:1H
E4-IN-05	1000	1400	400	12.2	7.2	184	274	1V:1H	2V:1H
E4-IN-06	1400	1700	300	7.2	4.9	170	260	1V:1H	3V:1H
E4-IN-07	1700	3100	1400	8.6	1.2	N/A	N/A	1V:1H	N/A
E4-OUT-01	0	300	300	2.8	2.3	121	31	1V:1H	N/A
E4-OUT-02	300	550	250	14.1	2.6	143	53	1V:1H	N/A
E4-OUT-03	550	900	350	10.5	3.1	175	85	1V:1H	3V:1H
E4-OUT-04	900	1050	150	13.2	10.5	183	93	1V:1H	3V:1H
E4-OUT-05	1050	1400	350	20.5	10.4	183	93	1V:1H	3V:1H
E4-OUT-06	1400	1500	100	10.4	8.3	215	125	1V:1H	3V:1H
E4-OUT-07	1500	1700	200	8.3	6.6	N/A	N/A	1V:1H	N/A
E4-OUT-08	1700	1900	200	7.9	6.9	N/A	N/A	1V:1H	N/A
E4-OUT-09	1900	2100	200	7.0	6.7	N/A	N/A	1V:1H	N/A
E4-OUT-10	2100	2200	100	11.5	7.0	89	359	1V:1H	1.5V:1H
E4-OUT-11	2200	2500	300	11.6	6.7	79	349	1V:1H	3V:1H
E4-OUT-12	2500	2750	250	10.8	3.0	93	3	1V:1H	3V:1H
E4-OUT-13	2750	3000	250	2.9	1.8	102	12	1V:1H	N/A

Source: Advisian (2017d)

B.2. C1 OSA rehabilitation design

B.2.1 Overview

The C1 OSA has been constructed to blend in with the surrounding hillside (Figure N-17). The topography of the underlying natural ground surface is variable and consequently the fill depth of the OSA varies. However, in general, the fill depth is generally around 20 to 30 m.

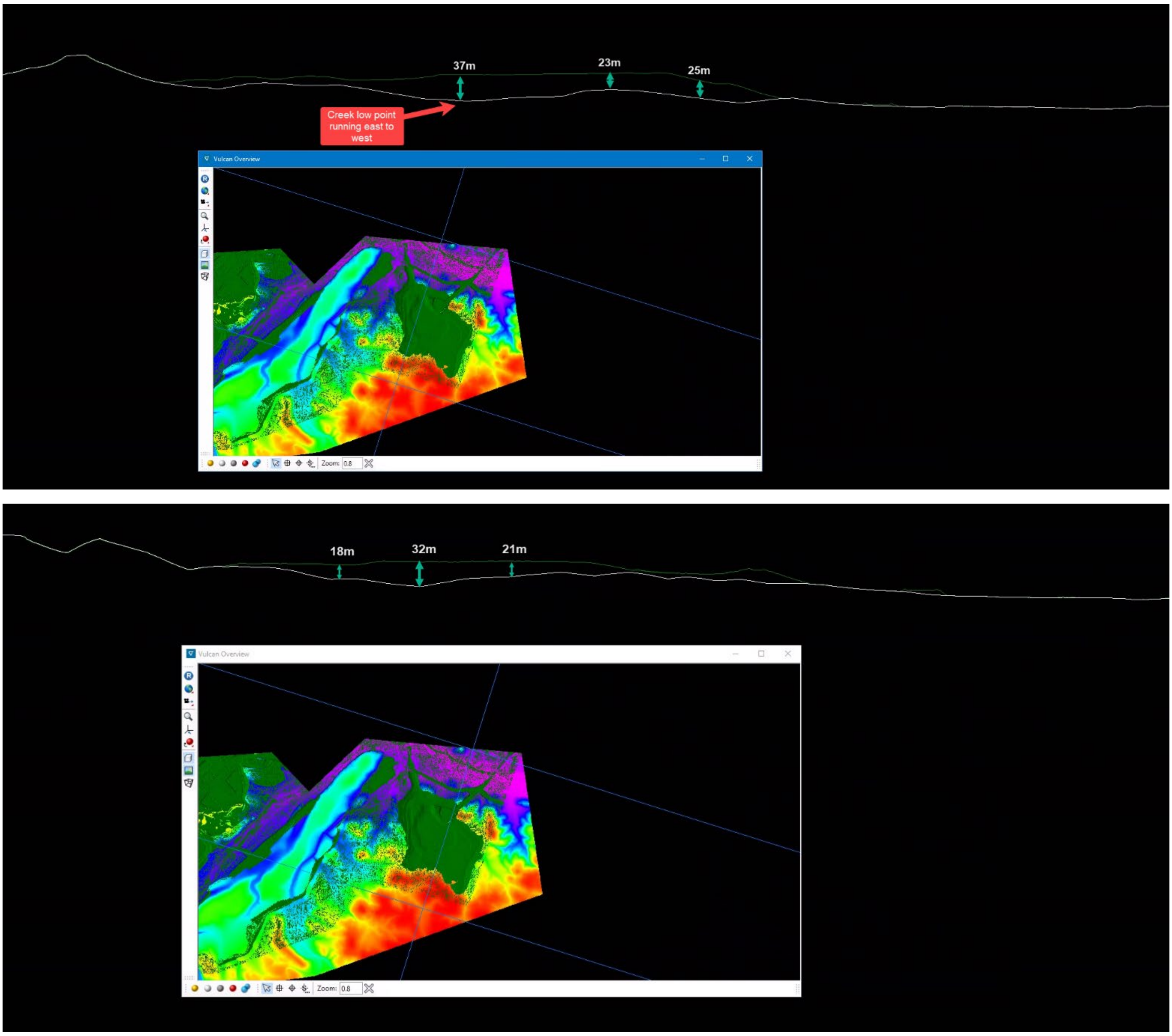


Figure B-17. Sections across C1 OSA

B.2.2 2005 rehabilitation

Landform design

The original 2005 design for the C1 OSA is provided as Figure N-18.

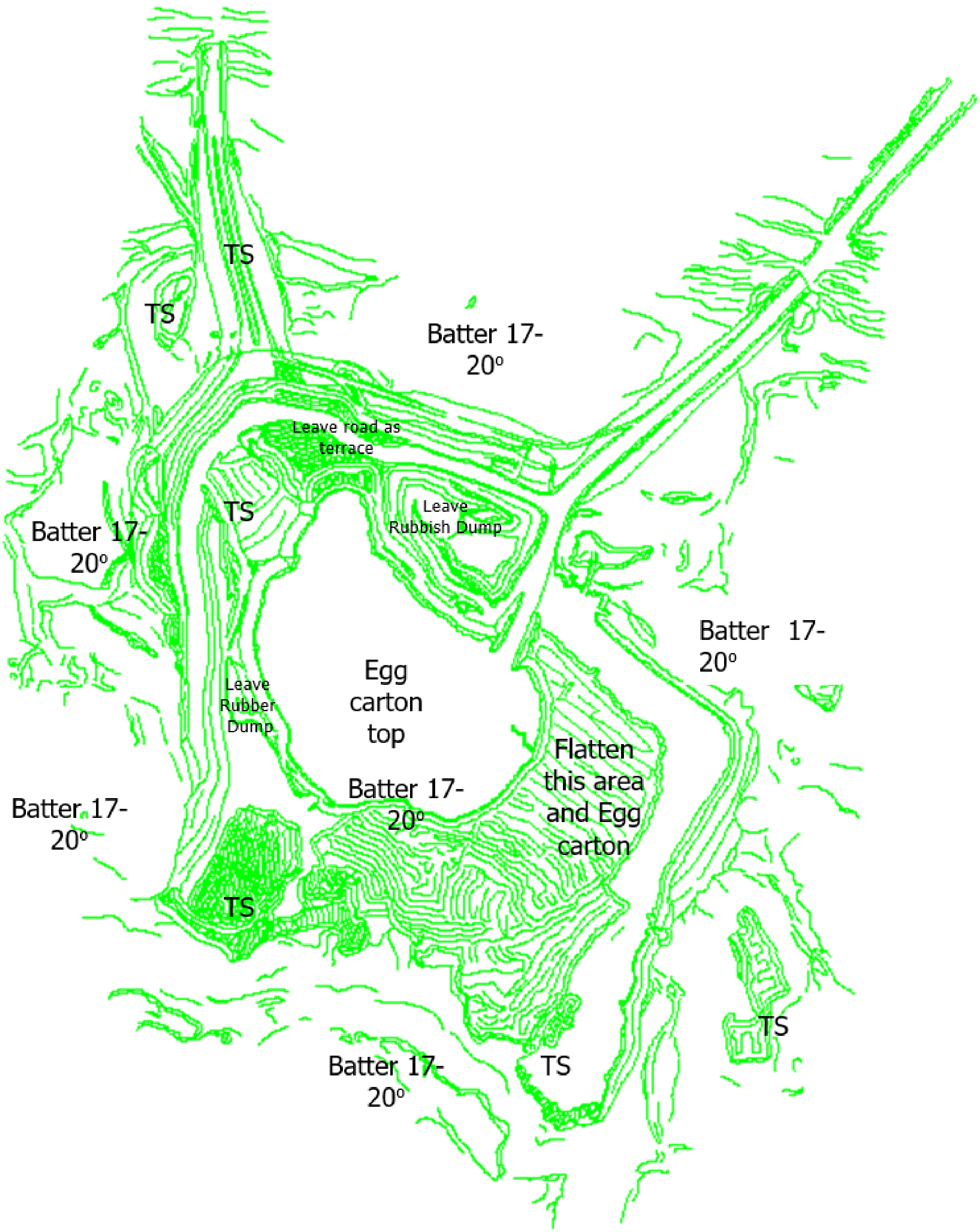


Figure B-18. C1 OSA 2005 design

2005 rehabilitation zones

The zones rehabilitated in 2005 are shown in Figure N-19 and the treatments outlined in the work pack are summarised in Table N-9.

Table B-9. 2005 rehabilitation activities outlined in rehabilitation schedule

Treatment	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Re-profile	✓	✓	✓	-	-
Spread topsoil	-	✓	✓	✓	✓
Deep rip	✓	-	-	✓	-
Contour rip	✓	✓	-	-	✓
Scalloping	✓	-	-	-	-
Seeding	-	-	-	-	-

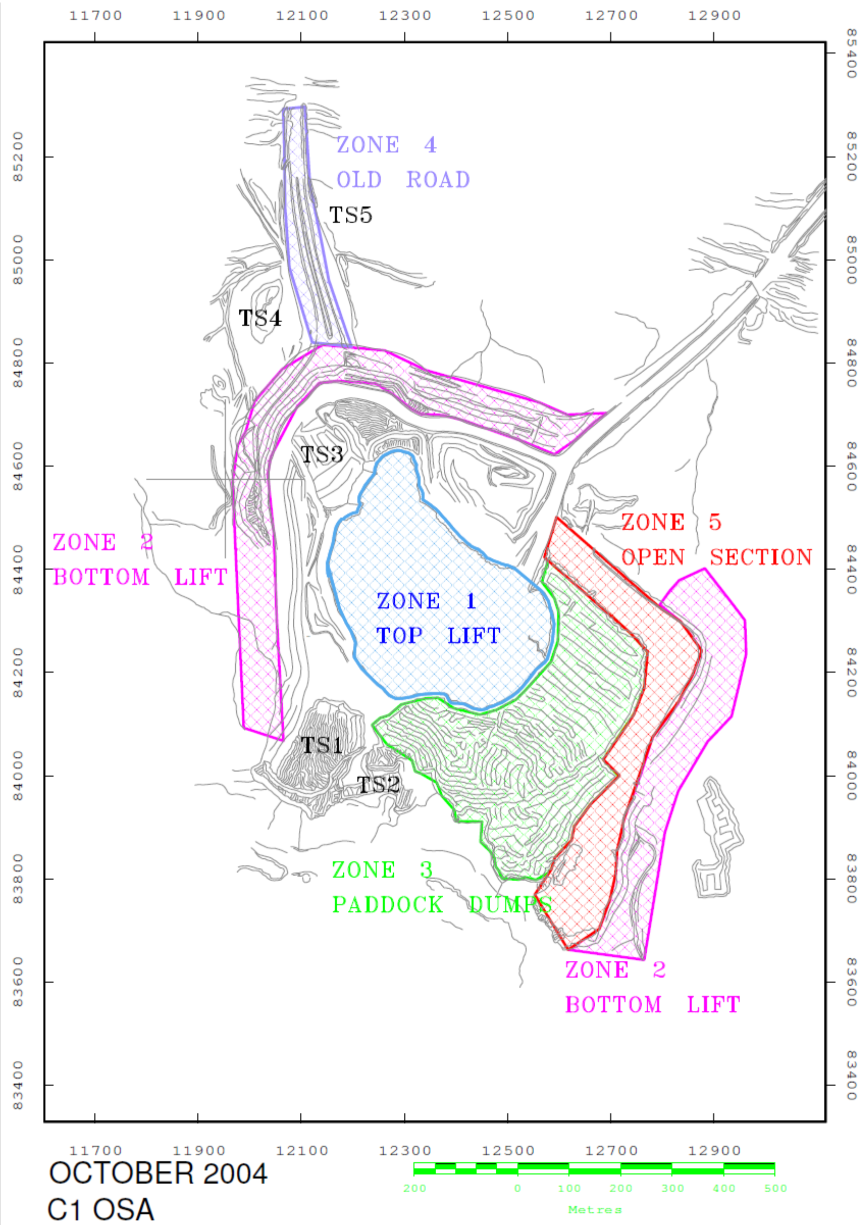


Figure B-19. 2005 rehabilitation zones

B.2.3 2011 rehabilitation

Table N-10 summarises the treatments listed in the 2011 rehabilitation summary report and work packs as being applied to the 2011 rehabilitation zones. The zones are shown in Figure N-21 to Figure N-23 and the crest windrow design in Figure N-20.

Table B-10. 2011 rehabilitation activities

Treatment	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Re-profile	-	-	-	-	-	15 - 20°	-
Spread topsoil	150 mm	150 mm	150 mm	150 mm	150 mm	150 mm	150 mm
Contour rip	✓	✓	✓	✓	✓	✓	✓
Seeded	8.71 kg/ha	8.71 kg/ha	8.71 kg/ha	8.71 kg/ha	8.71 kg/ha	8.71 kg/ha	8.71 kg/ha
Seed treatment	Half legumes treated in boiling water for 2 mins						
Seeding method	Hand seed	Hand seed	Hand seed	Hand seed	Hand seed	Hand seed	Hand seed
Crest windrows	1st lift ≥1.5 m high	Repair	-	2nd lift ≥1.5 m high	2nd lift ≥1.5 m high	2nd lift ≥1.5 m high	-
Fauna habitat	-	-	Use large logs & rocks		-	Use large logs & rocks on 1st lift	Use large logs & rocks
Surface scarification			✓	✓	✓	✓	✓

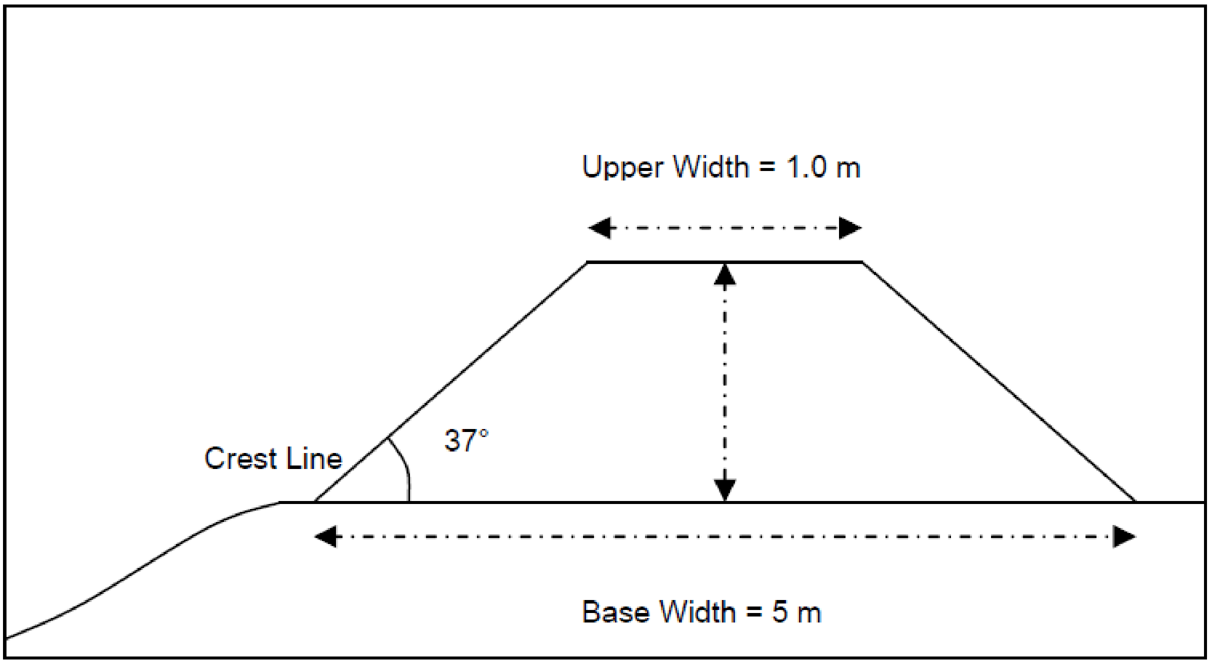


Figure B-20. 2011 crest bund design

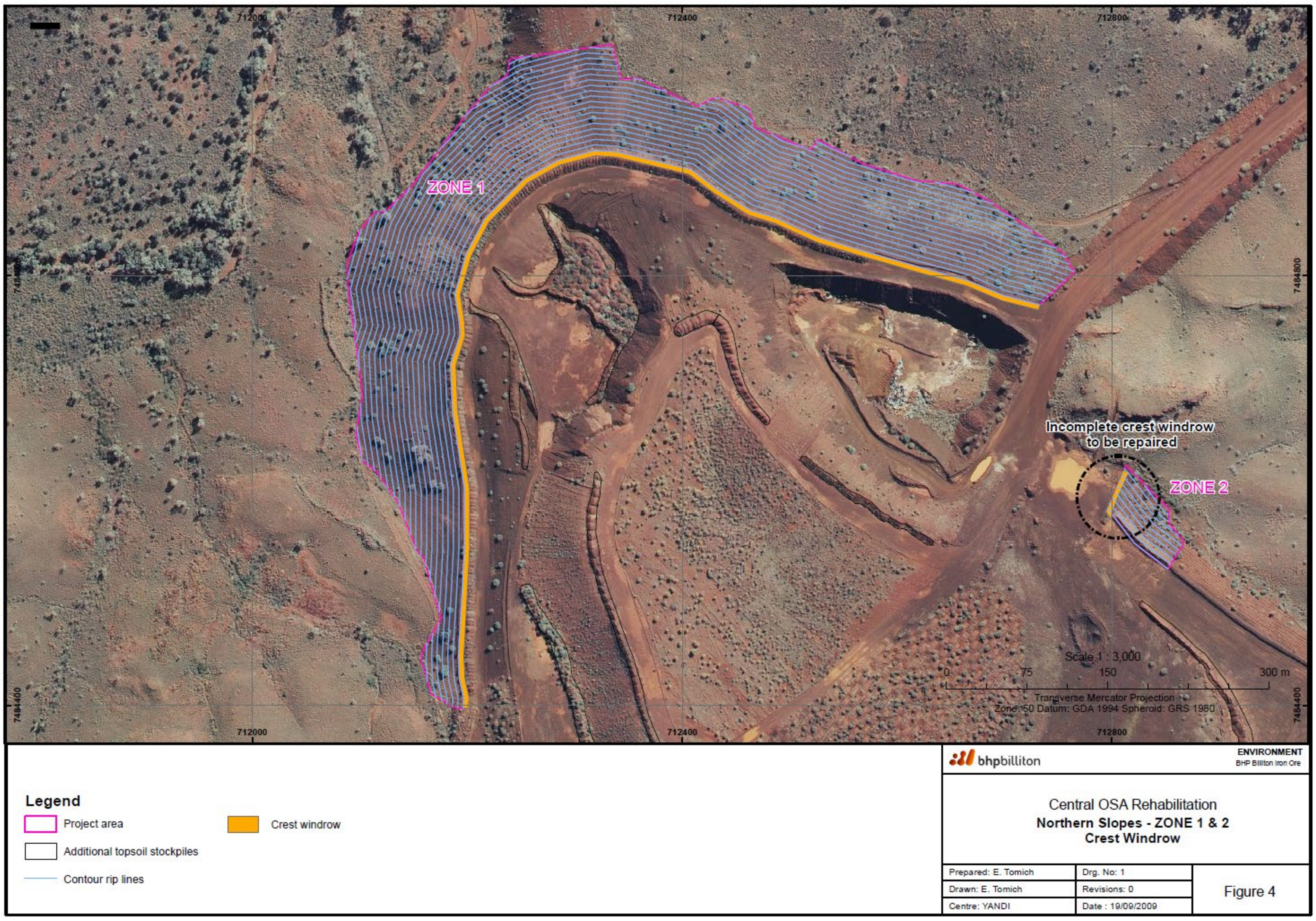


Figure B-21. 2011 rehabilitation zones 1 & 2

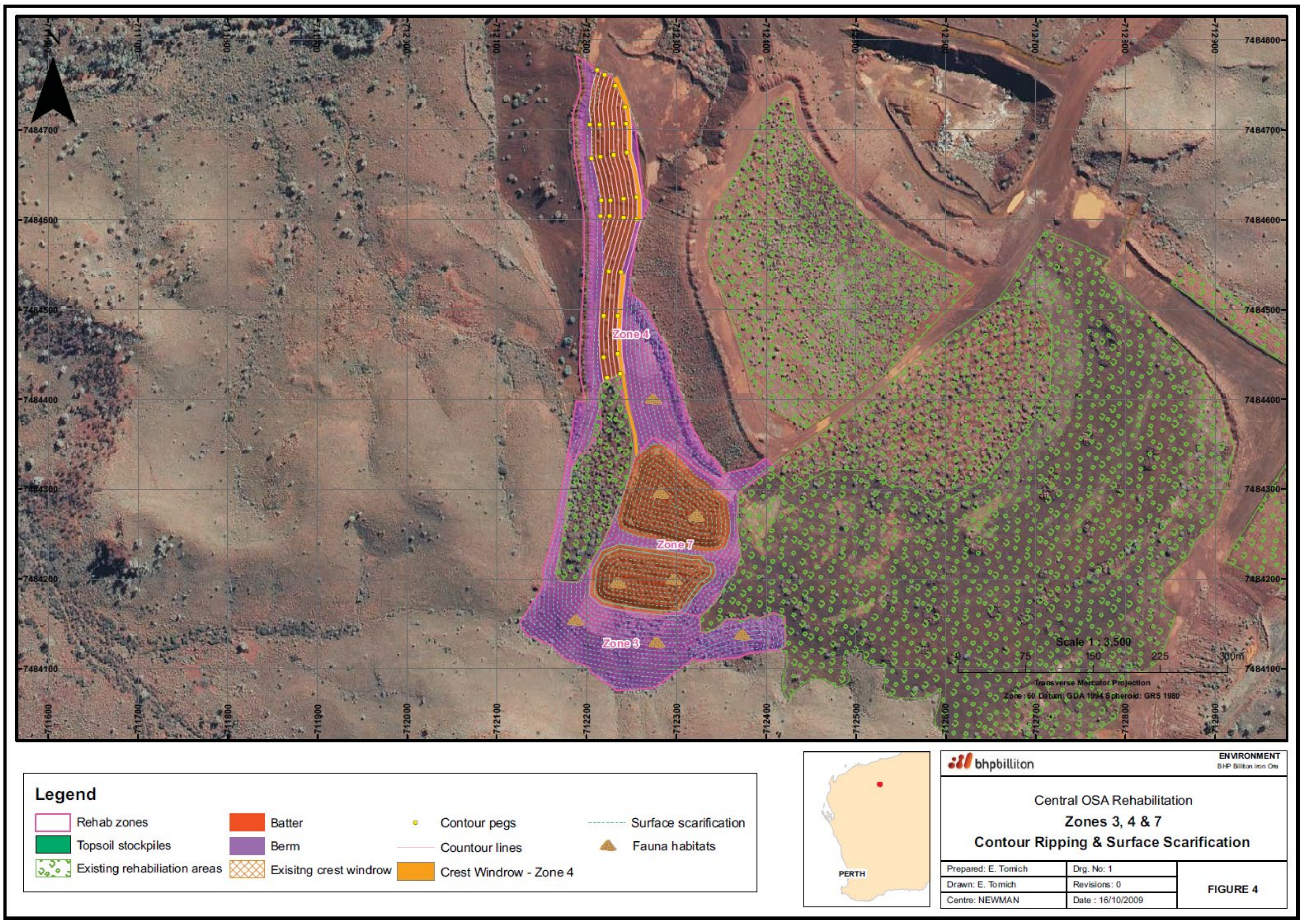


Figure B-22. 2011 rehabilitation zones 3, 4 & 7

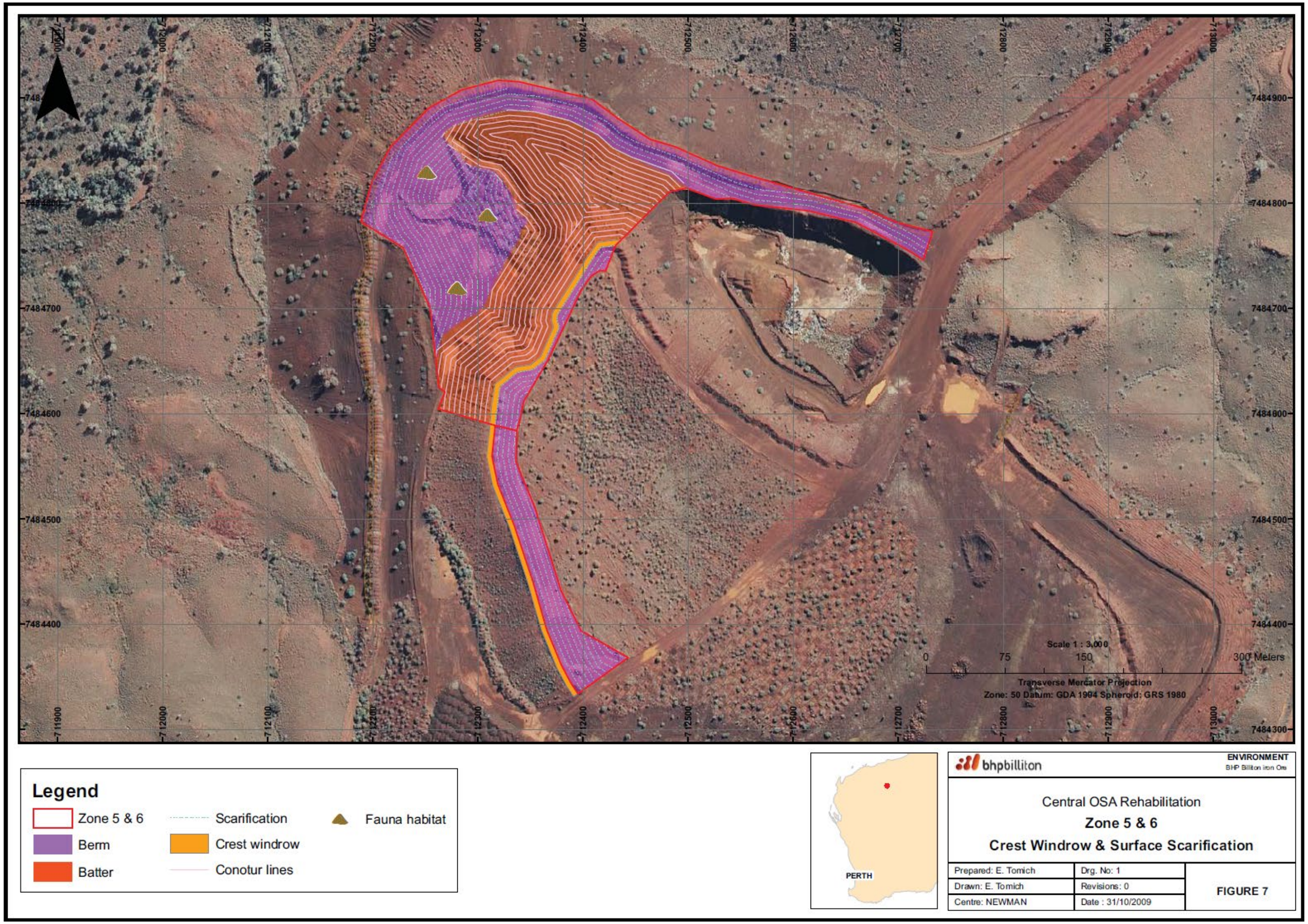


Figure B-23. 2011 rehabilitation zones 5 & 6

B.2.4 2020 east face rehabilitation

Landform design

The overburden source for the construction of the C1 OSA was from the C1 and C2 mining areas and is formed from the M4 and M3 overburden types. The overburden material is considered competent and suitable for the construction of the final landform with lifts between 20 and 30 m and slopes up to 18°. The final profile of the section of the landform regraded in 2020 is shown in Figure N-24.

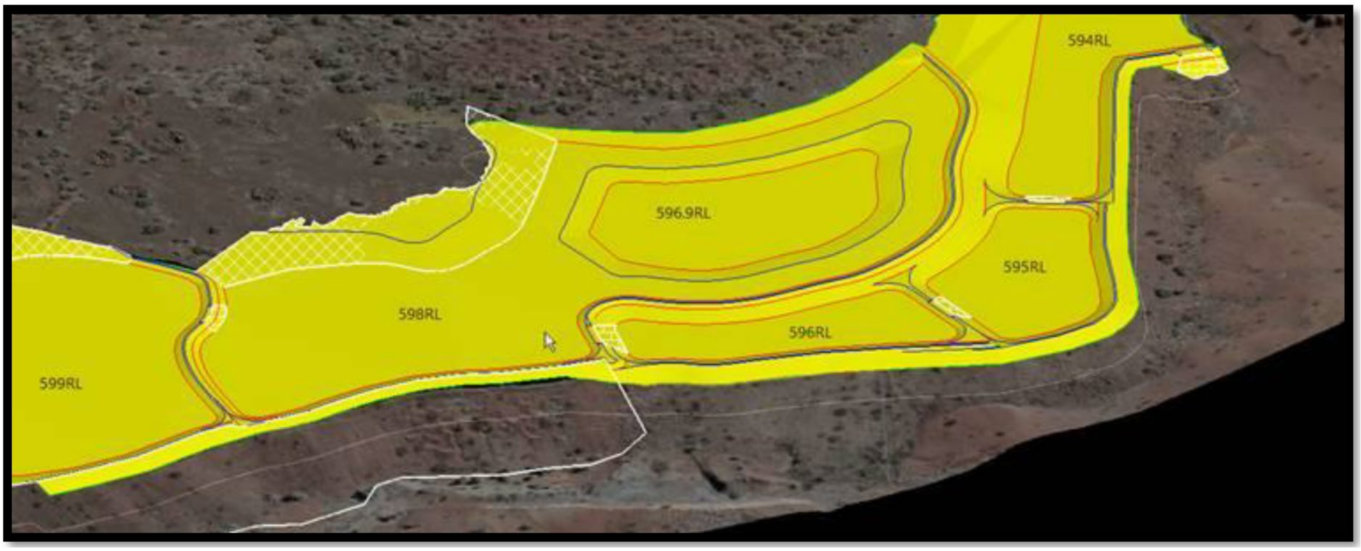


Figure B-24. C1 OSA final profile of area regraded in 2020

The OSA has been designed to contain surface water from a 72-hour 200-year ARI intensity rainfall event and to manage events that exceed that design intensity without causing excessive erosional damage and reducing the structural integrity of the landform. Catchment 1 (Figure N-25) represents the regional hillside catchment that discharges onto the OSA. Although the catchment is relatively small, the final rehabilitated design will need to consider armouring of the lower slope at the point the natural slope intersects the overburden (Armour Area 2, Figure N-26), as this will develop scouring if insufficient armour / riprap rocks are not installed to reduce the energy of the surface water flow.

Other areas requiring armour material include:

- An area on the south eastern end of the OSA where the topsoil thickness is considered excessively thick on the eastern slope (Amour Area 1, Figure N-26) and is demonstrating rilling and gully development, forming preferential flow paths which have eroded down to the underlying Yandi overburden.
- Spillway locations that allow excess surface water to be decanted into adjacent cells and then to be discharged to the external surface in a controlled manner in areas constructed to manage surface water flow.

Further details of the armouring and associated works required at key locations are provided below.

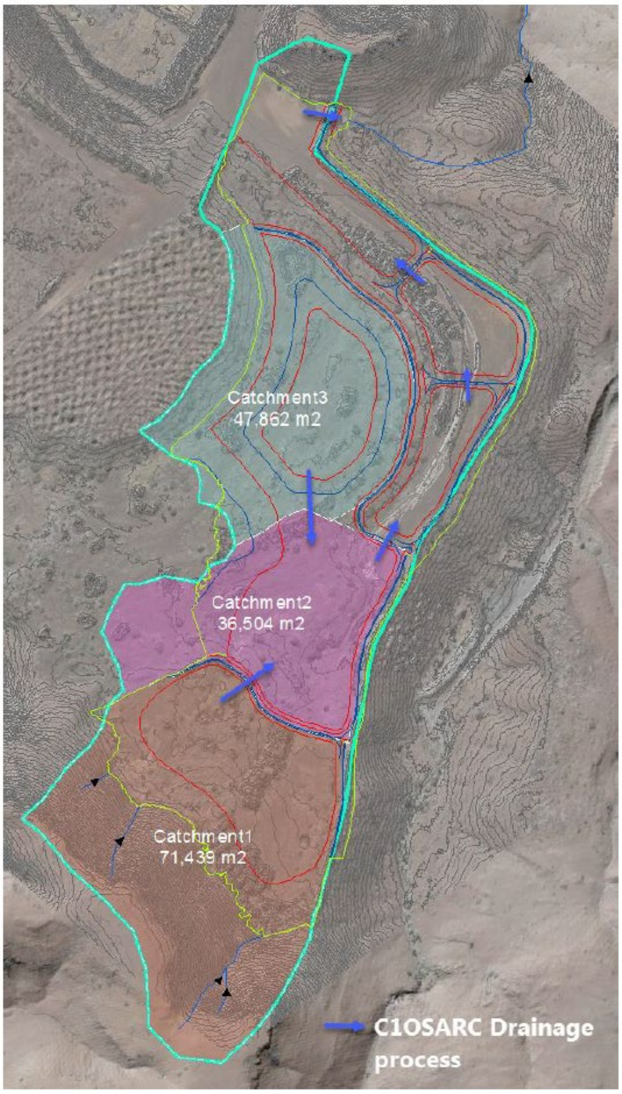


Figure B-25. C1 OSA catchments and surface water flows

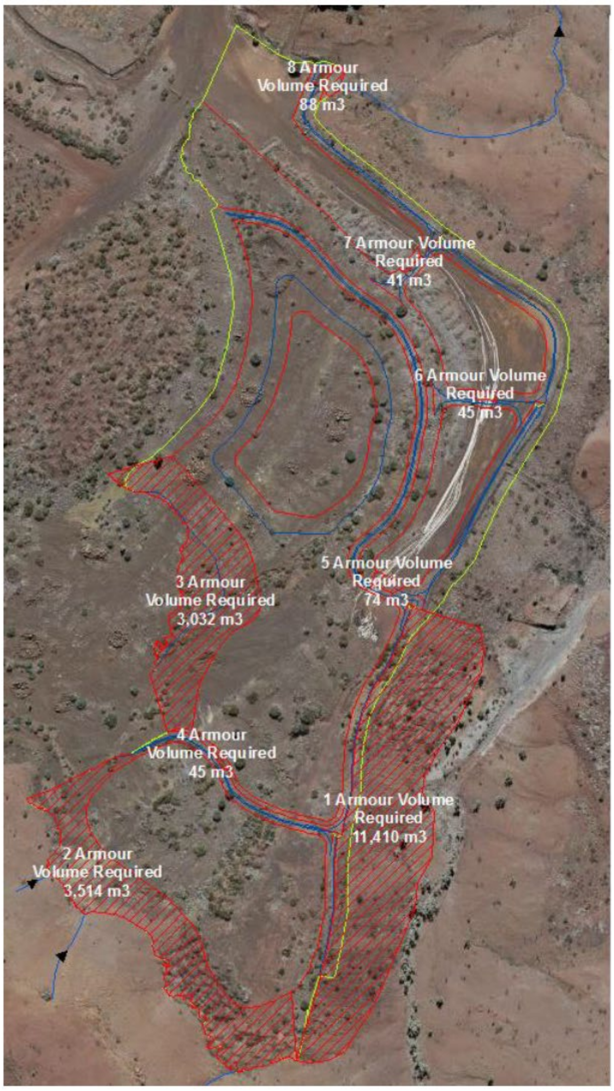


Figure B-26. C1 OSA areas requiring rock armour

Armour area 1

It is proposed to:

- Regrade sections of the OSA to remove preferential flow paths.
- Improve frontal crest bunds to manage flow down the face of the OSA.
- Integrate a volume of competent overburden into the existing surface to increase the rock percentage on the surface and reduce erosion rates. Approximately 11,410 m^3 of selected competent overburden will be recovered from the C1 OSA footprint to provide a 0.5 m thick layer that can be integrated into the topsoil in this area.

Armour area 2

This area is located on the southern end of the OSA and abuts the natural hillside (Figure N-26). It is proposed to develop a low gradient slope from the 605 m contour. The design slopes are dependent on the natural hillside and range between -7° to -10°. The underlying natural hillside is between -15° and -21°. Overburden slopes will be armoured to mitigate the erosional energy from the surface flows. It is expected that this area will require up to 3,500 m^3 of selected armour.

Spillways - armour areas 3 to 6

The C1 OSA design has a number of spillway locations that allow the decant of excess surface water into an adjacent cell. These surfaces were constructed using additional rock armour material track rolled into the underlying material forming an erosionally resistant surface. The spillways are approximately 20 m wide with a base width of approximately 17.7 m (Figure N-27).

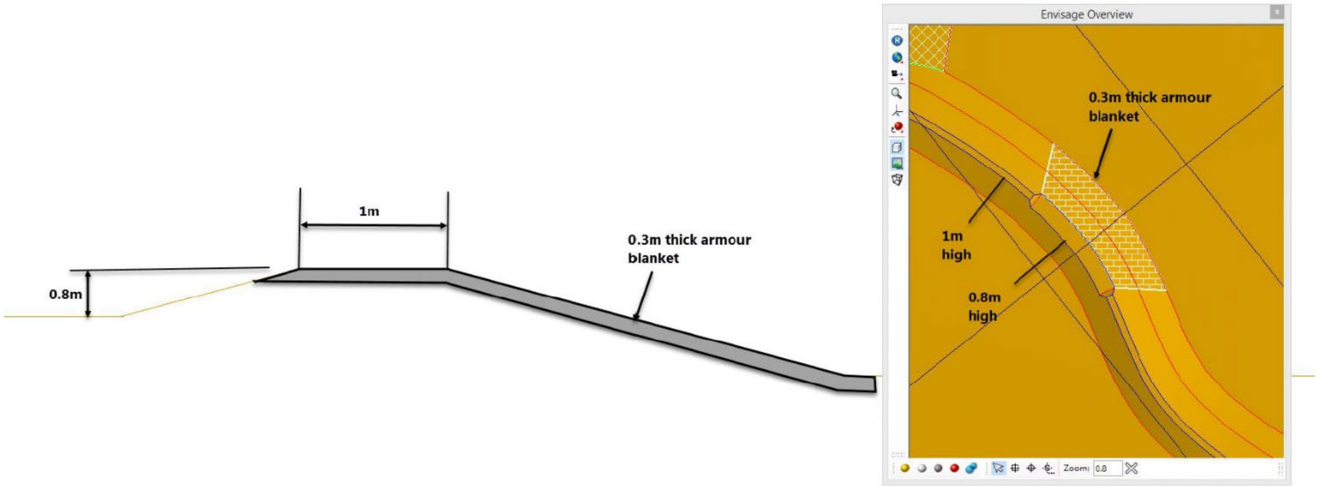


Figure B-27. C1 OSA spillway designs

Crest bunds were constructed 1.8 m high with an outer batter of 15 - 17° to blend with the OSA slope and a backslope of 10° (Figure N-28) and inter bunds were constructed in cells 1 and 2 (Figure N-29).

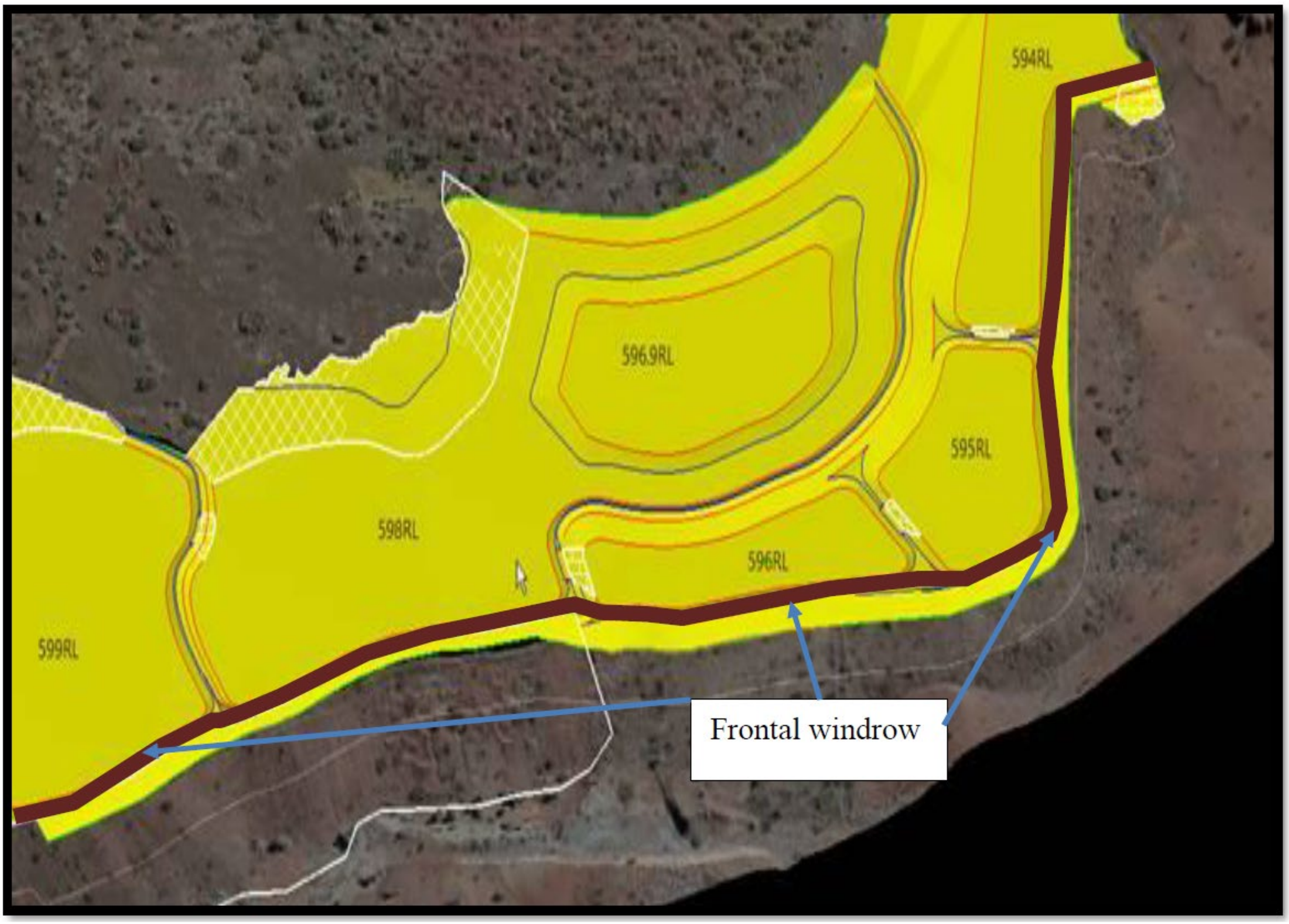
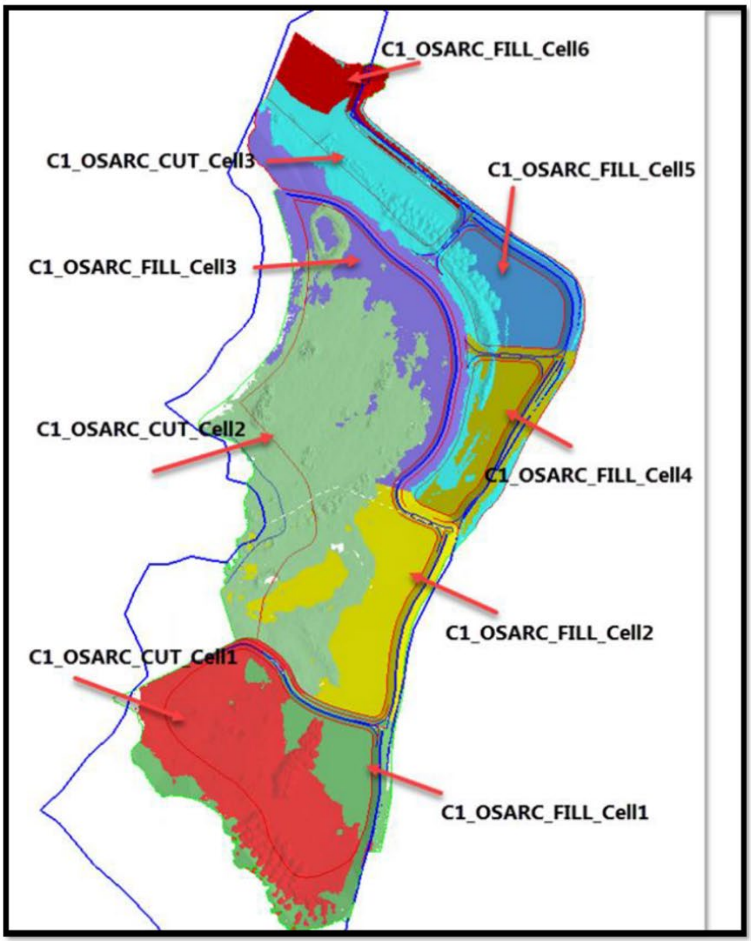


Figure B-28. C1 east face frontal crest bund



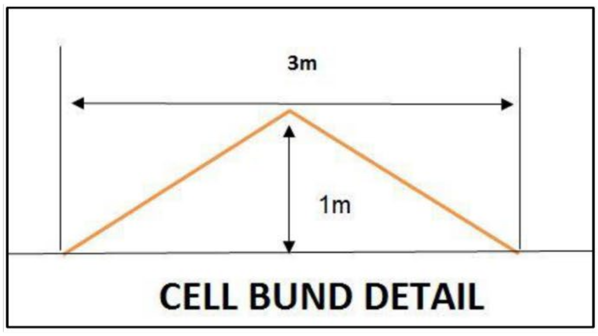


Figure B-29. C1 east face inter-bunds

Rehabilitation

All finished cell surfaces were deep ripped to a nominal 500 mm and cross ripped if necessary to reduce clod size to <300 mm diameter. Topsoil was applied with the rock armour at a rate of 1:4. Topsoil was spread 10 100 mm on OSA tops, benches and cell areas, but not frontal and inter-bunds. Following spreading, topsoil was scarified. Fauna habitat rock piles were established on flat areas.

B.3. E2 OSA

The E2 OSA has been constructed to blend in with the surrounding hillside (Figure N-30). The topography of the underlying natural ground surface is variable and consequently the fill depth of the OSA varies. The average vertical thickness across the landform is ~17 m although the thickness of some areas of overlying valleys may reach 40 m.

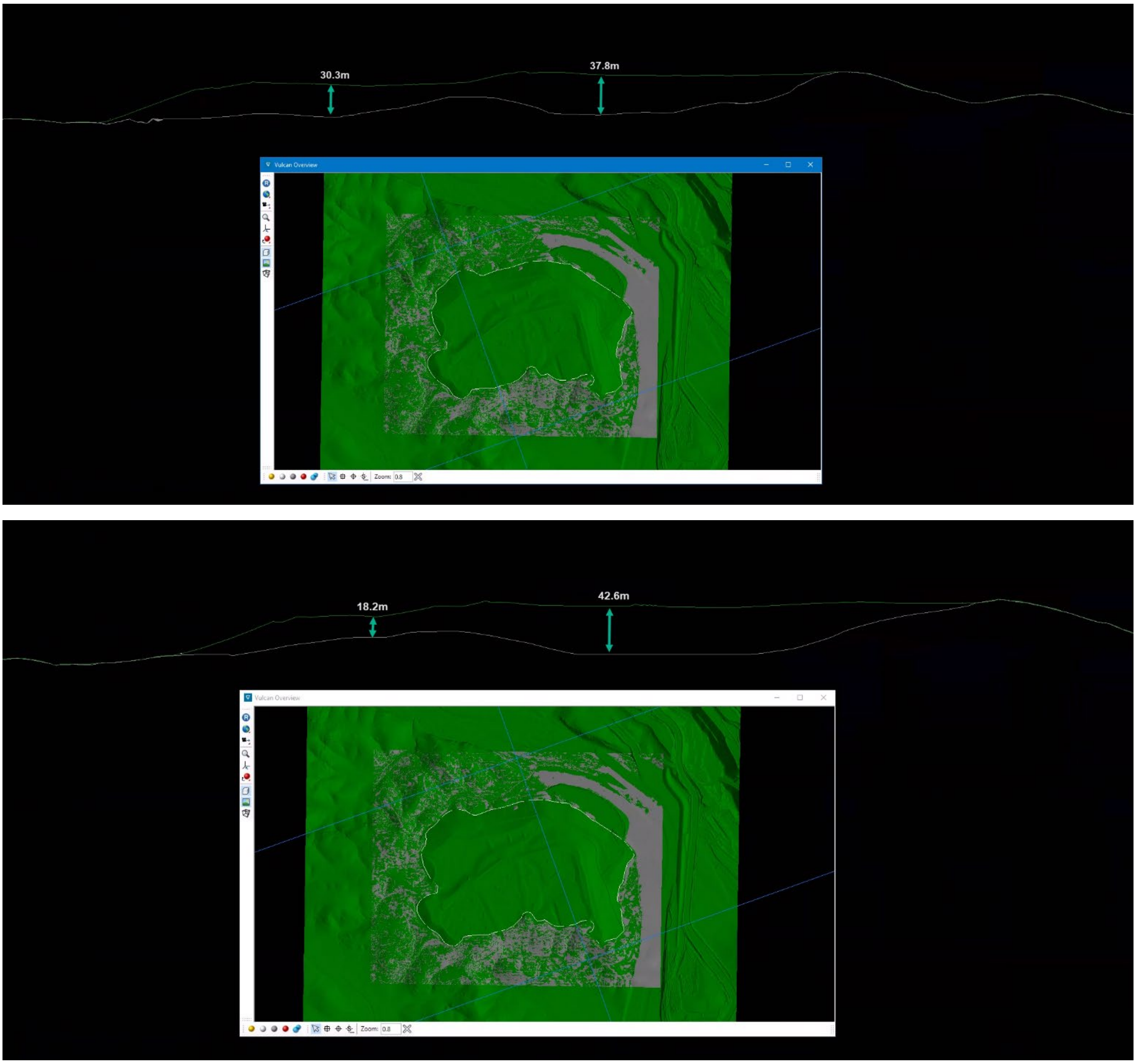


Figure B-30. Sections across E2 OSA

The original landform design for E2 is shown in Figure N-31 and the rehabilitation treatments applied to each area in Table N-11.

Drainage on the OSA was modelled and designed to be capable of withstanding a 100-year ARI rainfall event without significant scouring. The top surface of the OSA was designed to be internally draining; bunds were constructed around the perimeter of the top surface to prevent water from flowing down the slopes and minimise the potential for erosion.

Microhabitat features on the E2 OSA have included undulating final surfaces, erection of timber ‘stags’, and preferential placement of coarser rocky materials to “break-up” the rehabilitated profile and provide hollows, shelter, shade and vantage points for fauna (BHP Iron Ore, 2001).

Table B-11. Rehabilitation treatments E2 OSA

Location	Treatment	Year of Rehabilitation	Area (ha)	Monitoring Site
Lower Batter East Side		2002	41.9	BMC3

Location	Treatment	Year of Rehabilitation	Area (ha)	Monitoring Site
Upper Batter East Side	20° slope ripped on the contour. Topsoil was applied (80 - 100 mm) but no seeding was completed.		49.5	BMC4
West Face Upper Batter	Topsoil applied (80 - 100 mm), ripped but not seeded	2004	50	BMC5
North Face Upper Batter				BMC6
North crest	Deep ripped to ~0.5 m, divided into bunded cells to collect run-off. No topsoil, seeding	2004	?	-
North slope	Deep ripped to 0.5 m on the contour. Drainage channel runs diagonal down slope and consists of interceptor banks. Bunding on top and bottom of slope. No topsoil, seeding.	2004	?	-
West End	Topsoil applied (80 - 100 mm), ripped but not seeded	2004	5	BMC12A
				BMC12B
				BMC12C
				BMC12D
Upper Surface Cell A (Area 5 on Figure N-31)	Topsoil / subsoil mix spread on the high points around the edge of the cell (Figure N-32). Major drain placed on the south side of the cell. No seeding.	1998	5	BMC13A
				BMC13B
				BMC13C
				BMC13D
Upper Surface Cell B (Area 4 on Figure N-31)	Topsoil spread with some areas of subsoil (Figure N-32). A low point on the side of the cell allows for the overflow of excess water into Cell A (which then flows out the major drain). No seeding.	1998	5	BMC14A
				BMC14B
				BMC14C
				BMC14D
Upper Surface Cell C (Area 3 on Figure N-31)	Subsoil spread over the majority of the cell with a small area of topsoil / subsoil mix placed in the north-east corner. The edges of the cell in the northern half were spread with topsoil (Figure N-32). No seeding.	1998	5	BMC15A
				BMC15B
				BMC15C
				BMC15D

Source: (BHP Iron Ore, 2001; Outback Ecology, 2004; BHP Billiton Iron Ore, 2004)

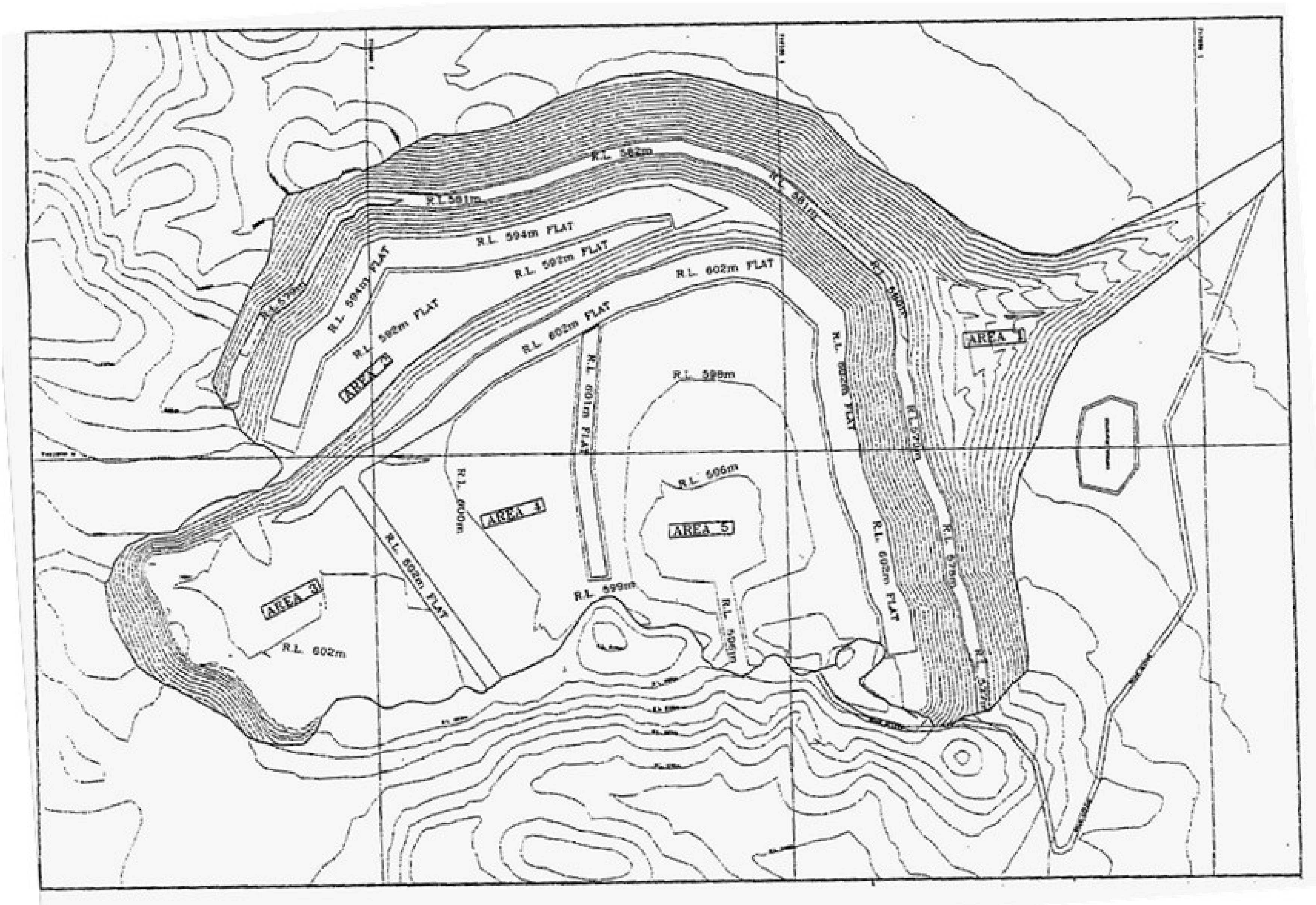


Figure B-31. Original design for E2

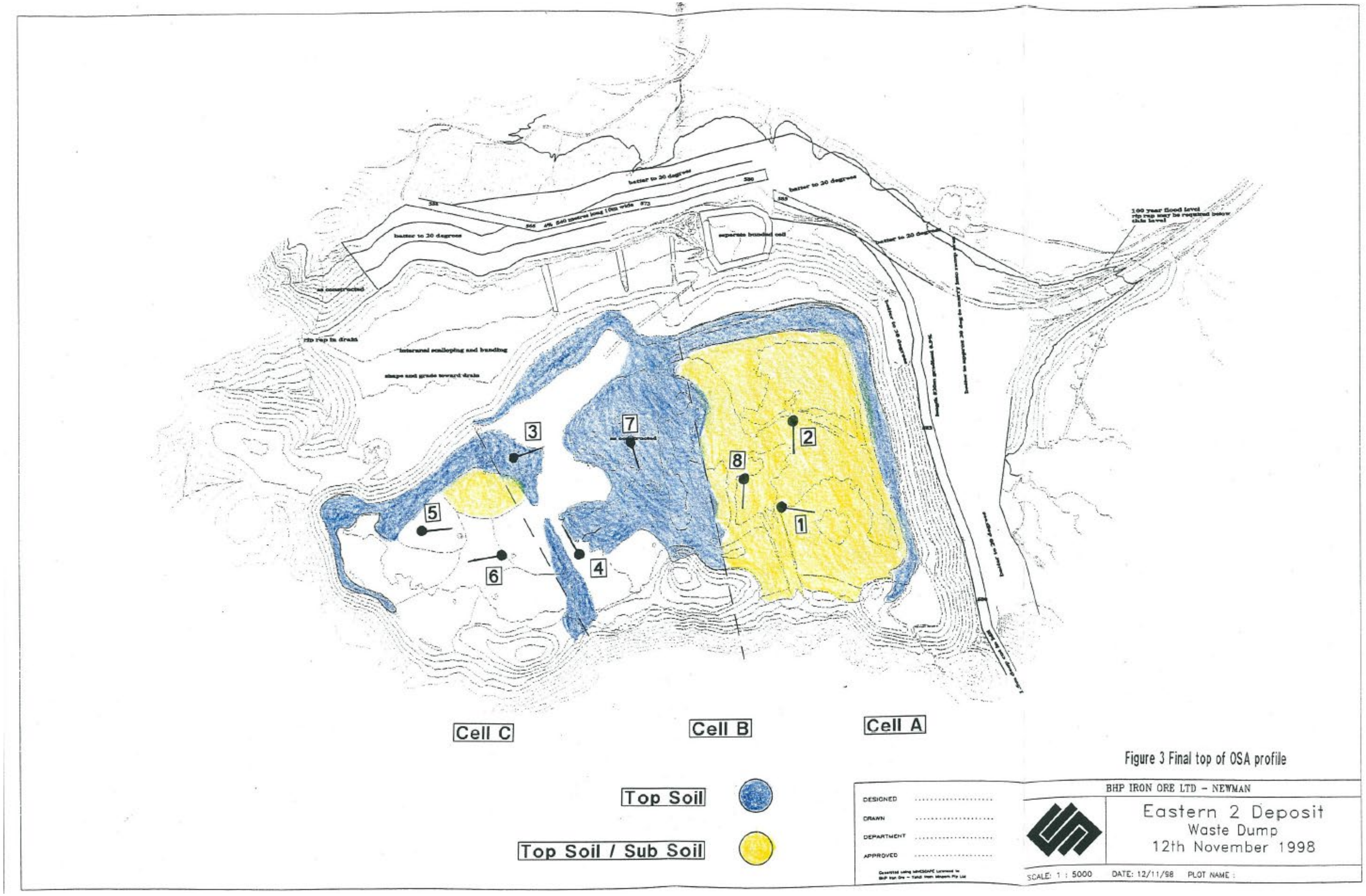


Figure B-32. Topsoil locations 1998

B.4. Rehabilitation monitoring results

Table N-12 summarises the most recent on-ground monitoring results for each rehabilitation monitoring site. It also provides a summary of the rehabilitation techniques applied at infrastructure areas, where this information is available. Figure N-33 shows the location of quadrat monitoring sites.

Table B-12. Yandi on-ground rehabilitation monitoring

Location	Monitoring Site	Landform	Rehabilitation Year	Date of Last Survey	Observations
E2 OSA	BMC3 BMC4	Slope	2002	2021	Remote sensing indicated that the area had a total native cover of 55.4% and weed cover of 20.3%, comprising *Cenchrus* spp. (19.8% cover) and *Aerva javanica* (0.5% cover). *Cenchrus* species cover was higher in 2021 compared to 2020 (0.8% cover), possibly due to an increase in the classification accuracy of other grass and *Cenchrus* sp. lifeforms. Hummock grass and other grass lifeforms were dominant, covering 23.8% and 19.0% of the area, respectively. Shrub, tree, and herb lifeforms provided 12.1%, 0.3%, and 0.2% cover, respectively. None of the area was classified as bare. On-ground monitoring described the vegetation as *Acacia pruinocarpa* low open woodland, with *Acacia dictyophleba* and *Grevillea wickhamii* tall sparse shrubland, over *Triodia wiseana* and *Triodia pungens* sparse low open hummock grassland with *Aristida holathera* var. *holathera* and *Cymbopogon ambiguus* low sparse tussock grassland. The native species richness recorded was 36 in BMC03 and 57 in BMC04. Perennial and annual species richness varied between 24-37 and 12-20 species, respectively. *Cenchrus ciliaris* was recorded with within BMC03 (25% cover) and BMC04 (12% cover). Weeds were noted as a disturbance across the site during the traverse. No erosion was recorded.
	BMC5	Slope	2004	2019	Vegetation comprises *Acacia bivenosa, Acacia colei var. colei*, and *Acacia monticola* tall open shrubland, over mixed low to mid isolated shrubs, with *Cymbopogon ambiguus* open tussock grassland. Native vegetation cover (31.6%) was within the analogue range. Vegetation structure was not similar to the analogue sites, with other grass as the dominant component, however like the analogues, shrubs were common. Native species richness (44 species; 38 perennial, six annual) was more than double the analogue mean (20 species; 18 perennial and three annual). There were no introduced species.
	BMC6	Slope	2004	2018	Vegetation comprises *Acacia monticola* (±*Acacia ancistrocarpa, Acacia pruinocarpa* and *Acacia pyrifolia var. pyrifolia*) mid to tall open shrubland, over *Acacia dictyophleba, Senna glutinosa subsp. glutinosa* and *Acacia adoxa var. adoxa* low sparse shrubland, with *Aristida inaequiglumis* (±*Cymbopogon ambiguus* and *Aristida holathera var. holathera*) open tussock grassland and *Triodia wiseana* sparse hummock grassland. Native vegetation cover (38.8%) was within the range of the analogues (22.1% to 41.2% cover). Vegetation structure showed similarities to the analogue sites, with a sparse outcropping shrub and a hummock grass component, however other grasses were the dominant lifeform. Species richness was higher (45 species, 31 perennials and 14 annuals) than the mean of the analogue sites (20 species, 16 perennials and four annuals). Of the 45 species recorded, 12 (27%) were common to analogue sites. There were no introduced species recorded. Erosion affected 9.0% of the transect. The rehabilitation was generally good.
	BMC12 BMC13 BMC14 BMC15	Crest	2004 (BMC12) 1998 (BMC13–BMC15)	2021	Remote sensing indicated that these areas had a total native cover of 81.2% and a total weed cover of 2.2%, comprising almost entirely *Cenchrus* species (2.0% cover). Shrub and other grass lifeforms were dominant, covering 24.3% and 30.9% of the area, respectively. Hummock grass (20.1% cover), tree (0.8% cover), and herb (0.4% cover) lifeforms comprised the remaining cover. None of the areas were classified as. Hummock grass cover declined by 9.2% (from 2020) and may have been the effect of an increase of other grass cover (15.7%) after above average rainfall conditions. On-ground assessment to determine species richness and composition described the vegetation as *Acacia pruinocarpa* low open woodland, over *Acacia dictyophleba* and *Acacia ancistrocarpa* mid open shrubland, over *Triodia pungens* and *Triodia wiseana* mid open hummock grassland with *Aristida contorta, Aristida inaequiglumis*, and *Cymbopogon ambiguus* low open tussock grassland. Native species richness recorded in quadrats varied between 25 - 63, perennial and annual species richness varied between 22 - 43 and 3 - 20, respectively. *Bidens bipinnata* and *Cenchrus ciliaris*, were recorded with within BMC13 and BMC14. No erosion was recorded.
C1 OSA	BMC20	Crest	2005	2021	During monitoring conducted 2019, there was evidence of a recent fire event (< 1 year). In 2021, remote sensing indicated that the area had a total native cover of 58.0% and weed cover of 2.2%, comprising *Cenchrus* species (2.1% cover) and *Aerva javanica* (0.1% cover). Hummock grass, other grass, and shrub covers were similar, covering 22.1%, 17.0%, and 15.6% of the area, respectively. Trees and herb lifeforms provided 0.02% and 3.4% cover, respectively. None of the area was classified as bare. During on-ground monitoring, the vegetation was described as *Corchorus lasiocarpus* low sparse shrubland, over *Triodia wiseana* and *Triodia pungens* sparse mid open hummock grassland with *Aristida contorta, Enneapogon polyphyllus*, and *Aristida inaequiglumis* mid sparse tussock grassland. Native species richness recorded within the quadrats was 45 species, and perennial and annual species richness were 30 and 15 species, respectively. *Cenchrus ciliaris was the only weed recorded. No erosion or other disturbances were recorded.
	BMC21 BMC26	Flat (BMC21) Crest (BMC26)	2009 (BMC21) 2011 (BMC26)	2021	Remote sensing indicated that the area had a total native cover of 79.2%, and a total weed cover of 5.9% comprising *Cenchrus* spp. (4.5% cover) and *Aerva javanica* (1.4% cover). Other grass and shrub lifeforms were dominant, covering 22.2% and 35.7% of the area, respectively. Hummock grass, tree, and herb lifeforms provided 13.6%, 0.8%, and 0.9% cover, respectively. None of the area was classified as bare. Hummock grass cover declined by 15.5% compared to 2020, potentially due to increased shrub cover (12.7%) after above average rainfall conditions. On-ground monitoring described the vegetation as *Acacia pruinocarpa* and *Acacia citrinoviridis* low open woodland with *Grevillea wickhamii* and *Acacia pyrifolia* var. *morrisonii* and tall open shrubland, over *Triodia pungens* and *Triodia epactia* low sparse hummock grassland with *Aristida contorta, Enneapogon polyphyllus* and *Cymbopogon ambiguus* low open tussock grassland. The native species richness recorded within BMC21 was 51, and perennial and annual species richness were 40 and 11, respectively. The native species richness recorded within BMC26 was 56, and perennial and annual species richness were 46 and 10, respectively. *Cenchrus ciliaris* was recorded with within both BMC21 and BMC26 and *Malvastrum americanum* was recorded within BMC21 only. No erosion was recorded.
	BMC247	Slope	2011	2021	Remote sensing indicated that the area had a total native cover of 81.7% and a total weed cover of 3.0%, comprising *Cenchrus* spp. (2.5% cover) and *Aerva javanica* (0.6% cover). Other grass and shrub lifeforms were dominant, covering 33.4% and 40.5% of the site, respectively. Hummock grass, tree, and herb lifeforms provided 6.3%, 0.9% and 0.7% cover, respectively. None of the area was classified as bare. Hummock grass cover declined by 12.3% compared to 2020, potentially as a result of increased shrub cover (21.3%) after above average rainfall conditions. On-ground monitoring described the vegetation as *Acacia pruinocarpa, Eucalyptus leucophloia* subsp. *Leucophloia*, and *Corymbia hamersleyana* low open woodland, over *Acacia ancistrocarpa, Acacia maitlandii*, and *Petalostylis labicheoides* low open shrubland, over *Triodia wiseana, Triodia basedowii* and *Triodia epactia* low sparse hummock grassland with *Enneapogon caerulescens, Enneapogon polyphyllus* and *Aristida holathera* low open tussock grassland. The native species richness recorded was 50, and the perennial and annual species richness were 40 and 10, respectively. No erosion was recorded.
C1 OSA continued	BMC25	Slope	2011	2017	Vegetation comprises *Acacia tumida var. pilbarensis* and *Grevillea wickhamii* open shrubland over *Aristida contorta* and *Cymbopogon ambiguus* sparse tussock grassland. Total vegetation cover in the quadrat was within the range of associated analogues (37%) and consisted of 30% perennial cover and 7% annual cover. Shrubs were the dominant lifeform (22.8%) followed by Tussock grasses (10.2%). Total *Triodia* cover was 4.3%. A higher native species richness (52) was recorded compared to analogues. Seven of these species (13%) were common to the analogue quadrats. The introduced species *Rumex vesicarius* was recorded with a cover of 0.01%, and *Cenchrus ciliaris* was observed during the site traverse. No erosion features were recorded.

Location	Monitoring Site	Landform	Rehabilitation Year	Date of Last Survey	Observations
W4 OSA	BMC29	Slope	2007	2015	Stability was within the range for analogues, while infiltration and nutrient cycling indices were above the analogue range. Overall native plant cover and density was within the range recorded for analogues. Plant cover was dominated by woody plant species followed by other grass species. This is not reflective of the composition of analogue transects, with the rehabilitation recording much lower *Triodia* species cover. Although plant cover consisted of predominantly native perennial cover, annual cover made up a considerable portion of the cover. A total of 35 native species were recorded; well above the range recorded for analogues. Rehabilitation consisted of multiple vegetation storeys including under, mid, upper and over-storey vegetation. Faunal niches comprising litter, logs / rocks, immature shrubs and mature shrubs were recorded, and evidence of fauna utilisation (including abundant multiple ant species and kangaroo scats) was observed. Overall, the rehabilitation is developing well. However, the lack of *Triodia* species cover is unlikely to improve without intervention given the low *Triodia* species density The introduced species **Cenchrus ciliaris* was recorded. Two erosion features classed as rills (< 0.3 m deep) were recorded. However, erosion levels were low and it was suggested that if plant cover continued to increase, erosion may be expected to decline over time.
	Landform appraisal		2007	2015	Plant cover was dominated by woody plants followed by *Triodia* species cover, while density was dominated by other grass species followed by herbaceous species. 33 native plant species were recorded in quadrats and an additional 24 native species were recorded opportunistically. There was a range of variation in species composition and vegetation structure. The introduced species **Aerva javanica*, **Cenchrus ciliaris* and **Malvastrum americanum* were recorded in the area, with numerous locations for **Cenchrus ciliaris*. Overall observations indicated that the rehabilitation was developing well for the majority of the area, with the exception of the northern section which had extensive **Cenchrus ciliaris* infestations. Multiple areas of active erosion, and two bare areas were noted, and it was suggested that intervention may be required.
RGP5 Spinifex Village HV Access YDI-15	BMC-R01	Crest	2012	2019	Rehabilitation included ripping and topsoil. Vegetation comprises *Acacia ancistrocarpa* and *Petalostylis labicheoides* tall sparse shrubland, over *Aristida holathera var. holathera* sparse tussock grassland and *Triodia basedowii* sparse hummock grassland. Native vegetation cover (14.1%) was lower than the analogue mean (32.8%), and lower still than the lowest analogue value (26.4%). Vegetation structure was similar to the analogue sites, where shrub was a dominant component. Hummock grass cover (1.5%), however, was considerably lower than the analogue mean (20.1%). The rehabilitation area is developing well and in time, hummock grasses should also continue to develop. There were no introduced flora species or erosion recorded, however an inappropriate landform and mounds were noted.
Access Rd upgrade Borrow Pits near W1	BMC-R02	Flat	2012	2019	Rehabilitation included ripping and topsoil application. There was evidence of a recent fire event (<1 year). Vegetation comprises *Eucalyptus gamophylla* and *Eucalyptus leucophloia* low open woodland, over *Acacia hilliana* low sparse shrubland and *Aristida holathera var. holathera* and *Eriachne benthamii* sparse tussock grassland. Native vegetation cover (18.0%) was lower than the lowest analogue value (25.9%). Vegetation structure was similar to the analogue sites, where shrub lifeform was a dominant component. Hummock grass cover (1.2%), however, was considerably lower than the analogue mean (25.7%). There were no introduced flora, erosion or other disturbances recorded. The rehabilitation area is developing well and in time should continue to develop towards an analogue state.
	BMC-R03				Rehabilitation included ripping and topsoil application. Vegetation comprises *Eucalyptus gamophylla* and *Eucalyptus leucophloia* low open woodland with *Acacia atkinsiana* tall sparse shrubland, over *Triodia vanleeuwenii* sparse hummock grassland. Native vegetation cover (10.1%) was approximately one third of the analogue mean (31.5%). Vegetation structure was similar to the analogue sites, where shrub and hummock grass lifeforms were the most dominant components. There were no introduced flora, erosion or other disturbances recorded. The rehabilitation area is developing well and in time should continue to develop towards an analogue state.
	BMC67	Flat	2012	2019	Rehabilitation included ripping and topsoil application. There was evidence of a recent fire event (1-2 years). Vegetation comprises *Acacia atkinsiana* and *Acacia tumida var. pilbarensis* mid to tall sparse shrubland, over *Corchorus crozophorifolius* and *Gompholobium oreophilum* low sparse shrubland, with *Triodia pungens* sparse hummock grassland. Native vegetation cover (22.6%) was slightly lower than the lowest analogue value (25.9%). Vegetation structure was similar to the analogue sites, where hummock grass and shrub lifeforms were the most dominant components. Native species richness (45 species; 39 perennial, six annual) was within the range of the analogues. There were no introduced flora, erosion or other disturbances recorded. The rehabilitation area is developing well and in time should continue to develop towards an analogue state.

Location	Monitoring Site	Landform	Rehabilitation Year	Date of Last Survey	Observations
Borrow Pit for Barimunya Airport	BMC8	Flat	2003	2018	Rehabilitation included topsoil application and ripping. There was evidence of fire (2-5 years). Vegetation comprises *Acacia inaequilatera* tall sparse shrubland, over *Grevillea wickhamii* and *Sida Arenicola* mid sparse shrubland, over *Indigofera monophylla*, *Acacia hilliana* and *Acacia adoxa var. adoxa* low open shrubland, with *Triodia vanleeuwenii* open hummock grassland, and *Paraneurachne muelleri* and *Aristida holathera var. holathera* sparse tussock grassland. Vegetation structure was similar to the analogue sites, where hummock grasses were the dominant structural component and there was a sparse shrubland. Native vegetation cover (44.2%) was higher than the highest analogue values (28.3% to 39.8% cover). Species richness was higher (43 species, 35 perennials and eight annuals) than the mean of the analogue sites (32 species, 20 perennials and 12 annuals). Of the 43 species recorded, 23 (53%) were common to analogue sites. There were no introduced species recorded. The rehabilitation was generally excellent, with a similar vegetation structure and species composition to the analogues, very good *Triodia* growth and vegetation cover, only scattered introduced flora and minor erosion or other disturbances recorded.
	BMC9				Rehabilitation included topsoil application and ripping. Vegetation comprises *Corymbia hamersleyana* low isolated trees, over *Acacia inaequilatera* and *Androcalva luteiflora* mid isolated shrubs, over *Acacia hilliana, Acacia adoxa var. adoxa* and *Gompholobium oreophilum* open low shrubland, with *Triodia vanleeuwenii* hummock grassland. Vegetation structure was similar to the analogue sites, where hummock grasses were the dominant structural component and there was a sparse shrubland. Native vegetation cover (45.8%) was higher than the highest analogue value (28.3% to 39.8% cover). Species richness was similar (43 species, 36 perennials and seven annuals) to the mean of the analogue sites (32 species, 20 perennials and 12 annuals). Of the 43 species recorded, 25 (58%) were common to analogue sites. There were no introduced species recorded. Small erosion rills and gullies were recorded in the wider rehabilitation polygon. The rehabilitation was generally excellent, with a similar vegetation structure and species composition to the analogues, very good *Triodia* growth and vegetation cover, and only scattered introduced flora and minor erosion or other disturbances recorded
	BMC10		2002		Rehabilitation included topsoil application and ripping. Vegetation comprises *Grevillea wickhamii* tall isolated shrubs, over *Gompholobium oreophilum* (±*Goodenia stobbsiana, Acacia adoxa var. adoxa* and *Acacia hilliana*) low open shrubland, with *Triodia vanleeuwenii* open hummock grassland. Vegetation structure was similar to the analogue sites, where hummock grasses were the dominant structural component and there was a sparse shrubland. Native vegetation cover (28.2%) was only slightly lower than the lowest analogue value (28.3% to 28.9% cover). Species richness was lower (22 species, 17 perennials and five annuals) than the mean of the analogue sites (32 species, 20 perennials and 12 annuals). Of the 22 species recorded, 15 (68%) were common to analogue sites. There were no introduced species recorded. Small erosion rills and gullies were recorded in the wider rehabilitation polygon. The rehabilitation was generally excellent, with a similar vegetation structure and species composition to the analogues, very good *Triodia* growth and vegetation cover, and only scattered introduced flora and minor erosion or other disturbances recorded.
Borrow Pit - Marillana	BMC18	Flat	2009	2019	Rehabilitation included ripping and topsoil. Vegetation comprised *Acacia dictyophleba* and *Acacia pruinocarpa* tall sparse shrubland, over **Cenchrus ciliaris* open tussock grassland and *Triodia wiseana* sparse hummock grassland. Native vegetation cover (15.2%) was approximately half that of the analogue mean (31.5%), and lower still than the lowest analogue value (25.9%). Vegetation structure showed similarities to the analogue sites, where tree and shrub lifeforms were the most dominant components, however hummock grass cover (3.0%) was considerably lower than the analogue mean (25.7%). Native species richness (42 species; 30 perennial, 12 annual) was higher than the analogue mean (27 species; 19 perennial and eight annual). Introduced cover was 26.0%, made up mostly of **Cenchrus ciliaris* (25.0%) and with scattered plants of **Aerva javanica* (0.01%), **Cenchrus setiger* (0.1%), **Malvastrum americanum* (0.4%), and **Vachellia farnesiana* (0.5%). Weeds, therefore, formed the dominant component at the site. The rehabilitation was characterised by lower than average native cover, low hummock grass cover, and high weed cover. There were some similarities to the vegetation structure of the analogues, with a mid to tall shrub layer and trees present, but it appears that the success of rehabilitation, in particular hummock grass development, is being impeded by weeds.
Infrastructure - OHP 2 Rail Loop FY11	BMC27	Flat	2011	2021	During monitoring conducted in 2019, there was evidence of a recent fire event (1-2 years). Remote sensing in 2021 indicated the area achieved most of the completion criteria targets, and on-ground monitoring indicated that all on-ground completion criteria targets were met. The site requires continued monitoring through remote sensing to determine if the tree and hummock grass cover completion criteria targets will be met in the future as the site continues to recover from a fire. Remote sensing in 2021 indicated the area had a total native cover of 64.2% and a total weed cover of 4.0%, comprising entirely **Cenchrus species*. Shrub and other grass lifeforms were dominant, covering 20.4% and 31.1% of the site, respectively. Hummock grass, tree, and herb lifeforms provided 8.1%, 0.7%, and 3.8% cover, respectively. None of the areas was classified as bare. Hummock grass cover declined by 33.6% from 2020, but may have been due to remote sensing ambiguity as the vegetation was recovering from a fire in 2018 / 2019. On-ground monitoring described the vegetation as *Acacia bivenosa* and *Corchorus lasiocarpus* low open shrubland, over *Triodia wiseana* and *Triodia pungens* low sparse hummock grassland with *Enneapogon lindleyanus, Enneapogon polyphyllus*, and *Aristida contorta* low open tussock grassland. Native species richness recorded in the quadrat was 33, perennial and annual species richness were 27 and six, respectively. **Aerva javanica* and **Cenchrus ciliaris*, were recorded. No erosion was recorded.
Yandi 2 Rail Loop Borrow Pit	BMC62	Flat	2011	2021	Many of the remote sensing completion criteria were achieved in 2020, but in 2021, the site did not meet the **Cenchrus* spp., total weed, or hummock grass cover completion criteria targets. All on-ground completion criteria targets were met in 2021. Remote sensing indicated that the area had a total native cover of 56.7% and a total weed cover of 11.3%, comprised entirely of **Cenchrus* species. Shrub and other grass lifeforms were dominant and covered 13.9% and 29.4% of the area, respectively. Hummock grass, tree, and herb lifeforms covered 10.6%, 0.2% and 2.6% of the area, respectively. None of the area was classified as bare. Hummock grass cover declined by 10.9% from 2020, potentially from increased 'other' grass cover (16.5%) and shrub cover (9.8%) after above average rainfall conditions. On-ground monitoring described the vegetation as *Acacia dictyophleba* low sparse shrubland, over *Triodia wiseana* low sparse hummock grassland with *Enneapogon polyphyllus, Enneapogon caerulescens*, and *Aristida contorta* low open tussock grassland. Native species richness recorded in the quadrat was 52, perennial and annual species richness were 31 and 21, respectively. **Aerva javanica*, **Cenchrus ciliaris*, and **Malvastrum americanum*, were recorded. No erosion was recorded.

Location	Monitoring Site	Landform	Rehabilitation Year	Date of Last Survey	Observations
W1 Pit Drainage	BMC63	Flat	2014	2017	Vegetation comprised *Acacia tumida var. pilbarensis, Acacia arida* and *Petalostylis labicheoides* sparse shrubland. Total vegetation cover was 25%, which is within the range of associated analogues, with less than 1% annuals. Woody shrubs were the most dominant lifeform (15.8%). Total *Triodia* cover was 0.25%. An inspection in 2021 indicated that hummock grass cover was 15% (but masked in remote sensing by high shrub cover). Species richness was 26 species and equivalent to flat analogues. Eleven species (41%) were common to the associated analogues. The introduced species, **Cenchrus ciliaris* had a cover of 0.01%. An erosion feature was recorded during the site traverse. The feature was active at the time of monitoring but appeared to be self-armouring and was considered unlikely to require remediation. Evidence of ant and termite activity on the woody debris and logs was observed throughout the site during the site traverse.
Infrastructure – Old Batch Plant	BMC24	Flat	2009	2016	Rehabilitation included seeding and topsoil application. There was negligible cover of spinifex (1.0%) compared to analogues (33-48%). Other grasses and herbs contributed substantially more cover than at analogues. Species richness has been high in most years of monitoring and 21 species were recorded. Considerably fewer native species were recorded from the analogue transects (between 6 and 13 species). A relatively high cover of **Cenchrus ciliaris* (22%) was recorded. No weeds were observed along analogue transects. An inspection in 2021 confirmed high weed cover.

Source: Woodman Environmental (2015); Biota (2016); Spectrum Ecology (2017; 2018; 2019; Spectrum, 2021)

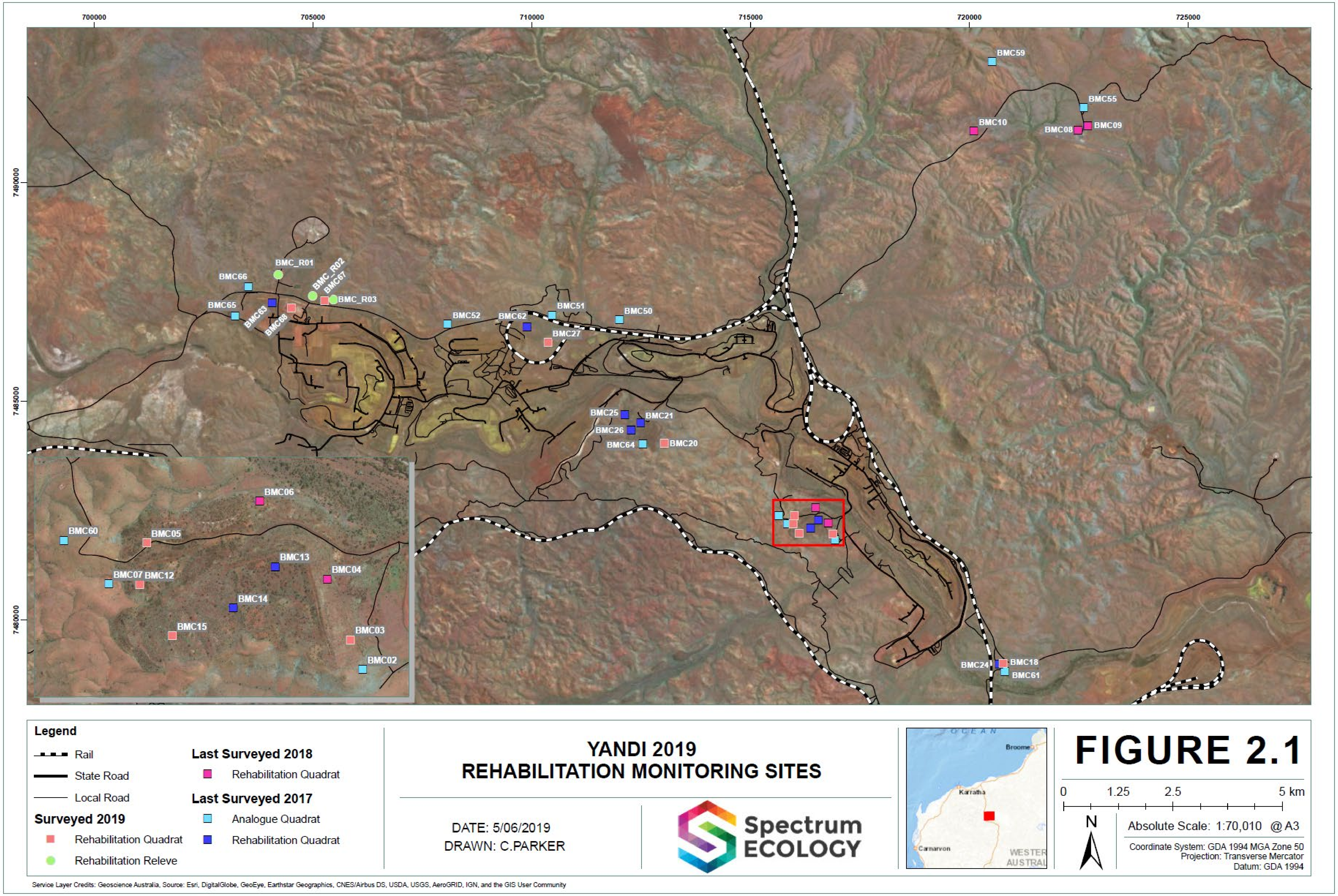


Figure B-33. Rehabilitation quadrat monitoring sites

Appendix C Snapshot of Stage 1 demolition status

Appendix D Design drawings

Appendix E Maps

Appendix F Technical Reports

The index of documents contained in this appendix is provided below. Each document is bookmarked in the navigation pane (refer to Section 1.6 of the MCP for instructions on how to use the navigation pane). Each document can also be accessed from the index by clicking on the document title (note the links will only work for documents contained within a particular volume).

Appendix R - Volume 1

R.1. Materials characterisation

R.1.1 Physical characterisation

Landloch. (2016). Yandi Waste Material Erosion Study

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