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Ecohydrological Conceptualisation of the Marillana Creek Region

Submitted to:
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REPORT

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EXECUTIVE SUMMARY

An ecohydrological conceptualisation has been developed of the Marillana Creek Region, as part of a broader Strategic Environmental Assessment associated with BHP Billiton Iron Ore's Pilbara Expansion. The overall objective was to provide an enhanced understanding of the ecohydrology, including the identification of hydrological processes that support the environment.

The specific aims of the conceptualisation were to:

- Present the major hydrological (surface water and groundwater) elements and processes with a clear link to supporting data.
- Define the catchment area based on robust hydrological (surface water and groundwater) evidence which will inform boundaries of subsequent hydrological models.
- Present the ecological values and characteristics, in terms of vegetation associations, fauna habitats, threatened species and communities, waterholes, landforms and soils.
- Identify key hydrological processes that influence and maintain the ecological characteristics of Marillana Creek (e.g. surface water drainage/flow, hydrogeology, water quality), in order to prioritise the identified ecohydrological aspects.
- Characterise interactions between mining developments and Marillana Creek.
- Provide data and derived information in a form which could be used as input to the potential development of future numerical surface water and groundwater models.

A landscape ecohydrological conceptualisation has been undertaken according to defined landscape types or ecohydrological units (EHUs). A total of nine EHUs have been identified according to landscape elements, including landscape position and land surface types, soil characteristics, water balance processes, surface drainage/redistribution processes, connectivity and interactions between surface water and groundwater systems, as well as major vegetation types and their water use strategies (refer table below).

Table 1: Summary of EHUs in the Marillana Creek Region

EHU	Percent project area	Distribution in project area	Component land systems
1	52%	The Hamersley Range comprising the uplands of the study area (predominantly the Newman Land System)	Newman; McKay (major) Oakover; Robe; Rocklea
2	27%	Foot slopes of the Hamersley Range	Boolgeeda; Platform
3	7%	Drainage floors within EHUs 1 and 2	Within EHUs 1 and 2
4	3%	Major channels within EHUs 1 and 2	
5	n/a	Sandplains in Fortescue River Valley	Not present in area
6	8%	Alluvial plains associated with major valley systems and generally adjacent to major drainage lines	Brockman; Pindering; Wannumunna
7	1%	Low calcrete platforms and plains, prominent in areas surrounding Marillana Creek between Flat Rocks and Munjina Claypan	Calcrete
8	2%	Associated with the lower reaches of Marillana Creek	River
9	0.4%	Munjina Claypan	Brockman

The study area is defined to be coincident with the surface water catchment of Marillana Creek and covers an approximate area of 2,480 km^2, and that includes the lower section of the Weeli Wolli Creek catchment. There are three active mines, including Yandi operated by BHP Billiton Iron Ore, Yandicoogina operated by Rio Tinto Iron Ore (RTIO) and Phil's Creek operated by Mineral Resources Ltd (MRL). BHP Billiton Iron Ore exploration/development projects are in various stages of development in the catchment including Munjina and Upper Marillana, Ministers North and Tandanya. There are a number of other mine development projects being progressed by other (third) parties.

There are a number of ecological assets in the study area; however, there are no recognised ecohydrological receptors. The most identifiable ecological asset is Marillana Creek itself, which is considered by BHP Billition Iron Ore to be a Tier 3 ecological asset as it contains no Threatened Ecological Communities (TECs) or Priority Ecological Communities (PECs), and has only local conservation significance. Other ecological assets include:

- Flora species of conservation significance not associated with key ecohydrological receptors, including Lepidium catapycnon and priority flora taxa recognised by Department of Parks and Wildlife
- Fauna species of conservation significance whose habitat requirements are not strongly dependent on, or otherwise intimately associated with, the key ecohydrological receptors.
- Uplands (EHUs 1 to 4) associated with intersection of the Karijini National Park.
- Uplands (EHUs 1 to 4), alluvial plains (EHU6) and calcrete plains (EHU7) associated with proposed 2015 pastoral lease exclusion areas.

The existing mining operations along Marillana Creek and Weeli Wolli Creek target Channel Iron Deposits (CIDs) that occur in a palaeochannel geomorphological environment. Other proposed mining operations also target iron ore in the Marra Mamba, Brockman Iron and Weeli Wolli Formations (all of which are banded iron formations - BIFs).

The major water-related stressors are existing, planned and potential mining operations, including Yandi, Munjina, Upper Marillana, Ministers North, Tandanya, Yandicoogina, Yandicoogina South, Phil's Creek, Iron Valley, Koodaideri Corridors and Pocket and Billiard South. Most mines will extend below the watertable and may therefore involve water-related or water-affecting activities, e.g. dewatering, groundwater supply development, surplus water discharge, surface water diversions and closure designs. The type of orebody being (or proposed to be) mined and the operation's interactions with surface water flows within Marillana Creek define the stressor. Changes to surface flows are also important because they define the behavioural responses of creek flora/fauna.

The ecohydrological conceptualisation has characterised the interactions between ecological and hydrological systems, and identifying the interactions between these systems and identified stressors. The main findings are:

- Average annual surface water flow from the catchment is about 18 GL representing around 2% of average incident rainfall of 868 GL/yr (350 mm/yr).
- Surface water flows are largely associated with remnant cyclonic rainfall events.
- There may be substantial decrease in downstream surface discharge unless Marillana Creek is diverted away from final voids.
- Groundwater discharge from the Marillana Creek catchment moves largely through the CID aquifer to the lower part of the Weeli Wolli Creek catchment, then to sub-surface discharge into the Fortescue River catchment.
- The groundwater component of catchment discharge is extremely small being approximately 1 GL/yr when compared with 868 GL/yr of annual average rainfall (about 0.1%).

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APPENDICES

APPENDIX A
Water Data Inventory

1.0 INTRODUCTION

1.1 Project description

Golder Associates (Golder) has been engaged by BHP Billiton Iron Ore to develop an ecohydrological conceptualisation of the Marillana Creek Region. It provides an understanding of the ecohydrology and identifies hydrological processes that support the environment.

This is one of four contiguous studies commissioned by BHP Billiton Iron Ore across the Central Pilbara (Figure 1). It aims to provide a regional and robust presentation of the ecohydrology within the Marillana Creek Region, and align with the other study areas being:

- Central Pilbara
- Eastern Pilbara; and
- Fortescue Marsh.

1.1.1 Location and extent

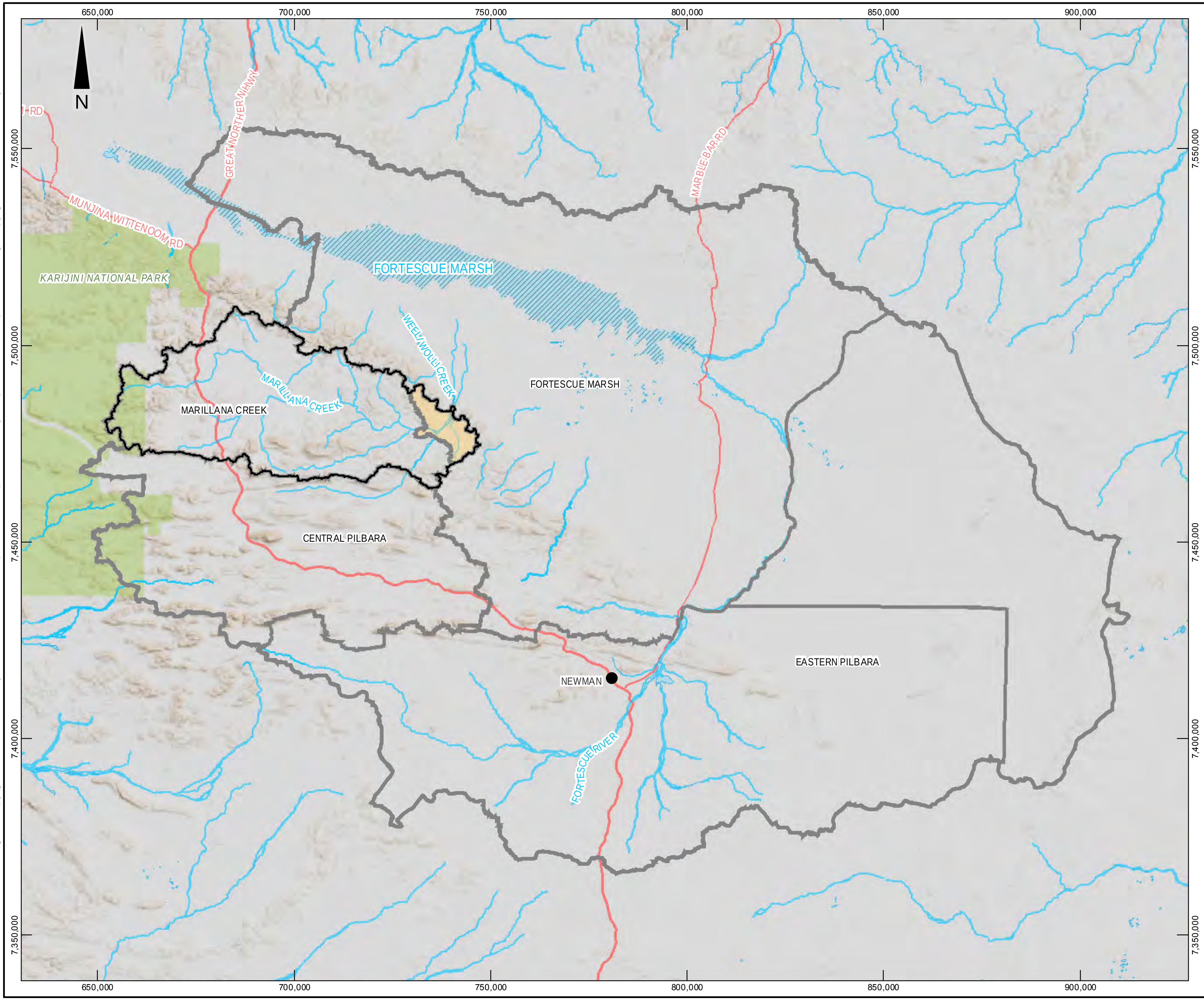
The Marillana Creek Region is about 250 km south of Port Hedland and 100 km north-west of Newman. It has an approximate catchment area of 2 480 km^2 that includes the lower section of the Weeli Wolli Creek catchment.

For this assessment, the study area is defined as the surface water catchment of Marillana Creek that is almost everywhere regarded as coincident with the groundwater catchment. The northern, southern and western boundaries are formed by low- to high-relief hills of Archaean to Lower Proterozoic rocks. The eastern part of the study area is formed by the lower part of the Weeli Wolli Creek catchment between Weeli Wolli Spring and Weeli Wolli Creek's discharge into the Fortescue Valley (Figure 2).

The only exception to the surface water and groundwater catchments being coincident is provided where Weeli Wolli Creek cuts across the main divide near the south-east corner. In this area, surface water, part of which is permanent groundwater discharge from Weeli Wolli Spring and part of which is ephemeral, flows into the lower part of the Weeli Wolli Creek catchment. Weeli Wolli Creek crosses into the study area, together with alluvial sediments and a channel iron deposit (CID) (both of which occur beneath it and follow the creek line). It is inferred that groundwater movement within the CID is in the same direction as surface water flows.

1.1.2 Areas of importance or significance within the study area

The existing mining operations along Marillana Creek and Weeli Wolli Creek target CIDs that occur in a palaeochannel geomorphological environment. Other proposed mining operations in the study area also target iron ore in the Marra Mamba, Brockman Iron and Weeli Wolli Formations (all of which are banded iron formations - BIFs). The development projects within the Marillana Creek Region, i.e. likely future mines, are shown in Figure 3.



LEGEND

- Town
- Primary road
- Creek
- Fortescue Marsh
- National park/state forest
- Marillana Creek project
- SEA project area
- SEA project overlap

NOTES

Coordinate System: GDA 1994 MGA Zone 50

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0 10 20 30 40 50
kilometres
SCALE (at A4) 1:1,300,000

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Marillana Creek SEA Project

SEA STUDY AREAS

FIGURE 1

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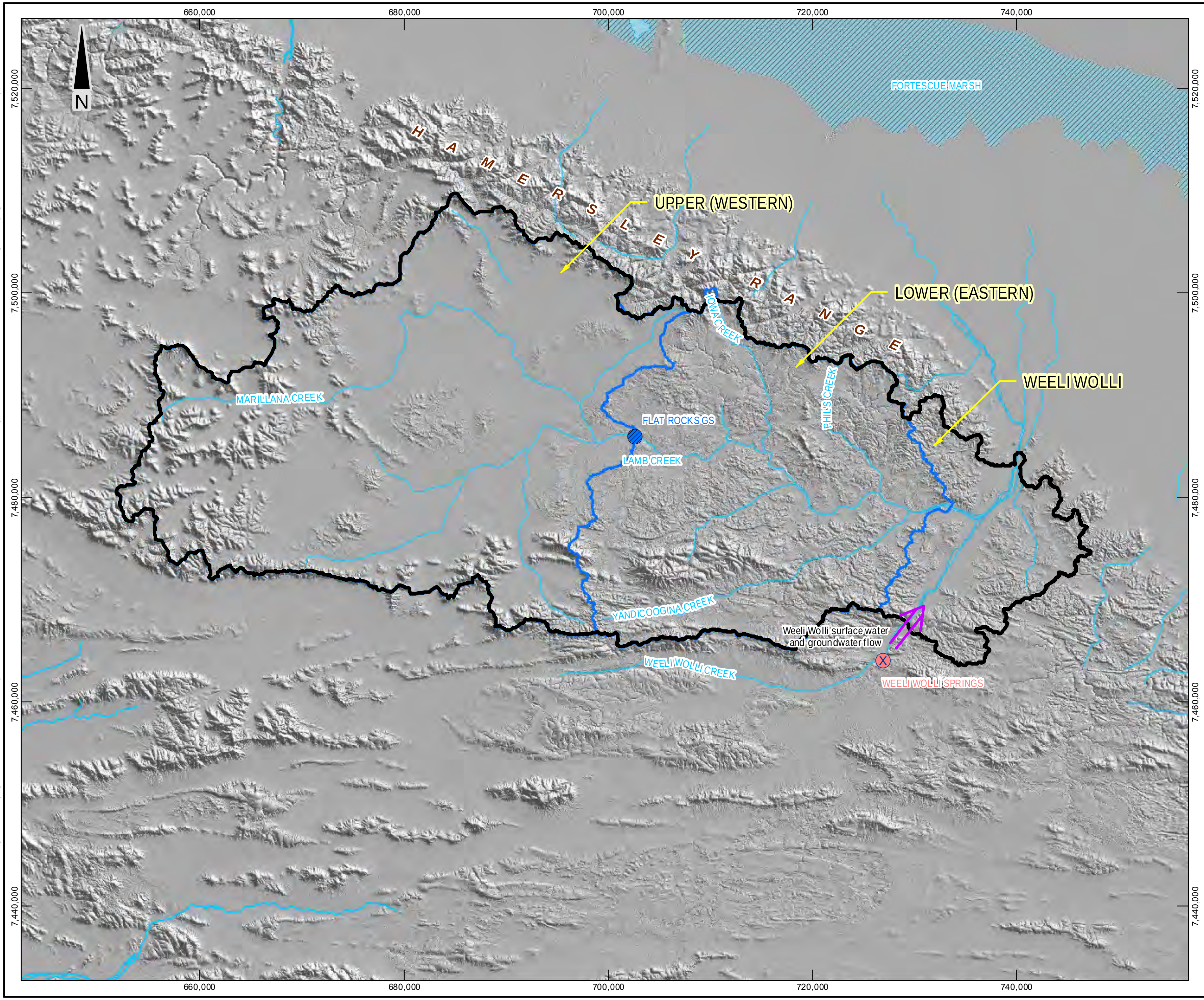

LEGEND

- Creek
- Fortescue Marsh
- Marillana Creek project
- Subcatchment divide
- Inferred direction of groundwater and surface water movement

NOTES

Coordinate System: GDA 1994 MGA Zone 50

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0 5 10 15 20
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Marillana Creek SEA Project

MARILLANA CREEK SUBCATCHMENTS

FIGURE 2

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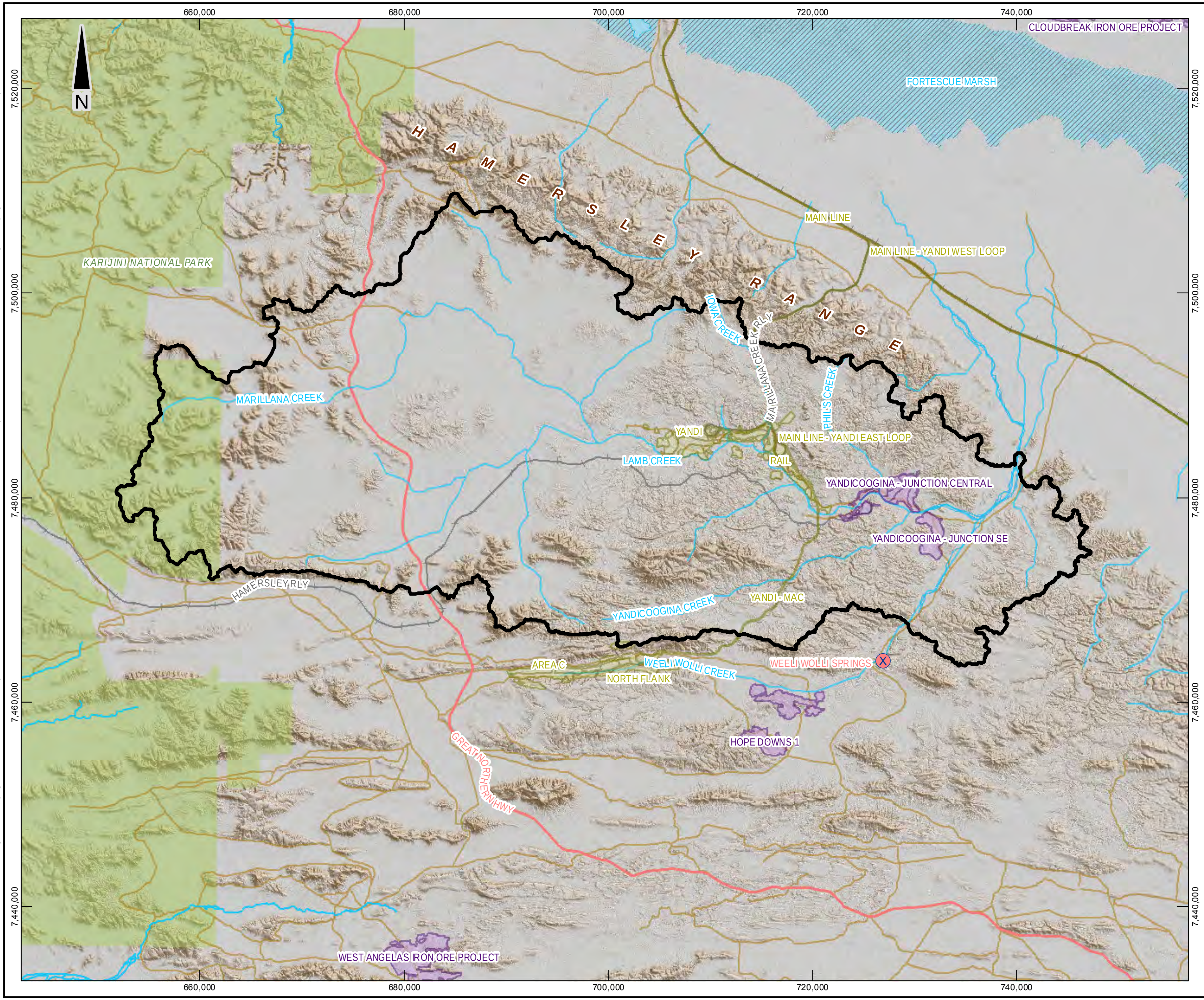

LEGEND

- Primary road
- Secondary road
- Railway
- Creek
- Fortescue Marsh
- National park
- Marillana Creek project
- Current BHP Billiton Iron Ore disturbance
- Current Third Party disturbance

The content of this map is conceptual only, of a general nature and does not purport to contain all information relevant to future project development associated with the Project. This map has been prepared solely for the purposes of informing environmental impact assessment pursuant to the Environmental Protection Act 1986 (WA) and Environment Protection and Biodiversity Conservation Act 1999 and is not intended for use for any other purpose. No representation or warranty is given that project development associated with any or all of the disturbance indicated on this map will actually proceed. As project development is dependent upon future events, the outcome of which is uncertain and cannot be assured, actual development may vary materially from this conceptual map.

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Marillana Creek
SEA Project

MARILLANA CREEK DEVELOPMENT PROJECTS

FIGURE 3

Active Mines

Three mines are active in the Marillana Creek Region being Yandi operated by BHP Billiton Iron Ore, Yandicoogina operated by Rio Tinto Iron Ore (RTIO) and Phil's Creek operated by Mineral Resources Ltd (MRL).

Proposed Development Projects

BHP Billiton Iron Ore exploration/development projects are in various stages of development in the catchment including Munjina and Upper Marillana, Ministers North and Tandanya. Other proposed development projects by third parties include Iron Valley (MRL), Yandicoogina South (Nexus Minerals Ltd, NML) and Koodaideri proposed corridor options (RTIO).

1.2 Scope and objectives

1.2.1 General

The general objectives of the ecohydrological conceptualisation are to:

- Represent the important features and processes of the hydrogeological and hydrological system; important water-dependent features and processes of the ecological system; and
- Explain the connectivity and linkages between the hydrology and ecology.

Data, information and knowledge on the study area were obtained from a wide variety of sources with the references being provided in Appendix A.

1.2.2 Specific to Marillana Creek Region

The ecohydrological conceptualisation of the Marillana Creek Region aims to:

- Present the major hydrological (surface water and groundwater) elements and processes within the study area with a clear link to supporting data.
- Define the catchment area based on sound hydrological (surface water and groundwater) evidence which will inform boundaries of subsequent hydrological models.
- Present the ecological values and characteristics, in terms of; vegetation associations, fauna habitats (including subterranean fauna), threatened species and communities, waterholes, landforms and soils.
- Identify, the key hydrological processes that influence and maintain the ecological characteristics of the creek (e.g. surface water drainage and flow, hydrogeology, water quality), in order to prioritise the identified ecohydrological aspects.
- Characterise interaction between mining developments and Marillana Creek (dependent on available data). Higher resolution and confidence are required around current and future BHP Billiton Iron Ore operations and other third-party operations.
- Provide data and derived information in a form which could be used as input to the potential development of future numerical surface water and groundwater models.

1.3 Ecohydrology

1.3.1 What is ecohydrology?

Ecohydrology is a relatively new and rapidly advancing interdisciplinary field. It integrates a wide range of disciplines including meteorology, hydrology/hydrogeology, geomorphology, biogeochemistry, soil science, and the various branches of ecology.

Ecohydrology has traditionally focused on the role of vegetation in regulating various components of the water cycle, or the influence of hydrology on plant community composition (Westbrook *et al.,* 2013). In a key publication in the Australian context, Eamus *et al.,* 2006 define ecohydrology as '*the study of how the movement and storage of water in the environment and the structure and function of vegetation are linked in reciprocal exchange*'.

Broader definitions, which consider interactions between hydrology and a wider array of biological processes, have also been proposed. For example:

*'Ecohydrology is the sub-discipline shared by the ecological and hydrological sciences that is concerned with the effects of hydrological processes on the distribution, structure and function of ecosystems, and on the effects of biotic processes on elements of the water cycle' (*Nuttle, 2002).

'*Ecohydrology* [is] *the science of integrating hydrological and biological processes over varied spatial and temporal scales*' (Bonacci *et al*., 2008).

'Ecohydrology [is] *the study of the interactions and interrelationships between hydrological processes and ecosystem patterns and dynamics'* (Neumann, 2013).

In all cases, ecohydrology seeks to provide an explanatory, rather than descriptive, understanding of landscapes. A practical impetus for gaining such understanding is the improved management, protection and/or restoration of landscape, water and ecological assets.

The broader definition of ecohydrology has been adopted in this report.

1.3.2 Ecohydrology principles

The Pilbara is a hot and dry environment. Recent studies of ecological processes in dryland environments with similarities to the Pilbara have highlighted the importance of relationships between ecology, geomorphology and hydrology for describing landscape ecohydrology (Turnbull *et al.,* 2012; Merino-Martín *et al.,* 2012; Miller *et al.,* 2012; Mueller *et al.,* 2014). Key concepts and principles underlying the development of an ecohydrological conceptualisation for the central Pilbara Region can be summarised as follows:

- Pathways and connectivity
- Spatial/temporal scales
- Vegetation patterns
- Plant water use strategies
- Landscape history
- Ecological water requirements of wetlands.

These aspects are discussed below.

Pathways and connectivity

This section considers:

- the various pathways that water can travel through the landscape, either on or beneath the land surface
- the factors that facilitate or impede the passage of water along different pathways
- how the pathways connect different landscape elements and ecosystem components.

Water is the primary medium of connectivity in dryland environments, because it controls physical and biological processes across different scales (Austin et al., 2004; Wang et al., 2009). Water not only connects and separates landscape elements, but is also the primary transporter of energy and across many of these landscapes.

Pathways and networks of high relevance for the Pilbara environment include:

- the soil–plant–atmosphere continuum (Figure 4). Note that soil properties such as infiltration and storage in the unsaturated profile influence runoff behaviour, and play an important role in making water available for uptake by vegetation. Sub-soil characteristics may facilitate or impede the infiltration of water into underlying groundwater resources.
- surface flow along preferred pathways such as channels, rivers and floodplains is dictated by topography and geomorphology but also influenced by vegetation (Figure 5).
- groundwater movement is primarily driven by hydraulic gradients, although salinity gradients can also give rise to flows induced by differences in water density. Properties of basement rocks and the regolith affect aquifer transmissivity. Preferred pathways, for example those associated with geological fault lines or palaeochannels, can be important for connecting landscape elements.

The term connectivity describes the nature of, and degree to which, landscape elements are connected by water pathways. In a spatial context connectivity operates in longitudinal, lateral and vertical dimensions; and also has a temporal dimension across each of these spatial dimensions (Jaeger & Olden, 2012). Note that connectivity both influences and is influenced by landscape and ecosystem processes. For example, vegetation root systems can contribute to the development of preferred pathways for groundwater recharge along root channels (Wilcox *et al*., 2008), or hardpan layers which impede deep drainage (Verboom & Pate, 2006). Hence, ‘ecohydrological connectivity’ can be regarded as a system level property, arising from linkages in the networks of water movement through ecosystems and by which feedbacks and other emergent system behaviours may be generated (Miller *et al*., 2012). The modification, loss or creation of connectivity has the potential to cause reversible or irreversible ecosystem change.

Rainfall is redistributed three dimensionally. Surface runoff is a key redistribution process. At landscape and sub-landscape scales, preferential surface flow via preferred pathways (drainages) is a major lateral and longitudinal connectivity factor in the Pilbara. Channel geomorphology can be categorised based on the magnitude and energy of transmitted flows (primarily a function of catchment size and topography).

- Minor drainages are associated with small catchment areas in upper landscape positions. Minor drainages aggregate to form larger drainages.
- High-energy drainages are generally large and incised, and often exhibit regular bed load movement. They receive the combined flows and energy of minor drainages, reinforced by topographic gradients along their own length. They generally occur in upland landscapes associated with hills and ranges. Systems transmitting very large flow volumes (e.g. Weeli Wolli Creek) can exhibit high energy drainage characteristics in zones of energy dissipation extending some distance from the base of the uplands across flatter country.
- Low-energy drainages are commonly braided, meandering and/or anabranching. They are prevalent in areas of low relief (predominantly broad alluvial plains) where the energy of upstream flows is dissipated. Low energy drainages often feature channel flow retardation structures related to avulsion, floodouts and splays.

Sheetflow can also be an important water redistribution process on some low gradient surface types (i.e. gentle slopes of about 1:50 to 1:500 as indicated by Bromley *et al*., 1997). In practice, it is difficult to distinguish between sheetflow and channel flow zones without very high resolution surface elevation data. Some landscape surfaces are likely to exhibit both sheetflow and preferential flow characteristics under different wetting scenarios.

Soil properties can influence the movement of water and nutrients in the landscape, which in turn affect patterns of vegetation. Soils in upland areas of the central Pilbara are generally shallow with relatively low water holding capacity. Deeper soils occur in association with drainage lines and depositional flats. Small rainfall pulses only recharge soil moisture in the top layers, whereas less frequent large pulses can penetrate to a greater depth where permitted by the soil profile. Sub-soil hardpans, which may restrict vegetation root depth, are common on Pilbara washplains and alluvial flats.

Groundwater flow through linked aquifers is an important pathway for catchment scale water distribution in the Pilbara and transferring water from areas where rainfall recharges groundwater (e.g. in uplands and river channels) to lower lying terrain. In certain geomorphologic circumstances, groundwater may express at the surface or within the depth of vegetation root systems. Ecosystems in these areas may have varying levels of dependence on groundwater availability.

Spatial/temporal scales

Ecohydrological processes can be considered at different spatial and temporal scales. Four spatial scales relevant to ecohydrology processes in dryland environments are commonly recognised (Mueller *et al*., 2014):

- Plant-interspace scale – individual plants and their adjacent bare interspaces
- Patch scale – multiple plant-interspaces, typically on the same soil or geomorphic unit
- Landscape scale – a landscape unit characterised by internal connectivity
- Regional scale – multiple landscape units, commonly within one or more contiguous biomes.

Temporal scales are important for water movement, storage, release and accessibility to biota. For example, overland flow connectivity in the Pilbara is episodic and unidirectional. Consequently, many Pilbara ecosystems are strongly influenced by, and are adapted to, erratic water inputs. Surface channels can transmit water long distances in a matter of hours. Conversely, stored soil water in deep, accessible profiles may sustain vegetation water use for many months or even years. Similarly vegetation may have access to transient or persistent groundwater.

Both spatial and/or temporal processes can be important for overall system understanding. The importance of localised versus wider scale processes will vary depending on specific requirements asked of particular ecohydrological models. In the case of this assessment, the primary interest is the evaluation of potential impacts on environmental assets beyond areas of direct disturbance associated with mining and infrastructure developments (i.e. outside vegetation clearing footprints). In this context, the scales of highest relevance for ecohydrological conceptualisation are landscape and region.

Vegetation patterns

In arid and semi-arid regions, the interaction and feedbacks between climate, soils, vegetation and topography give rise to distinct patterns of vegetation and surface water re-distribution. These patterns are important determinants of many other ecosystem attributes. As such, patterns of vegetation can provide information about ecohydrological processes. For example, banded vegetation formations are generally considered to be associated with zones of sheetflow, which occur as broad inter-drainage areas on alluvial plains near the base of hills and ranges. Major channels often host Eucalyptus woodland communities, which are sustained by inflows combined with deep soils that can store large volumes of water.

Leaf area index (LAI) provides an indicator of water availability for vegetation, consistent with the principle of ecological optimality (O’Grady *et al*., 2011; Ellis & Hatton, 2008). This principle suggests that over long time scales, vegetation in water limited environments will equilibrate with climate and soils to optimally use the available soil water. As a consequence, high LAI is correlated with high water availability and often occurs in areas with:

- deep soil profile with large water storage capacity, combined with surface or sub-surface lateral inflows

- low salinity groundwater accessible to vegetation root zones.

In the Pilbara, relationships between vegetation LAI and patterns of drainage are visually evident. It is important to note that, LAI is a dynamic vegetation characteristic influenced by climate, vegetation succession patterns and disturbances such as fire and grazing. Seasonal effects, including the growth cycle of ephemeral plants, may also be important. Areas that persistently maintain very high LAI relative to surrounding vegetation are more likely to have access to (and potentially a dependency on) groundwater.

Plant water use strategies

Plant species in water limited environments segregate along an eco-physiological spectrum of contrasting water use strategies. Relevant traits that determine water use strategies are: acquisition efficiency (root traits) and use efficiency (leaf and stem traits) as suggested by Moreno-Gutierrez *et al.* (2012). Broad plant functional water use types include:

1. Transient opportunistic – species with shallow systems; respond rapidly to rainfall pulses; exhibit a range of drought avoidance strategies (e.g. ephemeral life history, dormancy etc.).
2. Conservative shallow rooted – species with low but persistent water use; relatively low responsiveness to rainfall; exhibit a variety of adaptations for regulating root water uptake and transpiration (e.g. stomatal regulation, low hydraulic conductance of the root–stem–leaf pathway, succulence).
3. Deep rooted - species with persistent moderate water use; sustained through accessing stored water in the unsaturated soil profile. Relatively low responsiveness to rainfall. Restricted to zones of deeper soils, often in areas where rainfall inputs are augmented by run-on (e.g. drainage lines and floodplains).
4. Phreatophytic – species which use groundwater to meet some or all of their water use requirements. Access to groundwater may be permanent or temporary as dictated by site and species interactions. Groundwater in the Pilbara is generally deep and inaccessible to vegetation; hence, phreatophytic species (e.g. *Melaleuca argentea*) tend to have restricted distributions.

Each of these plant water use strategies is depicted in Figure 4. Different landscape elements can facilitate different water use strategies, although most vegetation communities include a mixture of species with different water use strategies. Indeed many observations of plant water use physiology in dryland environments are consistent with the two-layer hypothesis, which predicts that different plant species are able to coexist because they utilise water from different soil layers or depths (Gwenzi *et al*., 2013; Ogle & Reynolds, 2004).

Many plant species have a level of adaptive capacity to the growing conditions that they experience and may adopt multiple water use strategies across their range of occurrence. Even at the stand level, water sources used by plants may vary considerably amongst members of the same species. Some tree and shrub species possess the ability to switch between deep and shallow water sources as dictated by seasonal water availability (Ogle & Reynolds, 2004). In the Pilbara, the riparian species of *Eucalyptus camaldulensis* is considered to be a facultative phreatophyte, meaning it can persist on unsaturated storage derived from surface inputs, as well as utilise (and in some cases have a dependency on) groundwater when it is available. Global experience suggests that “obligate” phreotophytic behaviour seems to be more related to site-specific environmental conditions rather than to the capabilities of a given plant species (Thomas, 2014).

Landscape history

The Pilbara landscape is ancient and shaped by a complex set of geomorphic factors. In order to understand landscape function, it is necessary to consider historical landscape evolution processes and the effect these have had on the present day environment. As an example, palaeochannels are regionally significant hydrogeological features in the Pilbara that host a fully connected groundwater system and provide important habitat for stygofauna. Interactions between these palaeochannel features and present day river systems can be important for survival of both surface and subterranean ecosystems.

The poor fertility of Pilbara soils, a legacy of millennia of weathering and leaching, accentuates the importance of run-off and run-on processes for the supply of water and nutrients to vegetation. Patterns of vegetation are often related to surface geology, as mediated by the effect of geology on soil properties. Although different vegetation types may occur on different geological substrates, in many cases they are likely to exhibit similar water use strategies (for example floristically different spinifex communities).

Hardpans are commonly encountered within alluvial plains of the central Pilbara forming near surface indurated horizons and vary in thickness from centimetres to metres. Hardpans develop in soils where there is a net moisture deficit and lack of seasonal flushing, facilitating the accumulation and precipitation of cementing agents such as oxides of iron, aluminium and manganese, carbonates and/or silica. The process of hardpan formation can be prolonged and therefore requires stable surfaces over geological timescales. Hardpans generally have low permeability and thus may restrict the infiltration of rainfall.

Major drainage systems and basins of the central Pilbara commonly host groundwater-derived calcrete. The calcrete formations date from the Pleistocene and have developed in riverine or lacustrine alluvium subject to strongly evaporitic conditions and fluctuating groundwater levels (Mann & Horwitz, 1979). These conditions facilitate the precipitation of calcium carbonate where the solubility of calcite is exceeded. Varying degrees of silicification may be also exhibited, reflecting the influence of saline groundwater and silica precipitation/displacement of calcium carbonate. Some areas of groundwater calcrete occur higher in the landscape, in association with ancient drainage systems that are now dissected by more recent drainage systems. Carbonate precipitation remains active in spring discharge regions, such as at Millstream and Weeli Wolli Spring (Reeves *et al.,* 2007).

The Pilbara is a global ‘hotspot’ for stygofauna diversity. There is evidence that the aridification of Australia during the late Miocene contributed to the descent of terrestrial invertebrates into subterranean environments, based on affinities that many Pilbara stygofauna species have with tropical fauna lineages (Humphreys, 2001; Guzik *et al*., 2010). Subsequent erosion and other landscape formation processes have separated and/or isolated some aquifer environments resulting in speciation. This can predispose some species to restricted geographic distributions. Owing to their requirement for permanent groundwater and their ancient origins, the presence of stygofauna may indicate the long-term presence of suitable groundwater (Humphreys, 2006).

The Pilbara has been subject to many decades of pastoral land use, with associated land degradation issues (O’Grady, 2004). The effects of livestock grazing, the introduction of weed and feral animals, as well as modified fire regimes have all contributed to significant landscape changes affecting landscape ecohydrological connectivity. The spread of Buffel Grass (*Cenchrus ciliaris*) in riparian environments is a prime example, displacing native vegetation by increasing fuel loads, facilitating more frequent and intense fires and then regenerating/colonising rapidly after fire events. Such changes are likely to influence patterns of vegetation water use and infiltration/runoff processes. Post European settlement landscape effects are continuing with evolving rangelands management and need to be considered when interpreting and conceptualising ecohydrological processes.

Ecological water requirements of wetlands

Wetlands are areas that are permanently or persistently inundated or saturated by surface or groundwater, and may also include subterranean habitats. Such areas require special attention due to their potentially high level of connectivity with other landscape elements, restricted occurrence, and propensity to support unique or unusual ecosystems.

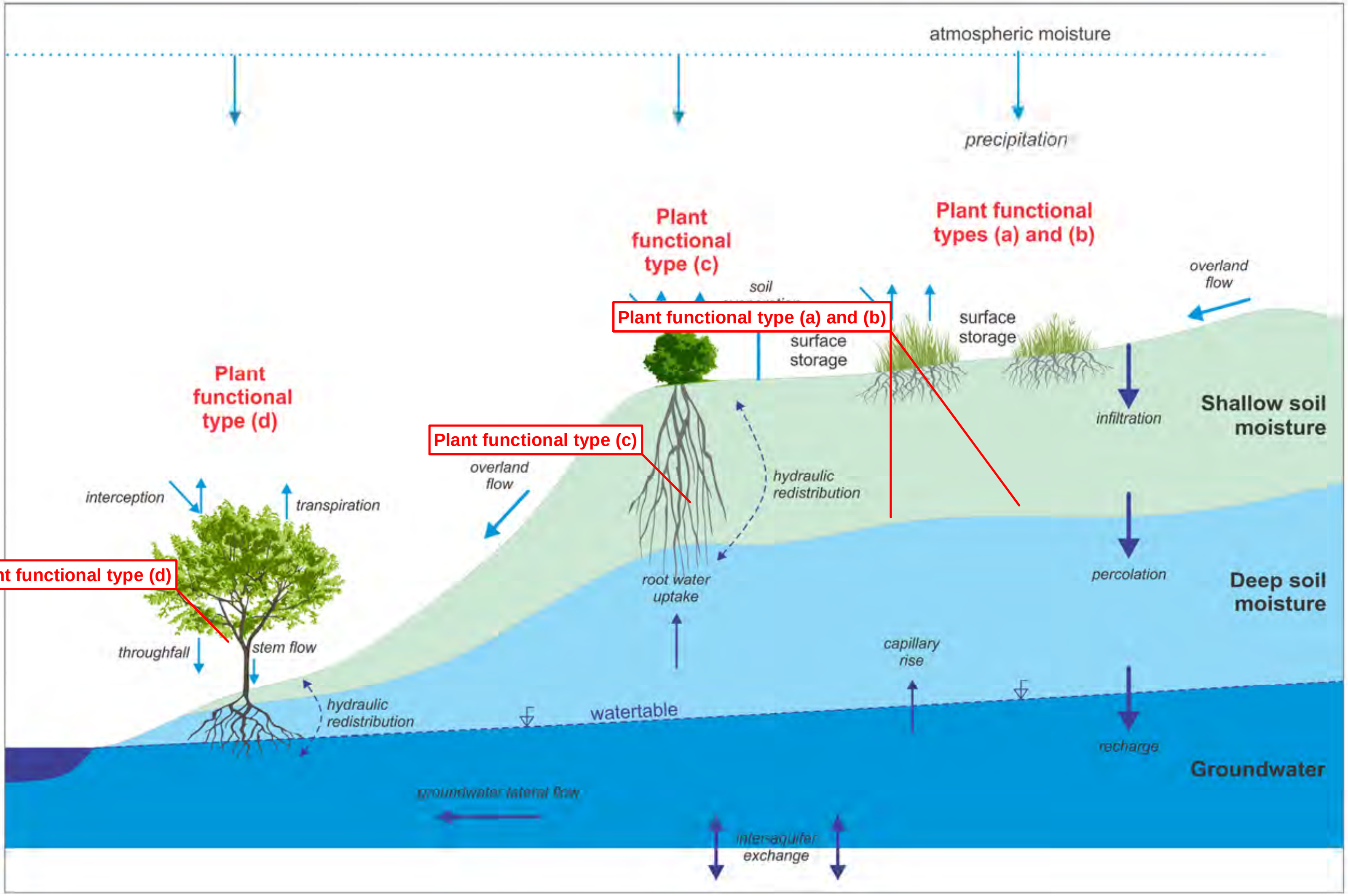
Water can converge and collect in wetlands (aquatic ecosystems) and arrive through many different pathways. Transit times along these pathways can vary spatially and temporally in response to inputs and the physical structure of the catchment resulting in dynamic and complex hydrological regimes (Neumann, 2013). In flat terrain where flow rates are lower, such as in wetland complexes or lake chain systems, water is exposed for a longer time to climatic and biogeochemical processes which alter its physicochemical properties. In steeper terrain where flow rates are higher, such as in rivers or headwater streams, there may be little modification of water properties owing to shorter transit times. The properties of groundwater contributing to a wetland environment may similarly be modified based on residence times in aquifers.

The level of persistence of aquatic environments has an important effect on their biotic assemblages, and their functional importance as refuges (Davis *et al*., 2013). Longer hydroperiod allows more species to colonise and greater habitat complexity to develop (Boulton & Jenkins, 1998; Sheldon *et al*., 2002). In ephemeral wetlands, the transition between wet and dry periods is important for driving biotic and abiotic exchanges, ecosystem succession processes, and maintaining ecosystem integrity (Boulton & Lloyd, 1992; Boulton & Jenkins, 1998; Junk *et al*., 1989).

Surface wetland ecosystems in central Pilbara tend to be strongly influenced by the episodic intense rainfall events and rapid surface water movement from source areas (Pinder *et al*., 2010). Many surface water features, such as river pools and claypans, are intermittent or ephemeral. The persistence of waterbodies is dictated by flood frequency and the rate of water loss following flood events by drainage, evapotranspiration and infiltration into deep groundwater systems; and the depth to groundwater Bank storage and/or perched groundwater may be important for prolonging waterbody persistence, where permitted by local area geomorphology. Different hydrological regimes associated with flooding and flow frequency, flood duration, salinity and source of water may produce different species assemblages. Different stages of the hydrological regime may also be important for species life cycles, such as the utilisation of flooded wetlands by waterbirds for breeding.

Permanent pools usually occur where bedrock structures impede hyporheic groundwater flow, where springs discharge groundwater or where flow has scoured pools that are sufficiently deep to encounter the watertable and shaded to persist (Pinder *et al*., 2010). These wetlands are uncommon, and typically support unusual or unique flora and fauna assemblages and can be important refuges for a range of aquatic species.

Subterranean habitats in groundwater are defined by the types of voids and interstitial spaces within host rocks and by groundwater chemistry (Halse *et al*., 2014). Both attributes are influenced by the host geology of the aquifer, the amount of landscape weathering, and local chemical and hydrological processes (Reeves *et al*., 2007). Connectivity with the surface influences the supply of oxygen and organic matter into subterranean ecosystems, highlighting the importance for recharge dynamics for these habitats (as associated with cyclonic recharge events). Depth to groundwater is considered to constrain the complexity and abundance of stygofauna communities in the Pilbara (Halse *et al*., 2014). The response of stygofauna to fluctuations in the watertable is poorly understood; however, their persistence over geological time suggests they have capacity to adapt to dynamic habitat availability.



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LATERAL AND VERTICAL WATER CONNECTIVITY IN AN ECOSYSTEM

FIGURE 4

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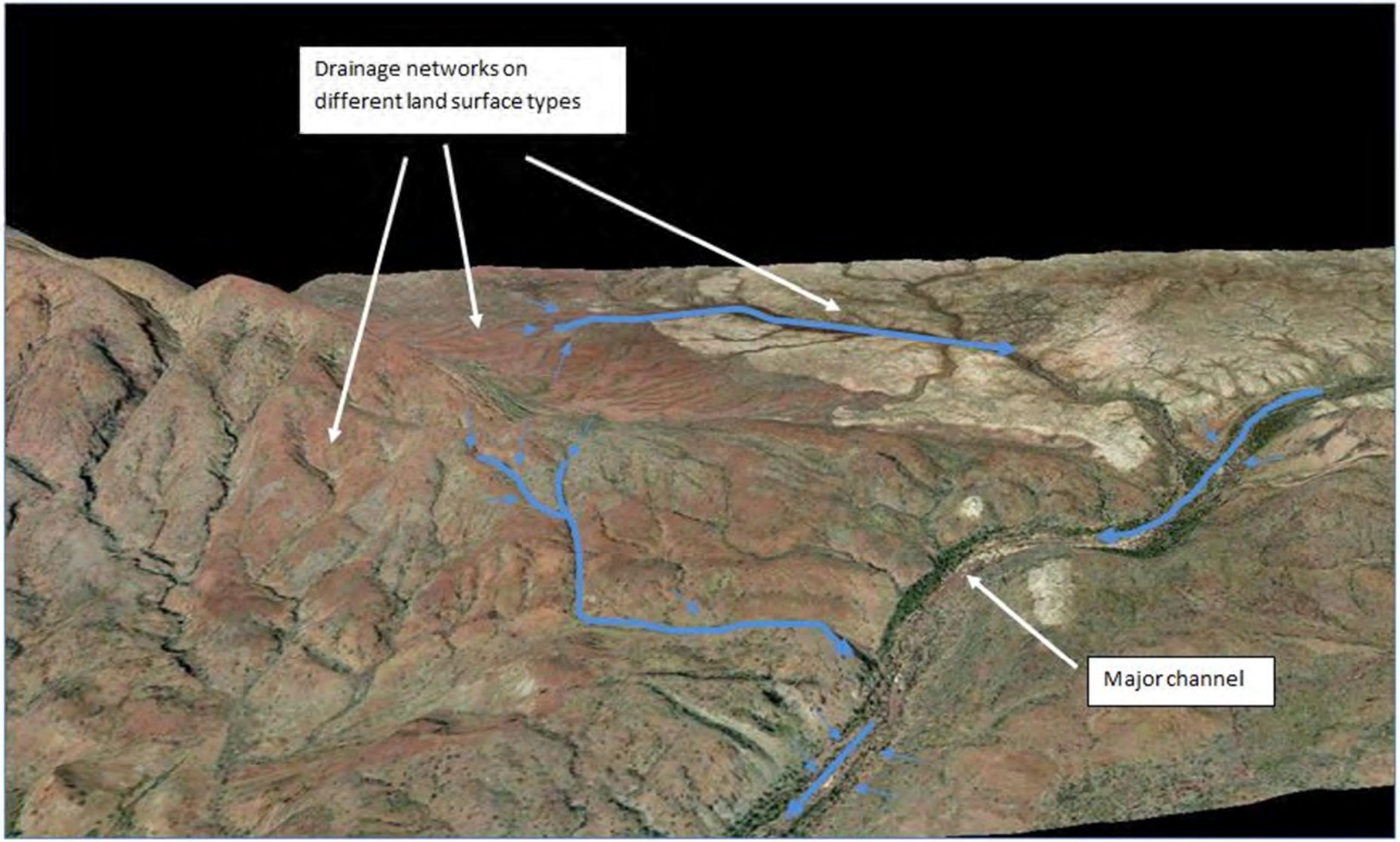

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LATERAL AND LONGITUDINAL CONNECTIVITY IN PILBARA UPLANDS DRAINAGE SYSTEMS

FIGURE 5

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1.3.3 Ecohydrological conceptualisation approach

A landscape ecohydrological conceptualisation of the central Pilbara Region, including the Marillana project area, has been developed through the definition landscape of ecohydrological units (EHUs). Each EHU represents a landscape element with broadly consistent and distinctive ecohydrological attributes. Nine EHUs are recognised as follows:

- EHU1 Upland source areas - hills, mountains, plateaux
- EHU2 Upland source areas – dissected slopes and plains
- EHU3 Upland transitional areas – drainage floors within EHUs 1 and 2 which tend to accumulate surface flows from up-gradient
- EHU4 Upland channel zones – channel systems of higher order streams (generally ≥5th order) which are typically flanked by EHU3 and dissect EHUs 1 and 2
- EHU5 Lowland sandplains – level to gently undulating surfaces with occasional linear dunes. Little organised drainage but some tracts receive overland flow from upland units
- EHU6 Lowland alluvial plains – typically of low relief and featuring low energy, dissipative drainage
- EHU7 Lowland calcrete plains – generally bordering major drainage tracts and termini, typically with shallow soils and frequent calcrete exposures
- EHU8 Lowland major channel systems and associated floodplains
- EHU9 Lowland receiving areas - drainage termini in the form of ephemeral lakes, claypans and flats.

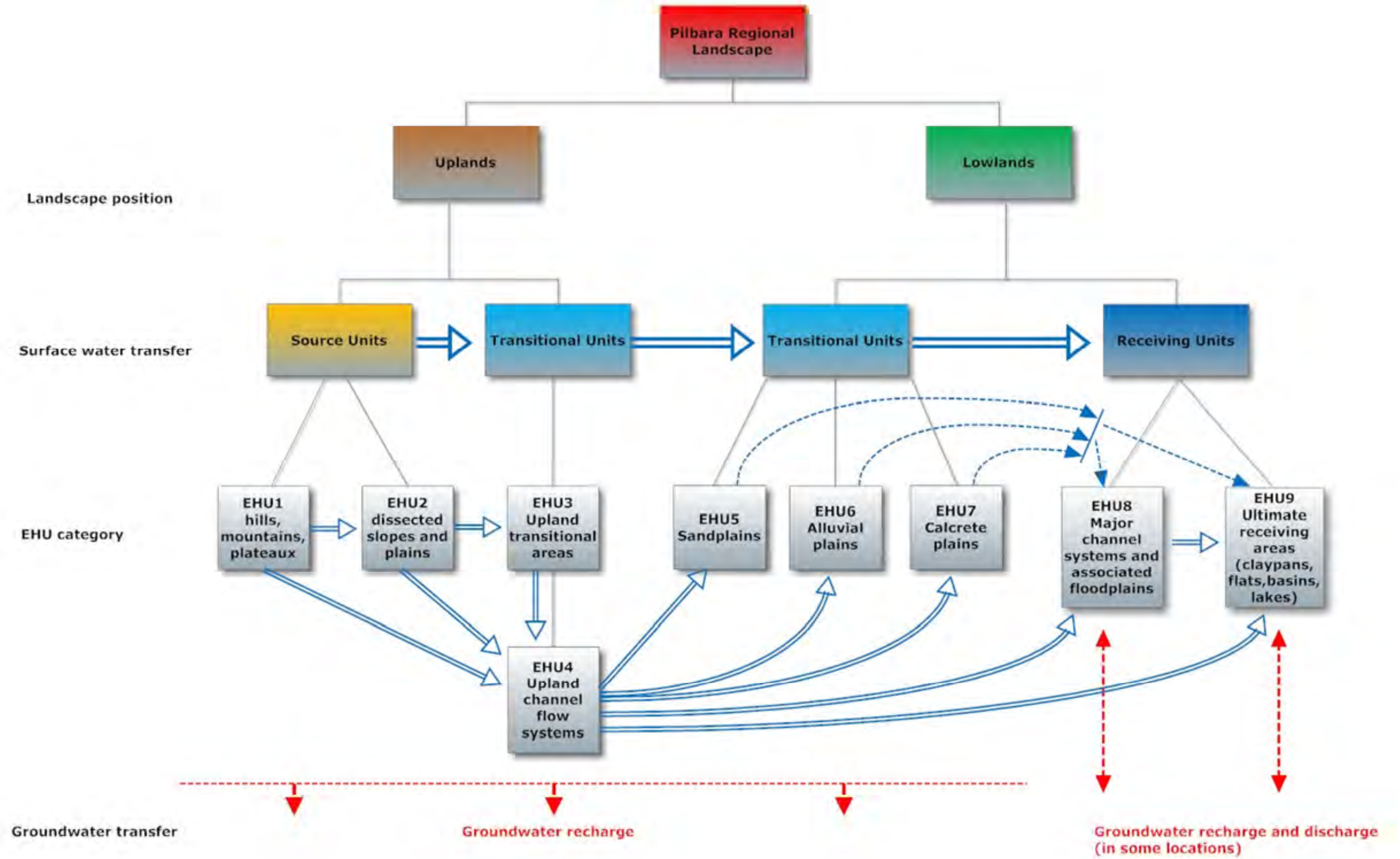
The factors considered in the definition of EHUs include:

- landscape position and land surface types, including soil characteristics
- landscape water balance processes
- surface drainage/redistribution processes
- connectivity and interactions between surface water and groundwater systems
- major vegetation types and their water use strategies.

The EHUs transition from upland to lowland environments in a spatial arrangement hierarchy as depicted in Figure 6. Descriptions of the general attributes of each EHU are described in Table 2.

In summary, the spatial definition of the EHUs is based on interpretation of land system mapping units as compiled by Department of Agriculture (Van Vreeswyk *et al*., 2004), surface drainage networks, groundwater systems, and inferred vegetation water use behaviour based on vegetation mapping (structure and dominant species) and Landsat Normalized Difference Vegetation Index (NDVI).

The landscape distribution of aquatic habitats such as pools, springs and ephemeral lakes were also considered in the definition of EHUs. These habitats are largely confined to EHUs 8 and 9, where surface water and groundwater flows accumulate and surface water/groundwater interactions may occur.



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LANDSCAPE ARRANGEMENT OF EHUs AND MAJOR WATER FLOW PATHWAYS

FIGURE 6

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Table 2: General attributes of landscape EHUs

EHU	Landscape position, land surface and soils	Dominant landscape water balance processes	Dominant surface drainage/ connectivity processes	Level of connectivity to groundwater systems	Major vegetation types
1	Upland source areas - hills, mountains, plateaux. Land surface is steep and rocky. Shallow or skeletal soils with frequent bedrock exposures.	Rainfall Infiltration Soil evaporation Run-off	Generally short distance overland flow into dendritic drainage networks (1st, 2nd and 3rd order streams).	Local and regional groundwater systems are deep and not accessible to vegetation[1]. Preferential recharge can occur as dictated by local-scale geology.	Hummock grasslands. Vegetation water demand met by direct rainfall and localised surface redistribution.
2	Upland source areas – dissected slopes and plains, down-gradient from EHU1. Land surface is sloping with shallow to moderately deep colluvial soils.	Rainfall Infiltration Soil evaporation Run-off	Overland flow short distance into channel drainage systems (mainly 1st to 4th order streams).	Local and regional groundwater systems are deep and not accessible to vegetation[1]. Preferential recharge can occur as dictated by local-scale geology.	Hummock grasslands. Vegetation water demand met by direct rainfall and localised surface redistribution.
3	Upland transitional areas – drainage floors within EHUs 1 and 2 which accumulate surface flows from up-gradient. Soils of variable depth derived from alluvium. Greater storage relative to soils in EHU 1 and 2.	Inflows Infiltration Storage Evapotranspiration	Surface accumulation and infiltration of flood flows (overland flows and channel breakouts). Excess volumes transferred to adjacent channels (EHU4).	Local and regional groundwater systems are deep and not accessible to vegetation.	Smaller drainage floors support hummock grasslands; larger drainage floors support *Eucalyptus* and *Acacia* shrublands and woodlands. Vegetation water demand met by direct rainfall and stored soil water replenished by infrequent flood events.
4	Upland channel zones - channel systems of higher order streams (generally ≥5th order) which dissect EHU1 and EHU2. Channels are high energy flow environments, subject to bed load movement and reworking. Soils of variable depth derived from alluvium including zones of deep soils. Generally high infiltration rates.	Inflows Infiltration Storage Evapotranspiration. Channel throughflow	Channel beds and banks accept and store water during flow events. Large flows are transmitted down-gradient. Channels may support intermittent or persistent pools replenished by flood flows.	Regional groundwater systems are deep and not accessible to vegetation. Transient or less commonly persistent shallow groundwater systems may develop beneath channels in places, as dictated by local scale geology/regolith. In rare cases these may be connected with pools. In rare cases vegetation may access perched groundwater for periods of time.	Channels are typically lined with narrow woodlands of *E. victrix*, *A. citrinoviridis* and/or other *Eucalyptus* and *Acacia* species. These are sustained by soil water replenishment from flow events.
5	Lowland sandplains - landform characterised level or gently undulating plains up to 10 km in extent. Deep sandy soils of aeolian origin. Uncommonly features linear dunes up to about 15 m in height.	Infiltration Storage Evapotranspiration Groundwater recharge	Poorly organised drainage. High rainfall infiltration and recharge. Runoff is minimal and if it does occur is generally localised, with accumulation in swales or depressions. Sandplains may receive and infiltrate inflows from channels deriving from up-gradient areas.	Groundwater systems are generally deep and not accessed by vegetation. May include important zones of recharge, with associated groundwater mounding. Possibility of transient or more persistent perched groundwater at localised scales, depending on regolith characteristics.	Hummock grasslands, with *Acacia* sp. and other shrubs, occasional mallee Eucalypts. Distinctive grassland communities relative to other EHUs. Tracts receiving run-on include *Acacia* and *Eremophila* shrublands.

[1] Special case exception – springs fed by fractured rock aquifers (rare in the central Pilbara Region).

EHU	Landscape position, land surface and soils	Dominant landscape water balance processes	Dominant surface drainage/ connectivity processes	Level of connectivity to groundwater systems	Major vegetation types
6	Lowland alluvial plains – broad depositional plains of low relief. Soils typically loams, earths and shallow duplex types. Subsurface calcareous hardpans are frequently encountered.	Localised surface redistribution. Infiltration Storage Evapotranspiration	Complex surface water drainage/redistribution patterns. Land surfaces are generally dissected by low energy channels of variable form and size. Areas of sheetflow can occur, which may be associated with banded vegetation formations. Some areas may be subject to infrequent flooding. Infiltration may be significant at local scales in association with drainage foci, These areas are likely to be correlated with relatively higher leaf area index.	Groundwater systems are generally moderately deep (>10 m) to deep (>20 m) and not accessed by vegetation.	Acacia shrublands; less commonly Hummock grasslands, Tussock grasslands or low shrublands of Bluebush/Saltbush.
7	Lowland calcrete plains – plains of low relief generally bordering major drainage tracts and termini. Shallow soils underlain by calcrete of variable thickness, which occasionally outcrops.	Localised surface redistribution. Infiltration Soil evaporation Groundwater recharge	Complex surface water drainage/redistribution patterns. Calcrete platforms may have varying permeability. Land surfaces are generally dissected by low energy channels of variable form and size. Generally characterised by numerous localised drainage termini.	Depth to groundwater can vary from shallow (<5 m) to deep (>20 m). Preferred pathways may facilitate rapid recharge at local scale. Groundwater systems are generally not accessed by vegetation. Groundwater systems in calcrete can provide important stygofauna habitat.	Hummock grasslands and *Acacia* scrublands with occasional Eucalypts. Distinctive vegetation communities relative to other EHUs.
8	Lowland major channel systems and associated floodplains - supporting large flow volumes in flood events. Channels are high-energy flow environments, subject to bed load movement and reworking. They may be physically altered by large floods.	Inflows Ponding Infiltration Storage Evapotranspiration. Channel throughflow Groundwater recharge Groundwater discharge (localised)	Channel beds and banks accept and store water during flow events. Large flows are transmitted down-gradient. Soil water in the floodplains is replenished during flooding breakouts. Channels support transient, persistent and permanent pools.	Depth to groundwater generally shallow. Channels are significant recharge zones. Transient, persistent or permanent shallow groundwater systems may develop beneath channels in places, as dictated by local scale geology/regolith. These may be connected with pools in some situations. Groundwater is generally fresh. Groundwater systems can be accessible to vegetation in some situations. Evaporative discharge of shallow groundwater may occur.	Inflows from up-gradient sources sustain *Eucalyptus* and *Acacia* forest and woodland vegetation communities or Tussock grasslands. Supports most of the recognised groundwater dependant vegetation communities in the central Pilbara (with the key indicator species being *Eucalyptus camaldulensis*, *E. victrix* and *Melaleuca argentea*).
9	Lowland receiving areas - drainage termini in the form of ephemeral lakes, claypans and flats. Deep silty and clay textured soils. Variable surface salinity (resulting from evaporites). Soils may be underlain by calcrete/ silcrete hardpans of variable depth.	Inflows Ponding Infiltration Storage Soil evaporation Evapotranspiration. Groundwater recharge Groundwater discharge (localised)	Drainage termini receive inflows from up-gradient drainage systems. Transient to persistent ponding may occur as dictated by flooding regimes, with spillovers possible in large flooding events. Sediment accumulation and evaporative concentration of salts.	Depth to groundwater generally shallow. Groundwater may be fresh, brackish or saline. Groundwater systems can be accessible to vegetation in some situations. Evaporative discharge of shallow groundwater may occur.	Fringed or occupied by distinctive vegetation communities such as Samphire. Regularly inundated areas may be largely devoid of vegetation. Vegetation adapted to waterlogging, flooding and salinity stressors. Potential to support groundwater dependant ecosystems (GDEs), depending on the level of surface and groundwater connectivity. However this is likely to be uncommon.

2.0 REGIONAL SETTING

2.1 Climate

2.1.1 Rainfall and evaporation

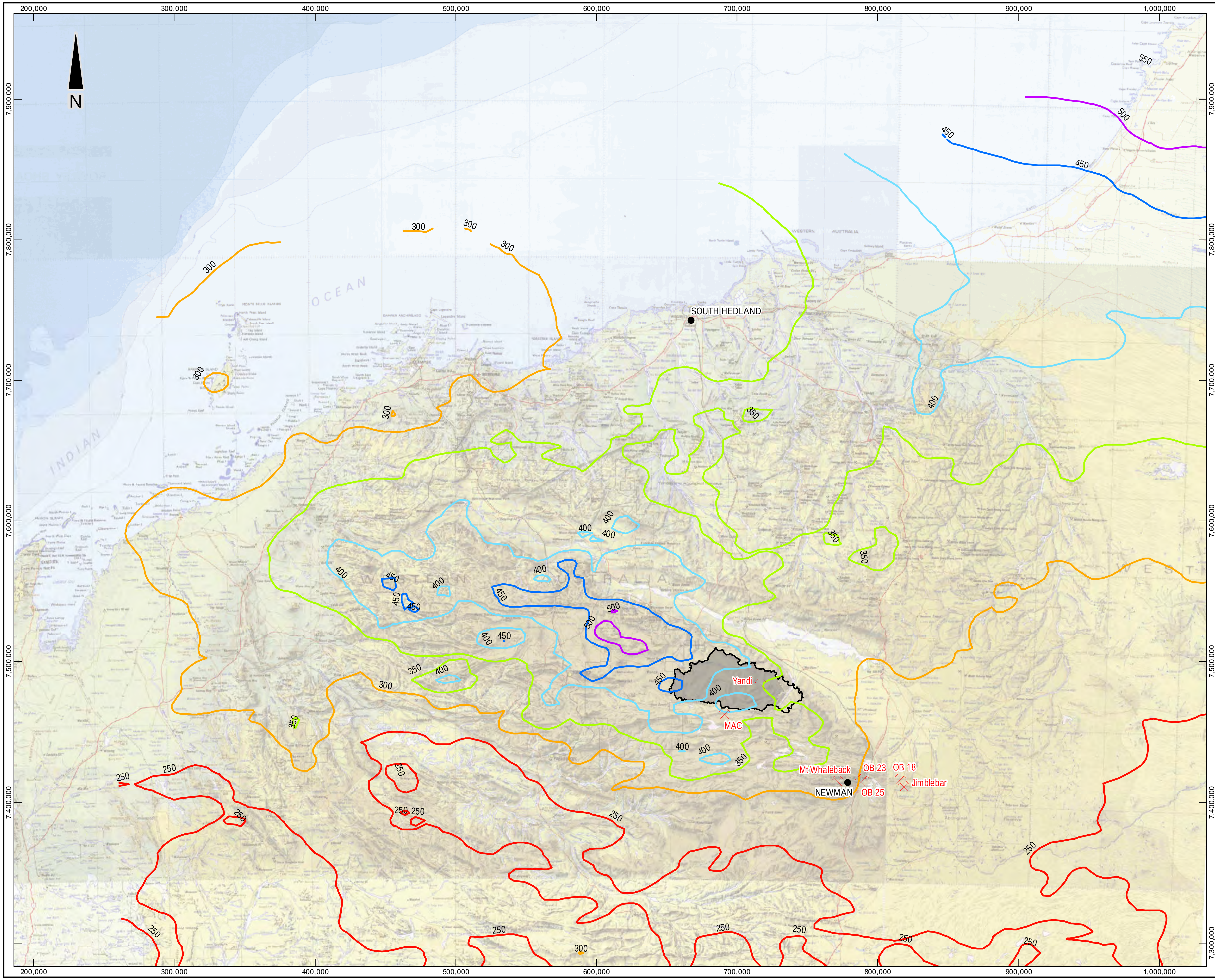
The Pilbara has highly variable rainfall, which is dominated by the occurrence of tropical cyclones from January to March. The variation in average annual rainfall in the Pilbara Region is shown in Figure 7. This indicates annual rainfall is generally around 300 mm to 350 mm, increasing locally to 500 mm within the Hamersley Range in the vicinity of Karijini some 100 km east of the project area. The project area, also highlighted in Figure 7, has reduced rainfall from west to east.

Tropical storms from the north bring sporadic and intense thunderstorms. With the exception of these large events, rainfall can be erratic, and localised, related to thunderstorm activity. Therefore, rainfall from a single site is not considered representative of spatially variability over a wider area.

During May and June, cold fronts move easterly across Western Australia and sometimes reach the Pilbara Region producing light winter rains.

The BoM Newman Aero climate station provides long-term rainfall data for the inland Pilbara where the annual average rainfall is 318 mm (BoM, 2013). Annual variability is high with recorded rainfall at Newman Aero varying between 37 mm (1996) and 619 mm (1999), depending on the occurrence or lack of cyclone-related rainfall in any particular year.

Rainfall data is also available from other sites: Wittenoom (No 005026), Marillana (No 005009) and Ethel Creek (No 005003). None of these stations are located within the Marillana Creek study area, with the closest one, Marillana, being located north of the study area boundary near the outlet of Weeli Wolli Creek into the Fortescue Valley. The BoM rainfall stations have variable rainfall records from a 106 year record at Ethel Creek to a 41 year record at Newman Aero. The average annual rainfall decreases eastward from the Wittenoom station (462 mm) to the Ethel Creek station (274 mm).



LEGEND

- ● Town
- ✕ BHPBIO mine site

Average Annual Rainfall 50mm Contours

- 250mm
- 300mm
- 350mm
- 400mm
- 450mm
- 500mm
- Marillana Creek project
- Marillana Creek catchment

NOTES

Coordinate System: GDA 1994 MGA Zone 50

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Data provided by client

0 20 40 60 80 100
kilometres

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AVERAGE ANNUAL SILO RAINFALL DISTRIBUTION (1961-2012)

FIGURE 7

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Historical data at BoM rainfall stations show increased rainfall since the 1990s. For example, the average yearly rainfall at the BoM Marillana Station for the period 1996 to 2011 is 415 mm compared with a long-term average of 317 mm. The historical data also show that increased rainfall is associated with and reflects more frequent larger storm events. This is shown in Figure 8 outlining the number of daily rainfalls within each year exceeding a defined threshold. Section 2.1.3 has more detail regarding the climate change studies that have been conducted in the Pilbara and predicted changes to the climate.

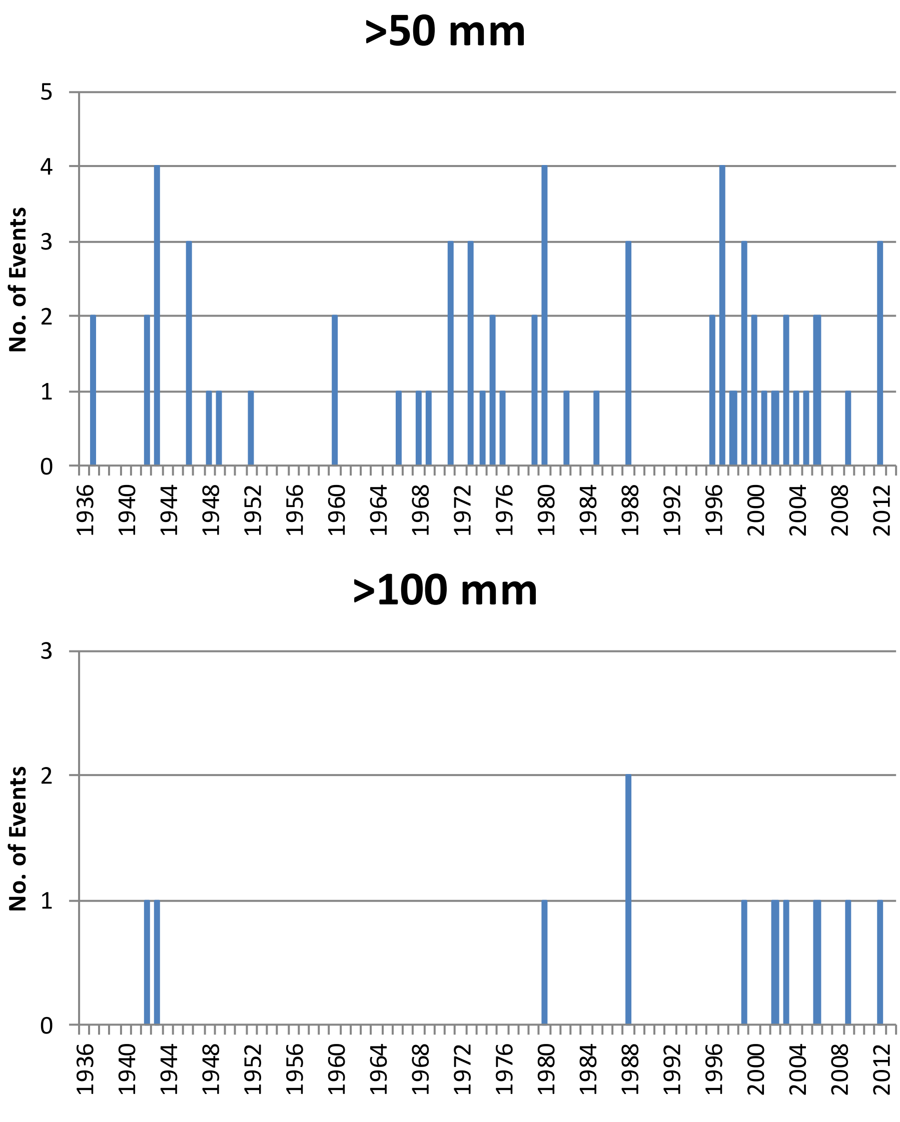


Figure 8: Daily rainfalls at Marillana Rainfall Station exceeding defined threshold values.

The mean annual pan evaporation rates at Jiggalong (east of the study area) are 4 066 mm and at Newman (south-east of the study area) 3 733 mm (Department of Agriculture, 1987). Yearly pan evaporation rates are about ten times higher than rainfall rates and evaporation exceeds rainfall every month of the year. The SILO evaporation estimates indicate average annual evaporation within the Marillana Creek catchment is lower, increasing from west to east across the catchment from around 3 080 mm to 3 270 mm (DSITIA, 2013). Estimates of areal potential evapotranspiration based on Morton's wet environment formula (Morton, 1983) are presented in the climate change report by CSIRO (2013). The annual potential evaporation (PE) for the Marillana catchment is around 1 800 mm.

The average monthly rainfalls and Class A pan evaporations for the catchment based on the SILO data for the site located centrally within the Marillana Creek catchment are shown in Table 3 and in Figure 9.

Table 3: Monthly Rainfall and Class A Pan Evaporation (mm/month)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall	73	70	53	25	23	26	14	10	3	5	10	34	347
Evaporation	370	319	293	240	173	133	144	183	258	338	385	394	3 231

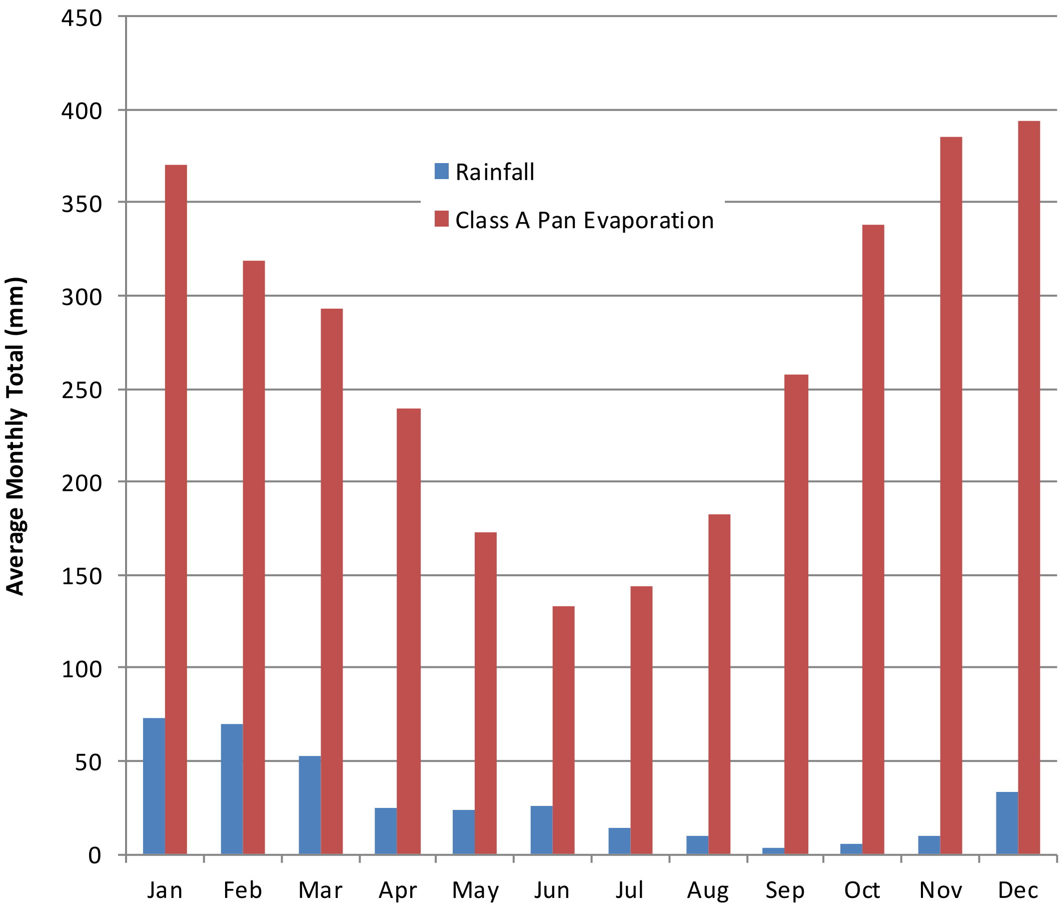


Figure 9: Average monthly rainfall and Class A Pan evaporation.

Annual average evaporation potential is far in excess of the annual average rainfall, as are evaporation potentials in all individual months. There is usually a large moisture deficit in the environment. Rainfall events below a threshold of ~20 mm tend to be insufficient to overcome this deficit and do not generate runoff.

Consequently:

- Streamflow is ephemeral and flows tend to be short in duration
- Recharge to the regional groundwater system occurs at very low rates
- Most groundwater recharge is associated with rainfall-runoff events along the major creeks and other areas of surface water concentration and inundation.

To provide an indication of the storm rainfall intensities in the area, estimated rainfall intensity-frequency-duration (IFD) curves were derived based on the approach developed by the Bureau of Meteorology (http://www.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml). These curves define the variation in average rainfall intensity for different storm durations and average recurrence intervals (ARI). These are presented in Figure 10.

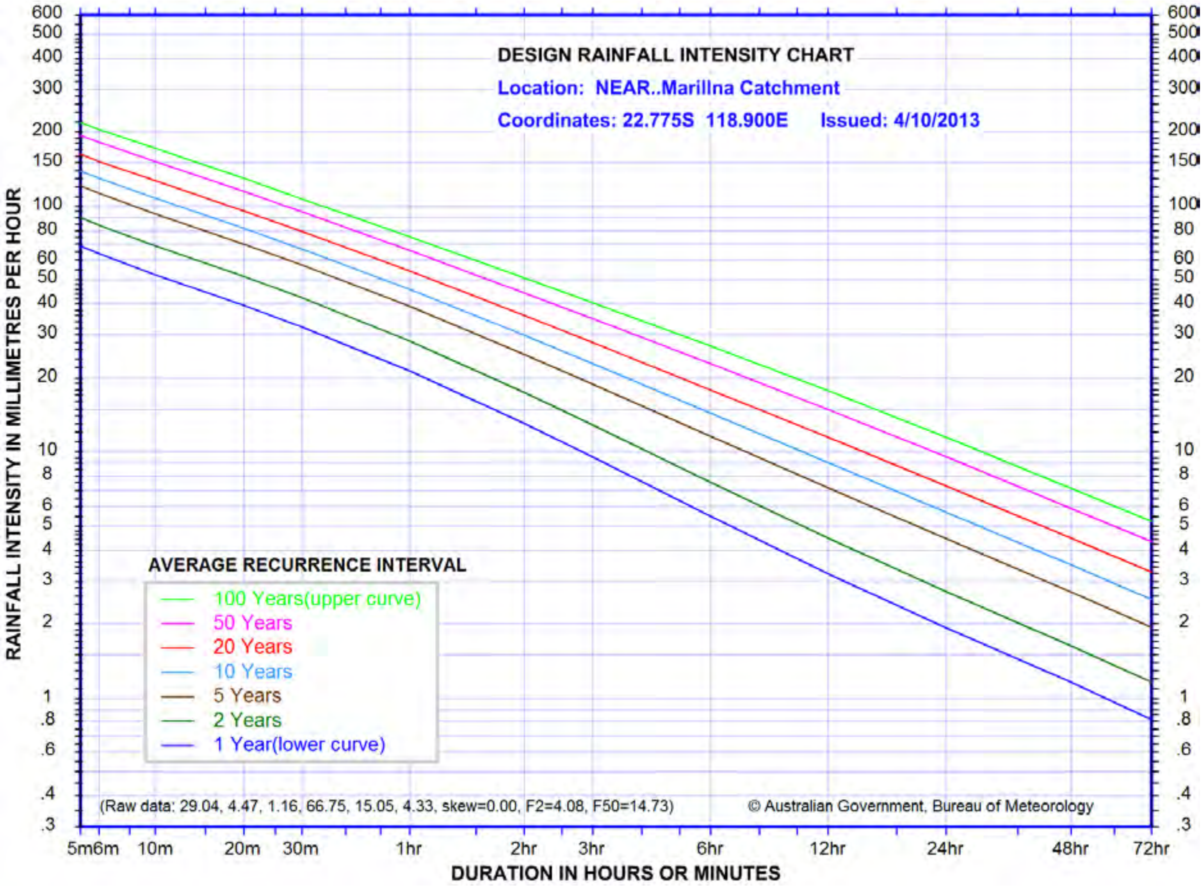


Figure 10: IFD curve for central Marillana Creek catchment.

2.1.2 Temperature

The Pilbara Region has an extreme temperature range, rising up to 50°C during the summer, and dropping to around 0°C in winter (Bureau of Meteorology - BoM). Mean monthly maximum temperatures at Newman Aero (No 007176) range from 39°C in January to 23°C in July, while mean monthly minimum temperatures range from 25°C in January to 6°C in July (BoM, 2013). The average monthly temperatures at Newman Aero are provided in Table 4. High summer temperatures and humidity seldom occur together, producing a very dry climate. Light frosts occasionally occur during the winter (dry) season.

Table 4: Newman Aero - Average Monthly Temperatures (1996 – 2013)

Average Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Max [°C]	39.4	36.9	34.7	31.7	27.2	23.1	23.0	26.0	30.3	34.8	37.3	38.9
Min [°C]	24.9	23.9	21.4	17.3	11.6	6.8	6.1	7.7	11.9	17.4	20.8	23.8

2.1.3 Climate change

The future climate of the Pilbara has been considered in detail by CSIRO, 2013. The CSIRO report explains that the scientific tool used to evaluate how the future climate will evolve in response to enhanced concentrations of atmospheric greenhouse gases is the Global Climate Model (GCM). The CSIRO report used GCM projections from 13 GCMs for two different emissions. A scaling approach was then applied to modify historical daily rainfall and potential evaporation data to produce data sets of how the historical data would have looked under future atmospheric conditions. The baseline period was 1961 to 2011. Future climate was based on 2030 and 2050 atmospheric conditions for both low and high emission scenarios.

2.1.3.1 Rainfall

The climate models produced a wide range of results with some models suggesting a decrease in rainfall and others an increase in rainfall. In general, the high emission scenario results in a drier climate when compared with the existing and lower emission scenarios. The median (between models) results suggest that future climate rainfall projections do not vary by more than 5% from current levels.

The CSIRO report concludes it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged owing to greenhouse warming. Modelling which has been undertaken on Australian tropical cyclone (TC) characteristics showed an approximate 100 km southward shift in genesis and decay regions of cyclones together with an increase in the wind speed, rainfall intensity and integrated kinetic energy (a measure of TC size and wind speed). These conclusions suggest that intensity of cyclonic rainfall in the Pilbara is likely to increase. The changes to thunderstorm intensity which are important for regular runoff events in smaller catchments were not assessed. The change in the characteristics of the Intensity Frequency Duration curves under future climate scenarios is currently being studied by BoM.

2.1.3.2 Potential Evaporation

The calculated changes in potential evaporation are more consistent than those obtained for rainfall as they are a function of the trend in increasing temperature projected by the GCMs, rather than the regional trend in rainfall that varies across a large range between the different GCMs. This is expected given that Potential Evaporation (PE) is calculated as a function of temperature, solar radiation and relative humidity.

As would be expected, the increase in PE is higher under the higher emissions scenario. The median (between models) increase in PE is 3% and 4% for the two emission scenarios at 2030 and 5% and 6% by 2050.

2.2 Topography

The study area is a broad catchment bound by the Hamersley and Hancock Ranges with, commonly, 400 m AHD to 700 m AHD hills rising to about 900 m AHD. Local peaks can reach 1 250 m AHD. Highly resistant to erosion, Hamersley Group BIFs, specifically the Brockman Iron and Weeli Wolli Formations, form the higher elevations in the landscape. The less resistant Hamersley Group rocks are typically exposed on valley flanks and floors. In the folded areas, valleys have developed where the more readily weathered and eroded lithologies have been removed. Differential erosion has produced an environment of, in places, extreme relief with hills, ranges, crests, ridges, spurs and gorges. The area is characterised as having hill tops and upper slopes stripped to fresh rock. Valley floors, lower slopes and most areas of low relief are typically under a blanket of unconsolidated sediments, and/or weathered and lateritic zones of variable thickness. Figure 2 shows two distinct topographic zones in the catchment. The upper catchment is dominated by broad valley floors in subtle sub-catchments; and meandering tributary streams that focus drainage through Munjina Claypan into Marillana Creek's lower catchment due to greater topographic relief and generally linear, strongly defined tributary valleys.

2.3 Regional drainage

Streamflow in the Pilbara Region is directly correlated to rainfall, with the majority of streamflow occurring during the summer months of December through to March associated with large and more intense rainfall events. Streamflow in the smaller flow channels is typically short in duration, and ceases soon after rainfall passes. In the larger river channels which drain the larger catchments, runoff can persist for weeks following major rainfall events resulting from tropical cyclones.

Streamflow gauging stations are widely distributed in the Pilbara Region. There is only one Department of Water (DoW) gauge located in the Marillana Creek catchment at Flat Rocks (GS708001). Flat Rocks is located where Marillana Creek crosses a broad exposure of bedrock being at the transition from the upper to the lower part of the catchment.

For ungauged catchments, peak flood discharges in the Pilbara Region can be estimated using empirical techniques, such as those recommended in “Australian Rainfall and Runoff” (IEAust, 1998).

The upper and lower parts of the Marillana Creek catchment are distinctly different. In the upper part of the catchment, the headwaters of Marillana Creek rise in high relief areas of the Hamersley Range in the west (at an elevation of around 1 200 m AHD). Several streams drain across broad areas of low relief in an easterly to north easterly direction into and through the Munjina Claypan. The claypan marks the downstream boundary of the upper part of the catchment. Surface water flows in excess of the internal storage capacity of Munjina Claypan before moving south east along Marillana Creek into the lower part of the catchment.

In the lower part of the catchment, Marillana Creek is incised into higher relief bedrock terrain with narrow flanking floodplains. The creek follows the same valley in which the CID palaeochannel developed and the creek bed has an increasing depth of alluvium moving from Flat Rocks (no alluvium) to BHP Billiton Iron Ore’s most easterly mines (some 20 m of alluvium) and probably greater thicknesses again through RTIO’s Yandicoogina mine to the confluence with Weeli Wolli Creek. Major tributaries to Marillana Creek downstream of the Munjina Claypan include Iowa Creek, Lamb Creek, Phil’s Creek and Yandicoogina Creek. Marillana Creek drains the catchment eastward into the lower reach of Weeli Wolli Creek before the latter discharges in a northerly direction into the Fortescue Valley.

In the upper part of the catchment, upstream of the Flat Rocks gauging station, CID deposits are below the watertable, often blanketed with sediments and occur in a low relief area beneath, and in the general vicinity of, the Munjina Claypan. The CID deposits are broadly coincident with Marillana Creek and several coalescing tributaries where broad, shallow flooding is expected during cyclonic rains. Mining in the upper part of the catchment will require some combination of flood exclusion bunding and stream diversions because:

- the pits would flood in the majority of summer rain seasons
- pits of the order of 1-2 km in length could accommodate much, or all, of the runoff associated with a larger cyclonic event, reducing environmental flows downstream.

In the lower part of the catchment, the creek flows alongside the CID, crosses it in some locations and in other sections it is remote from the CID and incised into bedrock. In the BHP Billiton Iron Ore lease, which starts at the upper boundary of the lower part of the Marillana Creek catchment, there are several areas where the creek is remote from the CID. Further downstream, in RTIO’s Yandicoogina mining area, Marillana Creek does not have broad floodplains but is commonly more or less coincident with potential mining areas. These existing mines and potential mines are subject to greater surface flows in Marillana and Weeli Wolli Creeks than the upper part of the catchment by virtue of the increased upstream area for runoff generation.

The mines in the lower part of the catchment have varying susceptibilities to flooding, according to the local topography and whether Marillana Creek is coincident with or remote from the deposit.

2.4 Geology

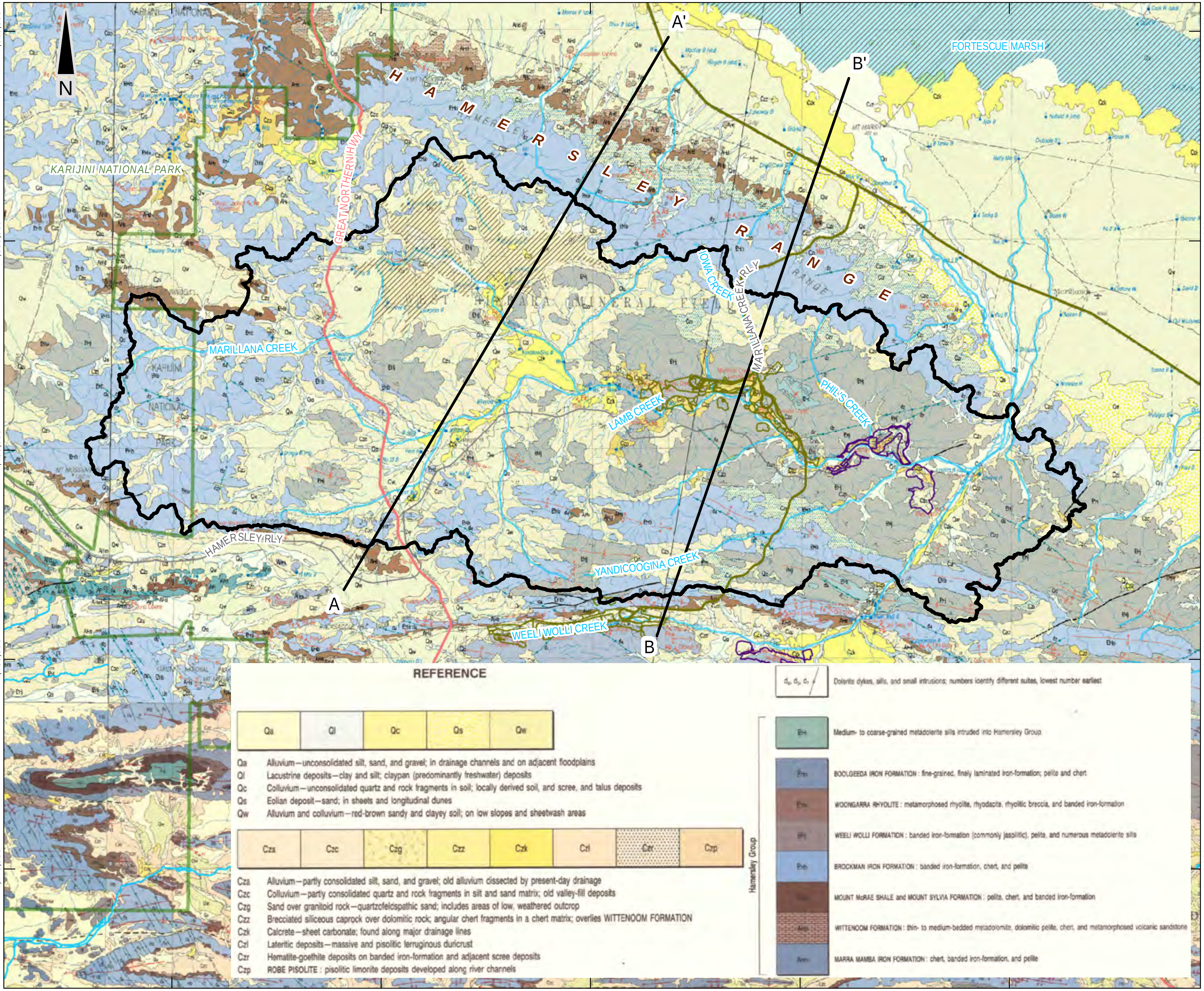
2.4.1 Regional setting

The Hamersley Province has a long geological history, broadly comprising, at its simplest, Archaean and Proterozoic metamorphic and sedimentary rocks with much younger (Tertiary) sedimentary deposits. In the Marillana Creek Region, those Tertiary deposits infill older erosion features, either broad valleys with clays and calcretes of groundwater derived origin, or narrow channel-fill deposits (including iron-rich CIDs in remnants of the main drainage lines).[2]

The oldest rocks in the Hamersley Province, which covers an area of about 80 000 km^2, are sediments and metasediments of late Archaean to Lower Proterozoic age (2 800 to 2 300 Ma), situated between Archaean granitoid rocks of the Yilgarn and Pilbara Blocks.

The surface geology map of the Marillana Creek catchment is shown in Figure 11. Two geological sections within the catchment, through the Upper (western) and Lower (eastern) zones of the Marillana Creek catchment are shown in Figure 12, Section A-A’ and Section B-B’, respectively. The bedrock is mostly Weeli Wolli Formation in the eastern part of the catchment, flanked to the north and south by Brockman Iron Formation, which forms both the catchment divides and most of the steep topographic relief in the western part of the catchment.

[2] Much of this section derives its content from Kneeshaw (2004, 2008) and the Explanatory Notes of the Roy Hill 250,000 geological sheet (Thorne and Tyler, 1997).



LEGEND

- Section line
- Primary road
- Creek
- Railway
- Munjina Claypan
- Fortescue Marsh
- National park
- Marillana Creek project
- Current BHP Billiton Iron Ore disturbance
- Current Third Party disturbance

The content of this map is conceptual only, of a general nature and does not purport to contain all information relevant to future project development associated with the Project. This map has been prepared solely for the purposes of informing environmental impact assessment pursuant to the Environmental Protection Act 1986 (WA) and Environment Protection and Biodiversity Conservation Act 1999 and is not intended for use for any other purpose. No representation or warranty is given that project development associated with any or all of the disturbance indicated on this map will actually proceed. As project development is dependent upon future events, the outcome of which is uncertain and cannot be assured, actual development may vary materially from this conceptual map.

NOTES

Coordinate System: GDA 1994 MGA Zone 50

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Mining tenements © Department of Mines and Petroleum, August 2013
Geology map © Geological Survey of WA
Topography interpreted from SRTM Digital Elevation Model of Australia © Geoscience Australia

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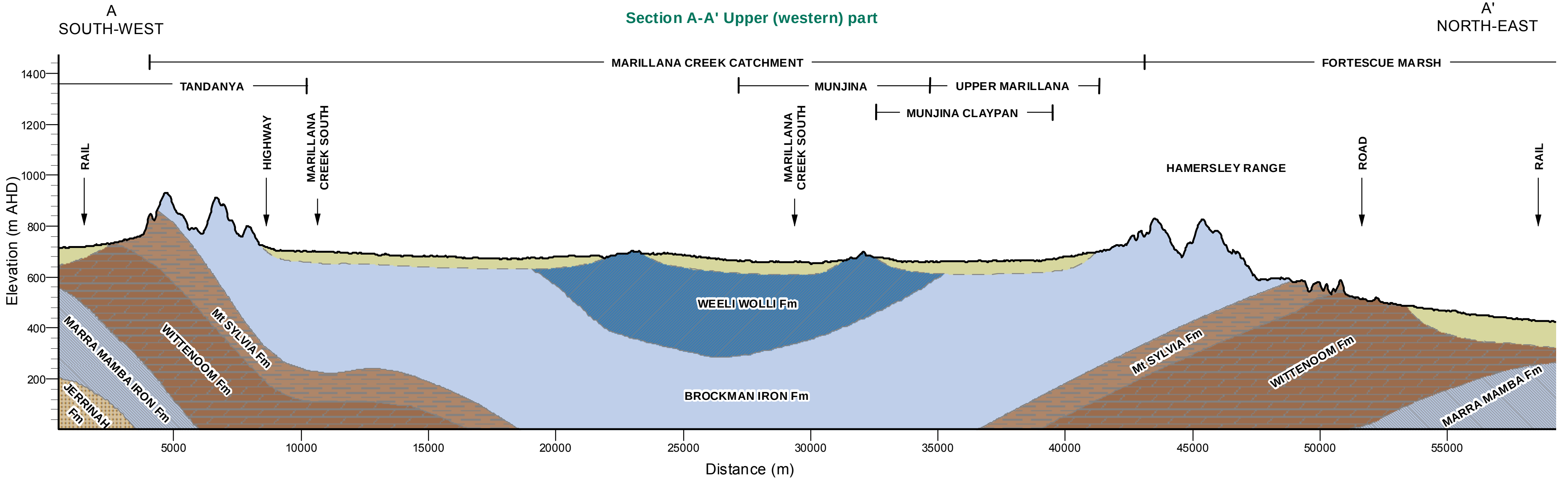
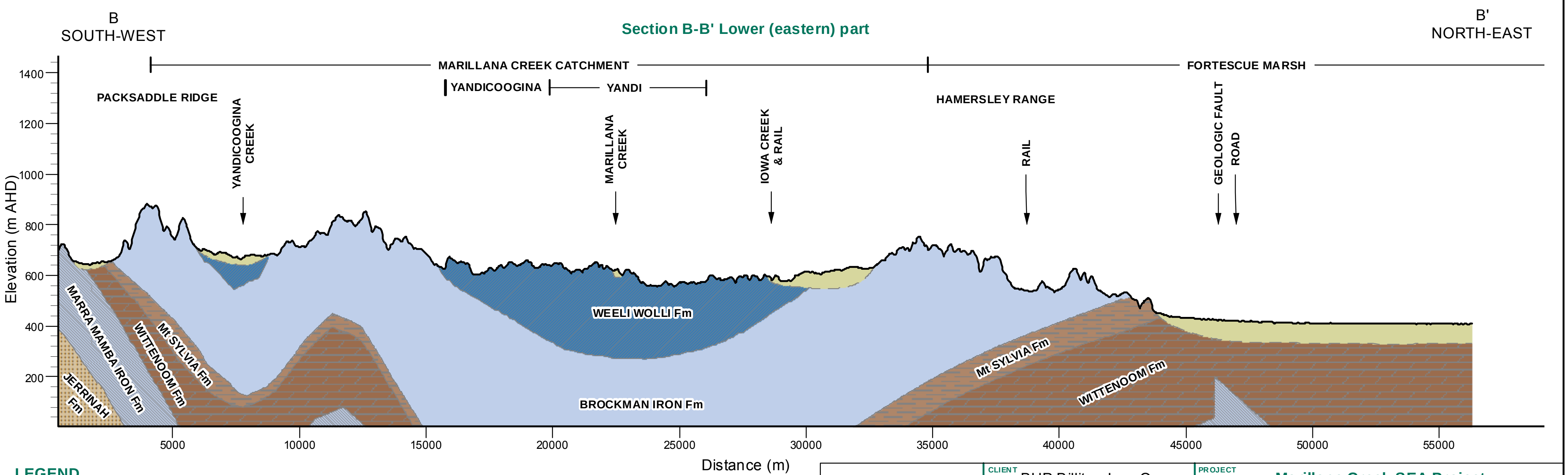
APPROVED GRH

Marillana Creek SEA Project

REGIONAL SURFACE GEOLOGY

FIGURE 11





LEGEND

- Surface
- Inferred geologic contact
- ALLUVIUM

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APPROVED	GRH	TITLE	GEOLOGICAL SECTIONS
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			FIGURE 12

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2.4.2 Stratigraphy

A stratigraphic summary identifying the geological units in the Marillana Creek Region of direct interest for this study is presented in Table 5 (modified after Johnson and Wright, 2001). The more detailed stratigraphy of the CIDs in the main palaeochannel down the centre of the catchment has been derived from a number of sources and is included below (Johnson and Wright, 2001; Kneeshaw, 2004; BHP Billiton Iron Ore, 2012b and RTIO, 2011a).

The stratigraphy can equally be referred to as hydrostratigraphy since the formations are all significant groundwater units (in their own right) within the catchment.

The Tertiary palaeochannel stratigraphy broadly applies to the other (i.e. non-BHP Billiton Iron Ore) deposits along Marillana and Weeli Wolli Creeks and some major tributaries, although individual units may be relatively thinner, thicker or even absent.

The description of each hydrostratigraphic unit includes outcomes from the recent modelling study (Golder, 2013b).

Typically, the alluvium is 2 to 20 m thick, increasing downstream (to the east) but absent immediately upstream from Yandi (at the Flat Rocks surface water gauging station). The alluvium is discontinuous along the western part of the deposit and in the east increases in thickness downstream towards and presumably through RTIO's Yandicoogina operations.

The Oligo-Miocene Marillana Formation, which disconformably overlies the Weeli Wolli Formation, is subdivided into three Members consisting of a basal conglomerate overlain by a basal clay collectively known as the Munjina Member (Kneeshaw, 2004). Overlying the Munjina Member is the Barimunya Member consisting of the Lower CID (LCID), overlain in part by unnamed ochreous clay and the Upper CID (UCID). The uppermost Eastern Member consists of CID and clay. The total thickness of the three Members is about 100 m.

Only the UCID has been extensively characterised by means of pumping tests and large-scale dewatering, as the LCID was not previously considered economically viable. Clay pods (10 to 30 cm in thickness) occur in both LCID and UCID units.

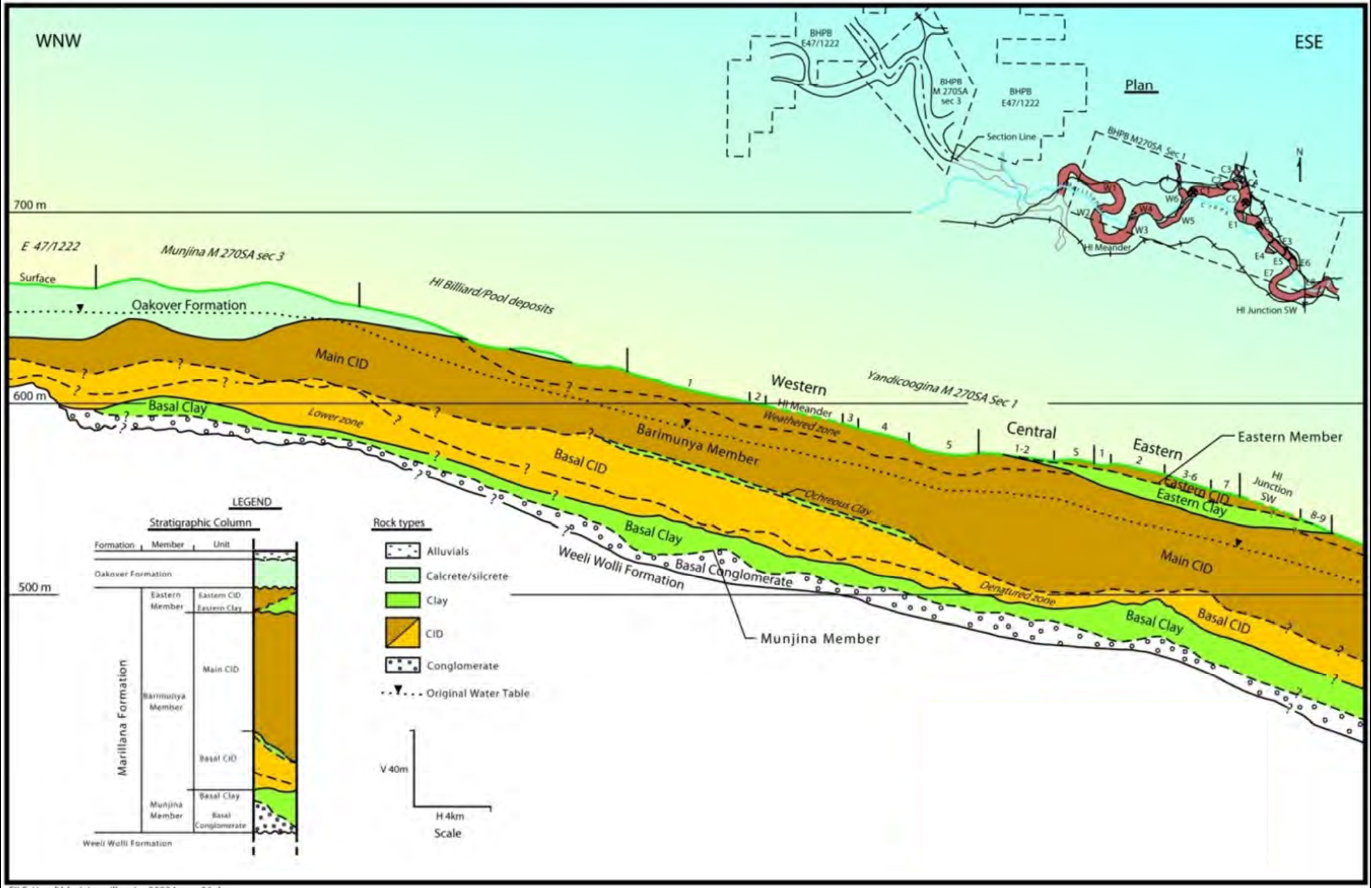
The depositional environment of the Marillana Formation comprises incised, meandering, mature river channels draining the Hamersley Ranges. The CIDs are believed to have formed pedogenically in a colluvial/alluvial environment, and gradually added to the channels as distally-derived, accretionally-layered fragments i.e. iron-rich placer deposits.

The Weeli Wolli Formation underlies the CID, and consists of BIF with abundant dolerite.

A long section of the CID stratigraphy at Yandi is presented in Figure 13, which can be considered representative of other CID deposits (Kneeshaw, 2004 and 2008).

Table 5: Hydrostratigraphic Summary

Age	Formation	Relevant Members	Dominant Lithology	Extent	Thickness (m)	Aquifer Properties
Quaternary	Un-named		Alluvium, colluvium	Within creeks	0-20	Unconfined
Tertiary	Oakover Marillana	 Eastern Barimunya (Upper CID) Barimunya (Lower CID) Munjina	Calcrete Clay UCID – cemented pisolite Ochreous clay (marker horizon) LCID – cemented pisolite with clay infill Basal Clay Basal Conglomerate	Localised areas Within Cainozoic or older palaeochannels	5-10 ~5 25-45 1-5 10-30 <20 <20	Unconfined Aquitard Unconfined Unconfined Unconfined Aquitard Confined/ Aquitard
Relevant Late Archaean/hard rock thicknesses from Early Proterozoic Units (Hamersley Group)	Weeli Wolli	-	Banded iron formation, dolerite, shale	Underlies the entire catchment	Hundreds of metres	Fractured rock
	Brockman Iron		Banded iron formation with interbedded shale	Fringing Uplands for whole catchment and hills within the western part	Hundreds of metres	
		Joffre and Dales Gorge	Banded iron formation, minor shale	As above		Fractured rock



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Marillana Creek
SEA Project

STRATIGRAPHIC LONG SECTION OF YANDI CID

FIGURE 13

2.5 Landscape and environment

2.5.1 Bioregion

The Pilbara biogeographic region corresponds closely to the Pilbara Block (Craton) (McKenzie *et al*., 2009). Under the Interim Biogeographic Regionalisation for Australia (IBRA), four geographically distinct biogeographic sub-regions are recognised in the Pilbara taking into account information on geology, landform, climate, vegetation and animal communities (Pepper *et al*., 2013):

- Chichester sub-region: encompasses the granite/greenstone terranes of the northern craton but also includes the Chichester Plateau of the Hamersley Basin. While the broader Chichester sub-region is characterised by deeply weathered regolith and is dominated by spinifex (*Triodia* spp.), grassland with irregularly scattered shrubs (shrub steppe), the Chichester Plateau (bordering the northern side of the Fortescue Valley) more closely reflects the soil landscape and vegetation of the Hamersley Plateau.

- Fortescue sub-region: delineated by the Fortescue River valley which cuts through the sedimentary rocks of the Hamersley Basin. This region consists of salt marshes, mulga-bunch grass and short grass communities, with eucalyptus (*Eucalyptus* spp.) woodlands along the permanent springs.

- Hamersley sub-region: the most prominent mountainous area in Western Australia, comprising a series of topographical features (ranges, ridges, hills and plateaux) encompassing isolated and continuous chains of uplands that rise above a plateau surface (McKenzie *et al*., 2009). Skeletal soils have developed on the iron-rich sedimentary rocks, and generally support spinifex grassland with mulga and snappy gum (tree steppe).

- Roebourne sub-region: encompasses the mudflats and low dunes of the coastal plain and is composed largely of alluvial and aeolian sediments, often with a cover of grasses and soft spinifex.

2.5.2 Land systems

The Pilbara Region has been surveyed by the Department of Agriculture and Food, Western Australian (DAFWA), for the purposes of land classification, mapping and resource evaluation. The region consists of over one hundred land systems; distinguished on the basis of topography, geology, soils and vegetation (Van Vreeswyk *et al*., 2004).

The Marillana Creek Region includes 12 land systems (Figure 14), the defining characteristics of which are described in Table 6. The major land systems include:

- Newman (EHU1) – peaks, ridges and plateaux of the Hamersley Range within the Project Area

- McKay (EHU1) – hills, ridges, plateaux, remnants and breakaways; prominent in eastern portions of the Project Area

- Boolgeeda (EHU2) – large portions of the lower slopes of the Hamersley Range principally in the western half of the Project Area

- Platform (EHU2) – dissected slopes abutting the Hamersley Range; with prominent occurrences in central and north eastern portions of the project Area

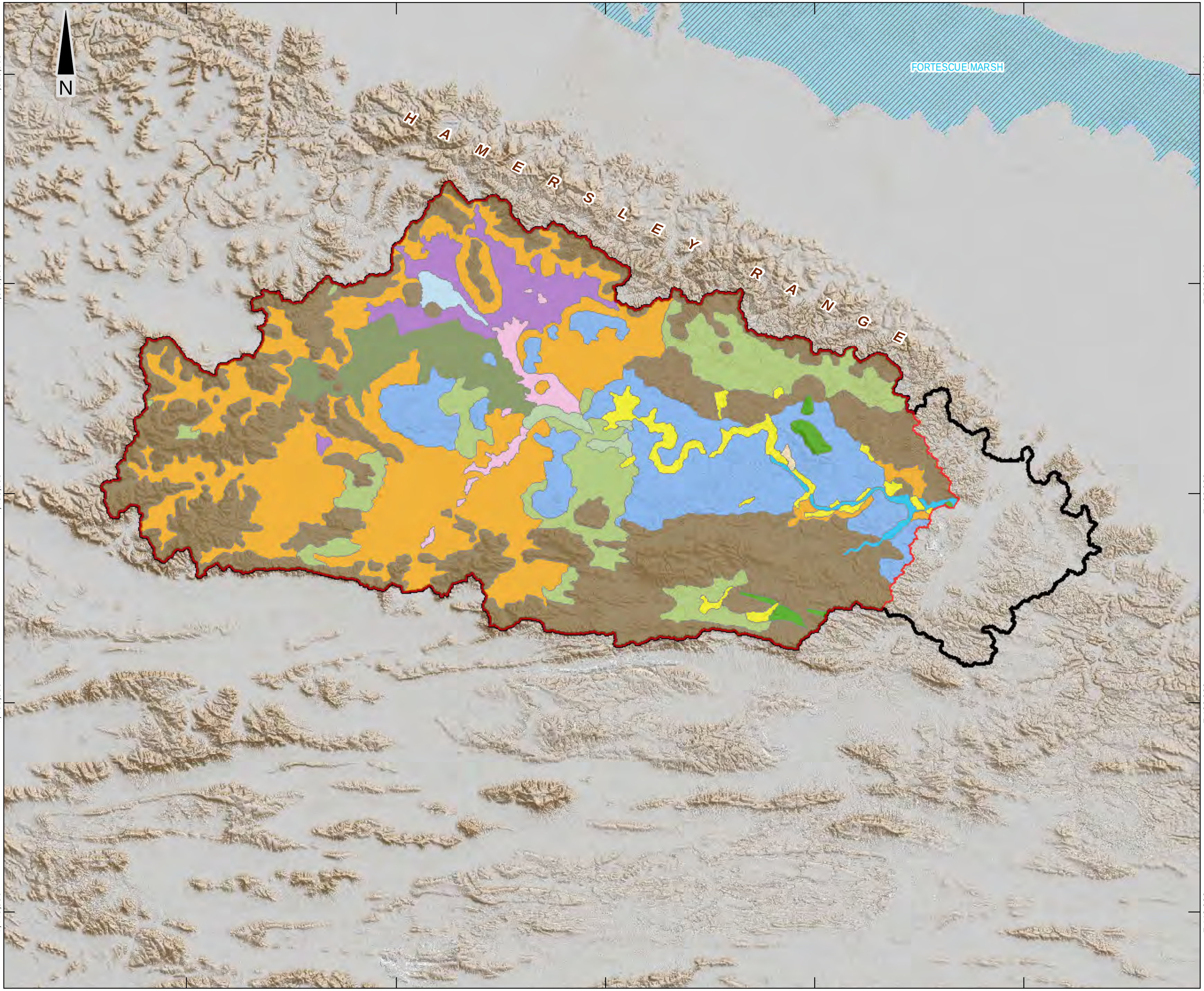
- Pindering (EHU6) – gravelly hardpan plains in valley areas west of Flat Rocks and south of Marillana Creek

- Wannamunna (EHU6) – hardpan plains of low relief principally associated with broad valley areas around the Munjina Claypan.

Other notable land systems include:

- Robe (EHU2) – low plateaux, mesas and buttes of limonites, associated with CIDs targeted by mining operations
- River (EHU8) – concordant with the river channel and floodplains of the lower Marillana Creek system
- Calcrete (EHU7) – low calcrete platforms and plains, prominent in areas surrounding Marillana Creek between Flat Rocks and Munjina Claypan
- Brockman (EHU9) – alluvial plains with cracking clay soils, associated with the Munjina Claypan.

Van Vreeswyk *et al*., 2004 grouped the Pilbara land systems into 18 land surface types according to a combination of more generic landforms, soils, vegetation and drainage patterns. This grouping provides information that is more suitable for regional scale assessments and has contributed to the delineation of landscape EHUs (refer to Section 1.3).



LEGEND

- Fortescue Marsh
- Marillana Creek project
- Marillana Creek catchment
- Mine

Land Systems

- Boolgeeda land system
- Brockman land system
- Calcrete land system
- McKay land system
- Newman land system
- Oakover land system
- Pindering land system
- Platform land system
- River land system
- Robe land system
- Rocklea land system
- Wannamunna land system

NOTES
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Marillana Creek SEA Project

LAND SYSTEMS IN MARILLANA STUDY AREA

FIGURE 14

Table 6: Land Systems in Marillana study area

Land system	Land surface type	Percent of Study Area	Description	Geomorphology and soils
Boolgeeda	8	25.0%	Stony lower slopes and plains below hill systems supporting hard and soft spinifex grasslands and Mulga shrublands. Widespread across the Pilbara Region.	Quaternary colluvium parent materials. Closely spaced dendritic and sub-parallel drainage lines. Predominantly depositional surfaces characterised by red loamy soils of variable depth.
Brockman	14	0.5%	Alluvial plains with cracking clay soils supporting tussock grasslands.	Depositional surfaces including level non-saline alluvial plains with clay soils and gilgai micro-relief. Flanked by slightly more elevated hardpan washplains. Sluggish internal drainage on plains. Predominantly clay soil types.
Calcrete	18	1.4%	Low calcrete platforms and plains supporting shrubby hard spinifex grasslands.	Tertiary calcrete formed in valley-fill deposits, with minor Quaternary alluvium. Drainage is generally indistinct. Soils are mainly shallow calcareous loams (<0.5 m overlying calcrete), with minor calcareous loamy earths and red shallow loams.
McKay	1	13.6%	Hills, ridges, plateau remnants and breakaways of meta-sedimentary and sedimentary rocks supporting hard spinifex grasslands.	Erosional surfaces with moderately spaced tributary drainage patterns incised in narrow valleys in upper parts, becoming broader and more widely spaced downstream. Soils are mainly shallow and stony.
Newman	1	35.9%	Rugged jaspilite plateaux, ridges and mountains supporting hard spinifex grasslands. Widespread across the Pilbara Region.	Erosional surfaces, characterised by skeletal soils (with abundant pebbles, cobbles and stones) and frequent rock outcropping. Soils are shallow and stony.
Oakover	3	0.6%	Breakaways, mesas, plateaux and stony plains of calcrete supporting hard spinifex grasslands.	Erosional and depositional surfaces including mesas and buttes with steep breakaway faces descend onto calcareous plains dissected by channels. Soils are dominated by calcareous shallow loams.
Pindering	12	4.5%	Gravelly hardpan plains supporting groved mulga shrublands with hard and soft spinfiex.	Depositional surfaces including level to gently undulating stony and gravelly plains on hardpan. Numerous small linear or arcuate drainage foci. Soils are generally red shallow loams and duplex types.

Land system	Land surface type	Percent of Study Area	Description	Geomorphology and soils
Platform	5	10.2%	Dissected slopes and raised plains supporting hard spinifex grasslands.	Erosional surfaces formed by partial dissection of the old Tertiary surface. Stony upper plains are separated by closely spaced dendritic or sub-parallel drainage lines, incised up to 30 m below the surrounding land surface. Soils are mainly red shallow loams and stony types, with red loamy earths in dissection zones.
River	17	0.6%	Active flood plains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft spinifex grasslands.	Riverine environments subject to flooding, with generally deep soils of various texture classes.
Robe	3	2.2%	Low limonite mesas and buttes supporting soft spinifex (and occasionally hard spinifex) grasslands.	Erosional surfaces formed by partial dissection of old Tertiary surfaces. Closely to moderately spaced narrow tributary drainage floors. Soils are generally shallow and gravelly.
Rocklea	1	0.7%	Basalt hills, plateaux, lower slopes and minor stony plains supporting hard spinifex (and occasionally soft spinifex) grasslands.	Erosional surfaces including hills, ridges and plateaux remnants. Tributary drainage patterns grade into broader floors and channels downslope. Soils are generally shallow with abundant basalt cobbles.
Wannamunna	12	4.2%	Hardpan plains and internal drainage tracts supporting mulga shrublands and woodlands (and occasionally Eucalypt woodlands).	Depositional surfaces including level hardpan washplains. Broad internal drainage flats with some localised, arcuate drainage foci. Soils are generally by shallow loams often with red-brown hardpans. Heavier soil types occur on drainage plains.

2.5.3 Vegetation and flora

The Marillana Creek Region is situated within the Fortescue Botanical District of the Eremaean Botanical Province, as described by Beard, 1975 & 1990. The vegetation of the Fortescue Botanical District is typically open and dominated by spinifex, *Acacia* small trees and shrubs, and occasional Eucalypts. Major plant families represented include Fabaceae (*Acacia* spp.), Myrtaceae (*Eucalyptus* spp.), Scrophulariaceae (*Eremophila* spp.), Chenopodiaceae (Samphires, Bluebushes, and Saltbushes), Asteraceae (Daisies) and Poaceae (Grasses).

The broad scale vegetation associations mapped by Beard, 1975 within the project area are summarised in Table 7 and spatially depicted in Figure 15.

Table 7: Vegetation associations in Marillana study area

Vegetation Association Reference	Percent of study area	Description
18	48.8%	Low woodland; mulga (*Acacia aneura* and its close relatives).
29	0.2%	Sparse low woodland; mulga, discontinuous in scattered groups.
82	51.0%	Hummock grasslands, low tree steppe; snappy gum over *Triodia wiseana.*

Source: Beard, 1975.

McKenzie *et al.,* 2009 provide a more recent synthesis of the broad patterns of vegetation in the IBRA sub-regions of the Pilbara bioregion. Their findings relevant for the project area are summarised as follows:

- On mountain summits the vegetation is characteristically shrub mallee (*E. kingsmillii, E. ewartiana, E. lucasii*) with emergent Snappy Gum (*Eucalyptus leucophloia*) or Iron Bloodwood (*Corymbia ferriticola*) over shrubs (*Acacia arida, Gastrolobium grandiflorum, Hibbertia glaberrima, Daviesia eremaea*) and hard spinifex (*Triodia brizoides*).
- The rolling hills and stony plains support an open woodland of Snappy Gum over low shrubs (*Acacia bivenosa, A. ancistrocarpa, A. maitlandii, Keraudrenia* spp.) and hard spinifex (*T. wiseana, T. basedowii, T. lanigera*), with upland drainage features supporting slightly denser vegetation mostly comprising wattle shrubs with some Pilbara Bloodwood (*Corymbia hamersleyana*). Shrub mallee (*Eucalyptus gamophylla, E. trivalva, E. socialis* subsp. *eucentrica, E. striaticalyx*) over tea tree (*Melaleuca eleuterostachya*) and hard hummock grasses (*T. basedowii, T. longiceps, T. angusta*) also constitute a common community on stony plains and rolling hills, particularly on calcareous pediments.
- The ironstone and basalt ridges, ranges and hills of the sub-region are dominated by Snappy Gum woodlands over shrubs (*Acacia hilliana, A. adoxa, Gompholobium karijini, Mirbelia viminalis*), tussock grasses (*Amphipogon carinatus, Cymbopogon* spp.) and hard spinifex (*T. wiseana, T. basedowii*). Various eucalypt mallee species (*E. gamophylla, E. pilbarensis, E. trivalva*) may also be common on the slopes.
- Overland flow, water-gaining slopes and bajadas[3] above detrital ferruginous deposits and valley-fill support a cover of Acacia woodland and shrubland dominated by Mulga (*A. aneura s.l., A. ayersiana, A. minyura*) over an understorey of open shrubs (*Ptilotus obovatus, Rhagodia eremaea, Senna glutinosa*) and tussock grasses (*Chrysopogon fallax, Eragrostis* spp., *Eriachne* spp).

[3] a series of coalescing alluvial fans along a mountain front

- The small drainages are dominated by emergent Pilbara Bloodwood, Pilbara Box (*Eucalyptus xerothermica*), Western Coolibah (*Eucalyptus victrix*) with Acacia (*A. maitlandii, A. monticola, A. tumida var. pilbarensis, A. ancistrocarpa*) shrubland over hard and soft hummock grasses (*T. wiseana, T. pungens*) and occasional tussock grasses (*Themeda* spp.) depending on landscape position.

- The large channels contain extensive alluvium and fine depositional deposits that support a fringing riparian open tall woodland of River Red Gum (*Eucalyptus camaldulensis*) and Western Coolibah over woodlands or tall shrublands of Pilbara Jam (*Acacia citrinoviridis*), slender petalostylis (*Petalostylis labicheoides*) and Weeping Wire Wood (*Acacia coriacea* subsp. pendens) over soft hummock grasses (*T. pungens, T. epactia*) and tussock grasses such as Buffel grass, kangaroo grass and Silky Browntop (*Eulalia aurea*).

- In sites where the drainage is interrupted and the watertable is shallow, extensive Silver Cadjeput (*Melaleuca argentea*) forests with River Red Gum and Western Coolibah woodlands over native cotton (*Gossypium* spp.) and sedgelands of Stiffleaf Sedge (*Cyperus vaginatus*) may exist.

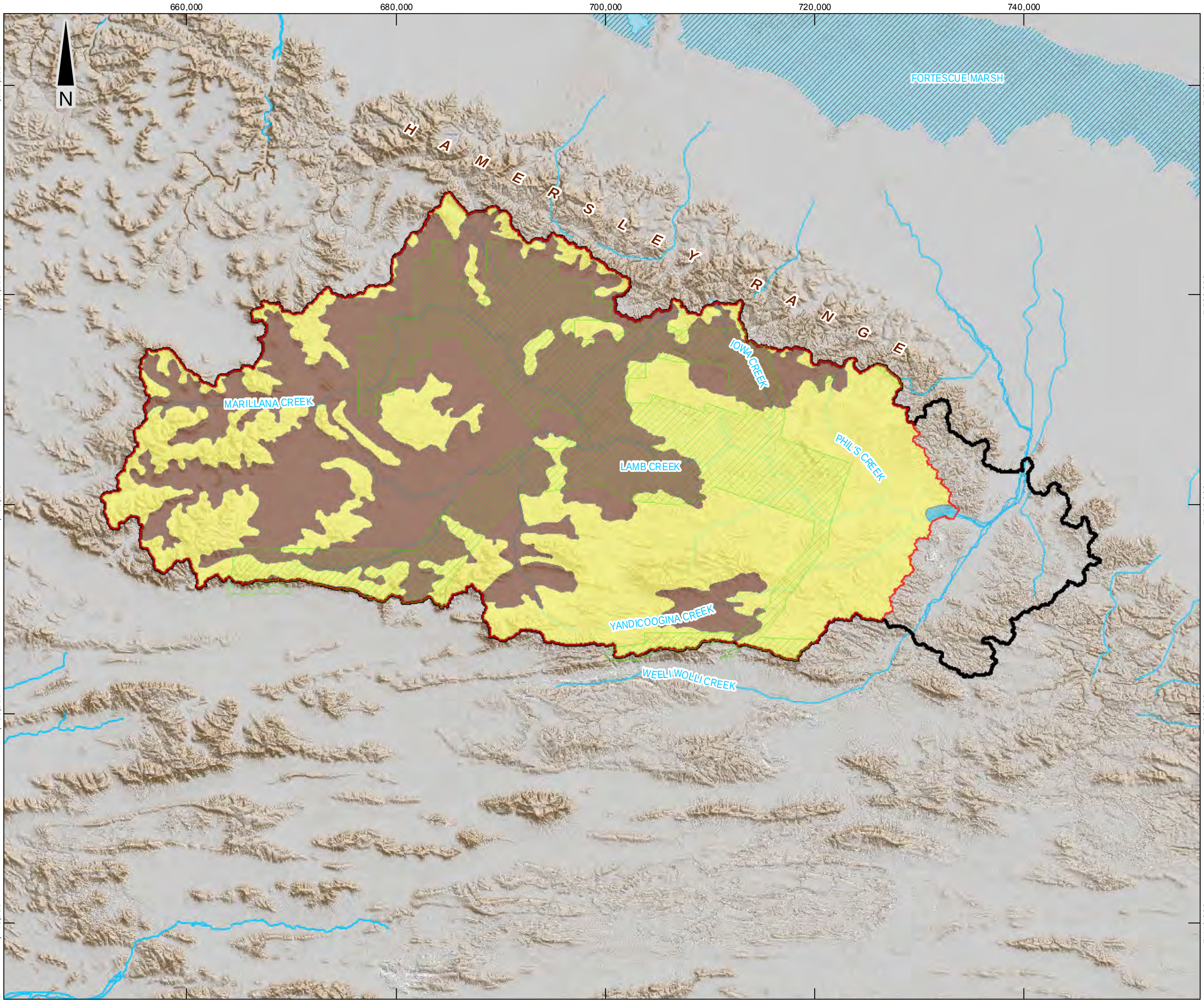
- Internal drainage basins (e.g. Lake Robinson, Munjina Claypan and the Mt Bruce, Coondewanna and Wanna Munna Flats) generally support extensive tall to low mulga woodland with scattered emergent Pilbara Box over bunch grasses (*Aristida* spp., *Eriachne* spp) on fine textured soils. The basement sump of such internal drainage basins is usually dominated by woodlands of Western Coolibah over tussock grasses (*Themeda triandra, Eulalia aurea, Eragrostis* spp., *Eriachne* spp., *Chrysopogon fallax*) or Lignum (*Muehlenbeckia florulenta*) and swamp grass.

- On very flat pediments, well-developed grove-intergrove mulga woodlands may exist with emergent Western Gidgee (*Acacia pruinocarpa*) and a suite of mulga allies (*A. paraneura, A. ayersiana, A. aneura var. intermedia, A. aneura var. macrocarpa, A. aneura var. pilbarana*). These are also termed banded mulga formations.

Over the past decade, BHP Billiton Iron Ore has completed more detailed vegetation surveys in parts of the Study Area (Figure 15). These surveys have generally been conducted in accordance with Environmental Protection Authority (EPA) guidelines for environmental impact assessment (EPA, 2002 and 2004). In addition to providing greater detail on vegetation floristic and species distributions more generally, this mapping has spatially delineated vegetation units including the potentially groundwater dependent species of *Melaleuca argentea, Eucalyptus camaldulensis* and *E. victrix*. These species are principally associated with the Marillana Creek system, and some of its major tributaries including Yandicoogina Creek.

Populations of the declared rare species *Lepidium catapycnon*, which is listed under State and Commonwealth legislation, have been recorded in upland parts of the project area. Several priority listed flora as recognised by the Department of Parks and Wildlife (DPaW) have also been recorded in various environmental settings within the project area.

A number of invasive introduced species occur in the project area. Of these, the perennial grass Buffel (*Cenchrus ciliaris*) is notable due to its propensity to rapidly colonise alluvial surfaces of river systems and displace indigenous shrub and grass cover.



LEGEND

- Creek
- Fortescue Marsh
- Marillana Creek project
- Marillana Creek catchment

Vegetation Systems (Associations)

- Fortescue Valley (29)
- Hamersley (18)
- Hamersley (82)
- BHPBIO vegetation survey area

NOTES

Coordinate System: GDA 1994 MGA Zone 50

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Catchment boundary © Department of Water

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0 5 10 15 20

kilometres

SCALE (at A4) 1:500,000

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DOCUMENT 137646040-002-R-Rev4

DATE 01 Sep 2015

COMPILED MS

APPROVED GRH

Marillana Creek SEA Project

VEGETATION ASSOCIATIONS AND BHP BILLITON IRON ORE VEGETATION SURVEY AREAS

FIGURE 15

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2.5.4 Terrestrial fauna

The fauna of the Pilbara Region is typified by arid-adapted vertebrates, with generally extensive regional distributions. Many species tend to have affinities with land surface substrates and vegetation structure. Climatic variables tend to have a weaker influence on species distributions.

The major habitat types in the study domain, informed by land system mapping and previously completed fauna surveys in sections of the study area, can be characterised as follows:

- Mountainous rugged terrain associated with the Hamersley Range comprising ridges, plateaux, steep hills with scree-free faces and stream channels
- Rolling hills and foothills associated with the Hamersley Range
- Mulga woodlands and scrublands of the broad valleys
- Calcrete plains adjacent to the upper Marillana Creek
- The major drainage systems and floodplains associated with the lower Marillana Creek and its major tributaries, including riparian woodlands
- Internal drainage basins (e.g. Munjina Claypan) including tussock grass and mulga woodlands.

The existing conservation reserve system in the Pilbara includes examples of a wide variety of the sandy, clayey and rocky substrates and geomorphic units that characterise the Pilbara (McKenzie *et al.,* 2003). With respect to the habitats of the study area within the Pilbara bioregion, these reserves provide suitable habitat for many of the Pilbara's recorded vertebrate species and are generally considered to provide adequate habitat to ensure species persistence with appropriate management (e.g. Gibson & McKenzie, 2009, Burbidge *et al.,* 2010, Doughty *et al.,* 2011). However riparian vegetation has been noted to support distinctive bird assemblages and may require special conservation attention (Burbidge *et al.,* 2010). The richest microbat assemblages are associated with well-developed riparian environments including complex vegetation structures and permanent pools set in cavernous landscapes (McKenzie & Bullen, 2009). Two microbat species (*Nyctophilus bifax* and *Chalinolobus morio*) are considered to be restricted to productive riparian environments.

A number of fauna of elevated conservation significance, including those listed under State and Commonwealth legislation, are known to exist within the study area. Several species have an association with wetland habitats including:

- Pilbara Olive Python (*Liasis olivaceus barroni*) - occurs in rocky areas, showing a preference for habitats near water in particular rock pools.
- Orange Leaf-nosed Bat (Pilbara form) (*Rhinonicteris aurantius*) - utilises deep caves offering suitable humidity and a stable temperature. In the Pilbara, this species is thought to be restricted to caves where at least semi-permanent water occurs nearby.
- Migratory wetland birds – utilise significant water bodies associated with major drainage systems and lakes. Examples include the Great Egret (*Ardea modesta*), Cattle Egret (*Ardea ibis*) and Eastern Osprey (*Pandion cristatus*).

2.5.5 Subterranean fauna

Stygofauna are animals that inhabit groundwater environments. They can be further classified depending on their level of dependency on the subterranean environment; stygoxenes are facultative users of groundwater; stygophiles are species that may inhabit groundwater environments for most or part of their life history; and stygobites are obligate groundwater inhabitants that are permanently restricted to their subterranean environments for their entire life cycle.

The Pilbara is a globally important region for stygofauna, with a rich fauna of subterranean invertebrates characterised by high endemicity (Halse *et al*., 2014). Ostracods are the dominant stygofaunal group in terms of species richness and animal abundance. Other major groups include copepods, amphipods and oligochaetes. Stygobitic species have the potential for restricted geographical distributions, depending on the extent and connectivity of groundwater systems. They may be classified as Short Range Endemic species (SRE's) where restricted to a particular aquifer system.

A variety of factors influencing the diversity and distribution of stygofauna at a range of habitat and temporal scales have been identified (Hancock *et al*., 2005; Boulton, 2000). Some of the more influential factors at the microhabitat (sediment) scale include interstitial pore size, inflow rates of energy resources (e.g. organic carbon, biofilm growth, prey), and water quality parameters such as water temperature, pH, salinity, dissolved oxygen, and organic carbon levels. At the mesohabitat (catchment) scale, factors include flow patterns along a watercourse influencing zones of upwelling and downwelling of energy resources or dissolved oxygen according to geomorphological features, as well as interactions with riparian and parafluvial sediments (Boulton *et al*., 1998).

A feature of the Pilbara is that stygofauna occur across most landscapes and lithologies, often where the depth to groundwater is considerable, although typically lower capture rates are associated with depth to groundwater of greater than 30 m. Porous and karstic aquifers of alluvium and calcrete often have greater species diversity and abundance (Maurice & Bloomfield, 2012). Heterogeneity of habitat and water chemistry within groundwater systems may give rise to distinct stygofauna assemblages, reflecting different habitat and water chemistry conditions (Hahn & Fuchs, 2009; Maurice & Bloomfield, 2012).

In general, optimal groundwater conditions for stygofauna include circum-neutral pH (~6.5 to 8.5) with the typical pH range of calcrete aquifers ranging from 7.2 to 8.2 (Humphreys, 2008). Although stygofauna have been recorded over a wide range of dissolved oxygen concentrations and have evolved to tolerate oxygen deficient groundwaters (Malard & Hervant, 1999), generally species diversity and abundance decline with reducing dissolved oxygen (Halse *et al*., 2014)[4].

No stygofauna hotspot areas occur within the study area. However, the groundwater system associated with the Marillana Creek valley is known to support a relatively diverse stygofauna assemblage. Downgradient from Flat Rocks there is high level of habitat connectivity within the alluvium, as well as significant seasonal water movement associated with cyclonic flows that suggests contiguity of habitat along the Marillana Creek valley and into the Weeli Wolli Creek groundwater system.

2.5.6 Ecological assets

BHP Billiton Iron Ore has developed a classification hierarchy for ecological assets in the Central Pilbara Region. A summary of ecological assets occurring within the Marillana Creek Region under this hierarchy is provided in Table 8.

There are a number of ecological assets in the study area; however, there are no recognised ecohydrological receptors.

The most identifiable ecological asset is Marillana Creek itself, which is considered by BHP Billition Iron Ore to be a Tier 3 ecological asset as it contains no Threatened Ecological Communities (TECs) or Priority Ecological Communities (PECs) (as described in DPaW, 2013), and has only local conservation significance.

[4] Dominant geology shown in parentheses

Other ecological assets include:

- Flora species of conservation significance not associated with key ecohydrological receptors, including Lepidium catapycnon and priority flora taxa recognised by Department of Parks and Wildlife.
- Fauna species of conservation significance whose habitat requirements are not strongly dependent on, or otherwise intimately associated with, the key ecohydrological receptors.
- Uplands (EHUs 1 to 4) associated with intersection of the Karijini National Park.
- Uplands (EHUs 1 to 4), alluvial plains (EHU6) and calcrete plains (EHU7) associated with proposed 2015 pastoral lease exclusion areas.

The western margin of the study area intersects the eastern boundary of Karijini National Park, including uplands of the Hamersley Range. The National Park constitutes a Tier 1 ecological asset under the BHP Billiton Iron Ore classification hierarchy.

Portions of the study area currently that are under pastoral management have been proposed for non-renewal and transfer into the conservation estate post-2015 by the DPaW. This includes much of the western third of the study area immediately east of Karijini National Park, including the Munjina Claypan. Note that current pastoral leases were granted under the now repealed *Land Act 1933* (WA), and all will expire on 30 June 2015 (EDO, 2010). The proposed exclusion areas are recognised as Tier 2 environmental assets under the BHP Billiton Iron Ore classification hierarchy.

Riparian vegetation along Marillana Creek has local conservation significance, owing to the relatively limited extent of this vegetation type compared with other locally occurring vegetation types and the ecological services that it provides. These ecological services include:

- provision of structural habitat elements, such as tree hollows
- protection of streambanks from erosion
- protection of water quality through sediment trapping and nutrient stripping
- transfer of subterranean water nutrients to the surface environment by some of the dominant tree species.

The groundwater system associated with Marillana Creek is known to host a diverse stygofauna community, including some regionally uncommon (and in some cases undescribed) taxa. Historical mining operations along the Marillana Creek CIDs have been required to implement subterranean fauna monitoring programs as part of environmental approval conditions.

The Munjina Claypan is an internally-draining basin with an area of approximately 274 km^2. It hosts a low open forest of *Acacia aptaneura* and *Acacia pruinocarpa* over open hummock grassland of *Triodia melvilei*, *T. wiseana* and *T. pungens* over tussock grassland of *Themeda triandra*, *Chrysopogon fallax* and *Aristida inaequiglumis*. As well as constituting an uncommon landform type, the claypan performs an important hydrological function by regulating the passage of cyclonic related flooding into the down-gradient Marillana Creek system.

Table 8: Ecological assets in Marillana study area[5]

Tier	Description	Ecological assets in or immediately adjacent to the study area
Ecological assets		
1	Assets that are recognised under formal international, national or state systems as having high value. These include assets listed under the Ramsar convention, by the IUCN as a Category Ia, Ib or II reserve, protected under state or federal law or otherwise endorsed by state or federal ministers, with the exception of declared Environmentally Sensitive Areas. For example, lands in the conservation reserve system, Ramsar wetlands, Wetlands identified in 'A Directory of Important Wetlands of Australia', TECs and federally listed communities. BHP Billiton Iron Ore considers these assets to have the highest priority for management.	Karijini National Park.
2	Assets that have no formal level of legislative protection[6] but for which BHP Billiton Iron Ore will undertake further consideration on a case-by-case basis to determine management priority. For example, State listed Priority Ecological Communities and the DPaW's proposed 2015 pastoral lease excision areas.	DPaW's proposed 2015 pastoral lease exclusion areas.
3	Other assets which have no formal level of protection or foreseeable level of future protection. BHP Billiton Iron Ore considers these assets to have the least priority for management.	Riparian woodlands. Marillana Creek stygofauna community. Munjina Claypan.

[5] Flora and fauna species listed under State and Commonwealth legislation not included.

[6] Exceptions with a legislated level of protection are declared Environmentally Sensitive Areas (which may include the buffer around a Tier 1 TEC)

Tier	Description	Ecological assets in or immediately adjacent to the study area
Species assets		
1	Species known to be under threat. These are species listed under IUCN Red-list categories and/ or the *Environment Protection and Biodiversity Conservation Act, 1999* (EPBC Act) as Critically Endangered, Endangered and Vulnerable, (i.e. Threatened species), and species listed under Schedules 1 and 4 of the *Wildlife Conservation Act, 1950* (WC Act) (e.g. DRF). BHP Billiton Iron Ore considers these species to have the highest priority for management.	State and Commonwealth listed flora. State and Commonwealth listed fauna.
2	Species that have no formal level of legislative protection as 'threatened' within Western Australia, but for which BHP Billiton Iron Ore will undertake further consideration on a case-by-case basis to determine management priority'. These are species listed under international conventions (e.g. JAMBA), as Marine or Migratory under the EPBC Act, in Schedule 3 of the WC Act or as a Priority species.	Priority flora and fauna recognised by the DPaW.
3	Other species that have no formal level of protection as a threatened species, or foreseeable level of future protection (noting that all native species are protected under the WC Act, but not all are specially protected as Schedule species). BHP Billiton Iron Ore considers these species to have the least priority for management.	None specified.

2.6 Water Use

Consumptive water use in the study area is largely dependent on the development and utilisation of groundwater resources (DoA, 2004). Groundwater usage is in two main categories:

- Pastoral: water is required for livestock and is obtained from wells and permanent pools within ephemeral watercourses. The volume of water used for stock watering is minimal, when compared with abstraction for mining.
- Mining: the main water use is for mineral processing and dust suppression being obtained from dewatering activities. An additional water supply is often required for potable use.

Elsewhere in the Pilbara, groundwater is used for town water supplies. Apart from temporary mining camps for fly-in, fly-out workers, there are no ‘permanent’ towns in the study area.

Pastoral industry

The pastoral industry is a minor groundwater user in the Marillana Creek Region. Shallow bores and hand-dug wells were initially constructed to meet the pastoral requirements for stock watering. Cattle and sheep stations are dependent on groundwater supplies and surface water features, such as waterholes or springs, for watering stock. There are no known springs; however, a number of waterholes are scattered along major creeks.

The number of functioning bores throughout the catchment is not known with certainty with many bores abandoned or poorly maintained. Most bores tend to be concentrated in the low lying areas of alluvium rather than the topographically higher, colluvial soils or areas of bedrock outcrop. There are approximately 23 pastoral bores identified in the catchment with the majority located in the western area where alluvium and colluvium deposits occur. Approximately 6 of the 23 pastoral bores are positioned over calcrete deposits. In general, groundwater supplies are readily located, but many exploratory sites have been abandoned due to drilling issues or inadequate supplies.

Most bores used by the pastoral industry are less than 30 m deep and are typically equipped with a windmill, with yields up to 10 kL/d (DoW WinSite data, 2013). Supplies in excess of 20 kL/d are available from areas of calcrete and thick alluvium. Groundwater is generally of low salinity, although groundwater up to 7000 mg/L TDS can be utilised for stock watering. Station domestic supplies commonly rely on rainwater tanks supplemented by potable groundwater, if available.

Mining industry

The various mining operations in Marillana Creek have a wide range in groundwater abstraction requirements. Operations located in the uplands where groundwater tables are deep have minor or non-existent dewatering requirements. The target ore may be mostly or entirely above the water-table (above water table mining). These operations frequently have a water deficit (water requirements exceed abstraction) or become water deficit during their mine life. They may obtain water for dust suppression and any ore processing requirements are met from dewatering borefields of nearby mines that have water surpluses. Operations located in receiving landscapes where groundwater levels are shallow have significant dewatering requirements and are frequently water surplus (abstraction exceeds water requirements). Surplus water is managed with consideration of hydrological interactions between surrounding operations, future mine water supply requirements and environmental impacts.

2.7 Land use

Historical land use since the late 1880s has largely comprised the development of pastoral land and artificial stock watering points. Pastoral leases (lease holders) within the study area include Marillana Station (BHP Billiton Iron Ore) and Juna Downs Station (Hamersley Iron i.e. RTIO). Livestock grazing in the Pilbara caused a depletion of indigenous grasses alongside main drainage channels and introduced species including buffel grass (*Cenchrus ciliaris*) and Birdwood grass (*Cenchrus setigerus*). The introduction of artificial stock watering points fostered an increase in kangaroo and emu populations. Prior to the 1970s, livestock were predominantly sheep and during the following years pastoral stations shifted to cattle enterprises with few sheep grazing on stations currently (DoA, 2004).

Current land use includes conservation areas (Karijini National Park - Karijini), iron ore mining (BHP Billiton Iron Ore Yandi, RTIO Yandicoogina, MRL's Phil's Creek); transportation (roads and railways) and low intensity stock grazing in areas not directly affected by mining activities (Figure 16).

Proposed mining operations in the Marillana Creek catchment include BHP Billiton Iron Ore's Upper Marillana, Munjina, Ministers North and Tandanya; RTIO's Yandicoogina expansion and Koodaideri development (access corridors only), MRL's Iron Valley project, and potentially Hemisphere Resources' (Nexus Minerals) Yandicoogina South.

Karijini is located within the centre of the Hamersley Range and extends approximately 8 km into the western section of the Marillana Creek catchment. Karijini is one of Australia's largest national parks, and has significant environmental values. The closest proposed mining operations are Tandanya (about 2 km east of the park boundary) and Upper Marillana (about 15 km east of the park boundary).

Some portions of pastoral land were excluded from lease renewals for the purposes of conservation, recreation, tourism, protection of aboriginal sites and expansion of existing towns (EDO, 2010). A 571 km^2 portion of the Juna Downs station extending east from Karijini to the Great Northern Highway and approximately 20 km further north-east across the north Marillana Creek tributary has been proposed as an exclusion area and tenure to be converted to conservation, mining or crown land. Portions of the proposed Upper Marillana, Munjina and Tandanya BHP Billiton Iron Ore mining operations are located within the proposed exclusion areas.

Future land use (post mining) will likely include public recreational areas, conservation areas and pastoral use which will be decided in conjunction with stakeholder consultation as part of closure planning for each of the mining operations.

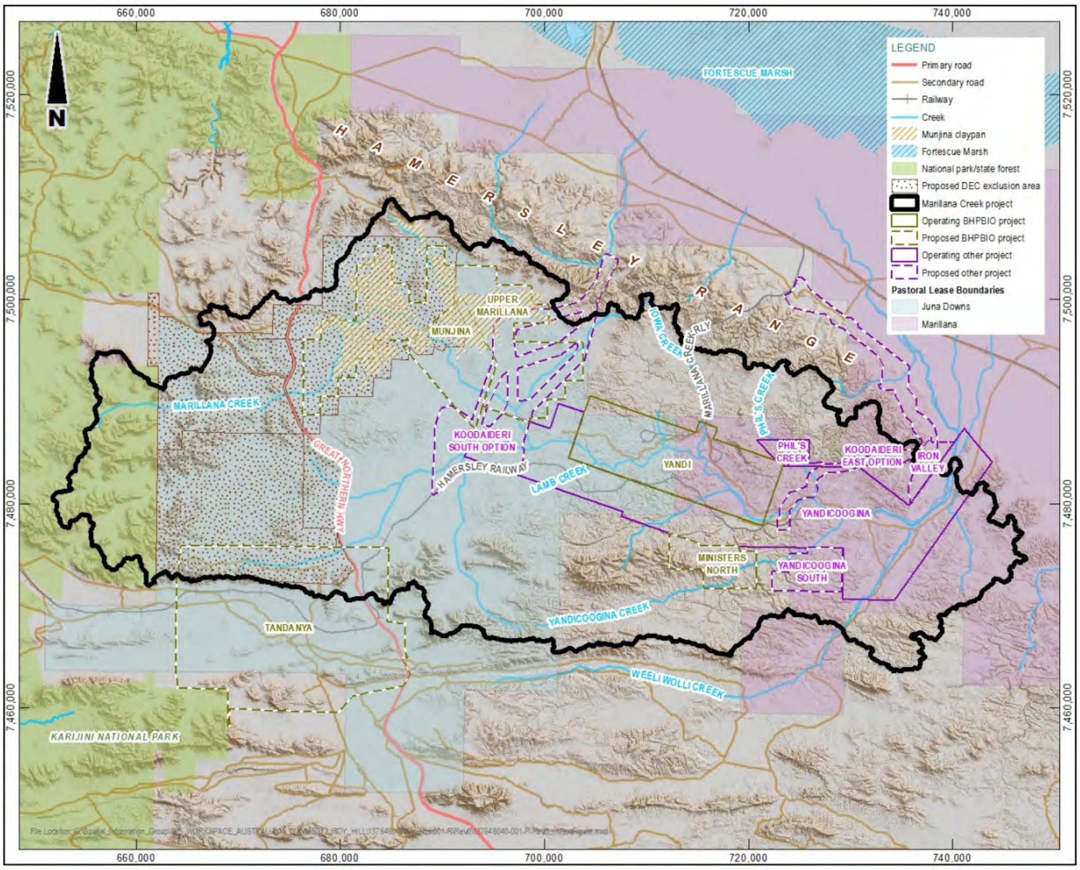


Figure 16: Land use in the Marillana Creek Region

3.0 REGIONAL HYDROLOGY

The Marillana Creek catchment is characterised by irregular and generally low annual rainfalls (typically less than 400 mm/year) with periodic large storm events associated with remnant tropical cyclones contributing most of the annual total. The drainages are ephemeral with streams flowing for relatively short periods of time.

There is little or no permanent surface water flow in the catchment. Although persistent, possibly permanent, small pools and baseflows may occur from alluvium immediately upstream of the Flat Rocks gauging station.

Groundwater is regarded as ubiquitous within the catchment. However, aquifers are believed mostly to be limited to the CID, alluvial deposits and calcrete where thick enough to be saturated. The Weeli Wolli and Brockman Iron Formations may have localised aquifers where they are mineralised or intensely fractured.

3.1 Surface water

3.1.1 Setting and key features

The Marillana Creek catchment comprises a number of main tributaries including Iowa, Lamb, Phil's and Yandicoogina Creeks (see Figure 2). Channel gradients along Marillana Creek are low at around 2 m/km. In the central and eastern sections of the catchment, the Marillana Creek alignment is topographically controlled with the river channel typically varying in width from 70 m to 150 m. The profile of Marillana Creek from its headwaters to near its confluence with Weeli Wolli Creek is shown in Figure 17. The variation in topography within the Marillana Creek catchment is shown in Figure 18.

The overall length of the main channel is around 104 km. The lower 80 km has an average gradient of around 2.5 m/km, increasing to around 9 m/km over the remaining 24 km. There is also a short steeper section immediately upstream of Flat Rocks gauging station.

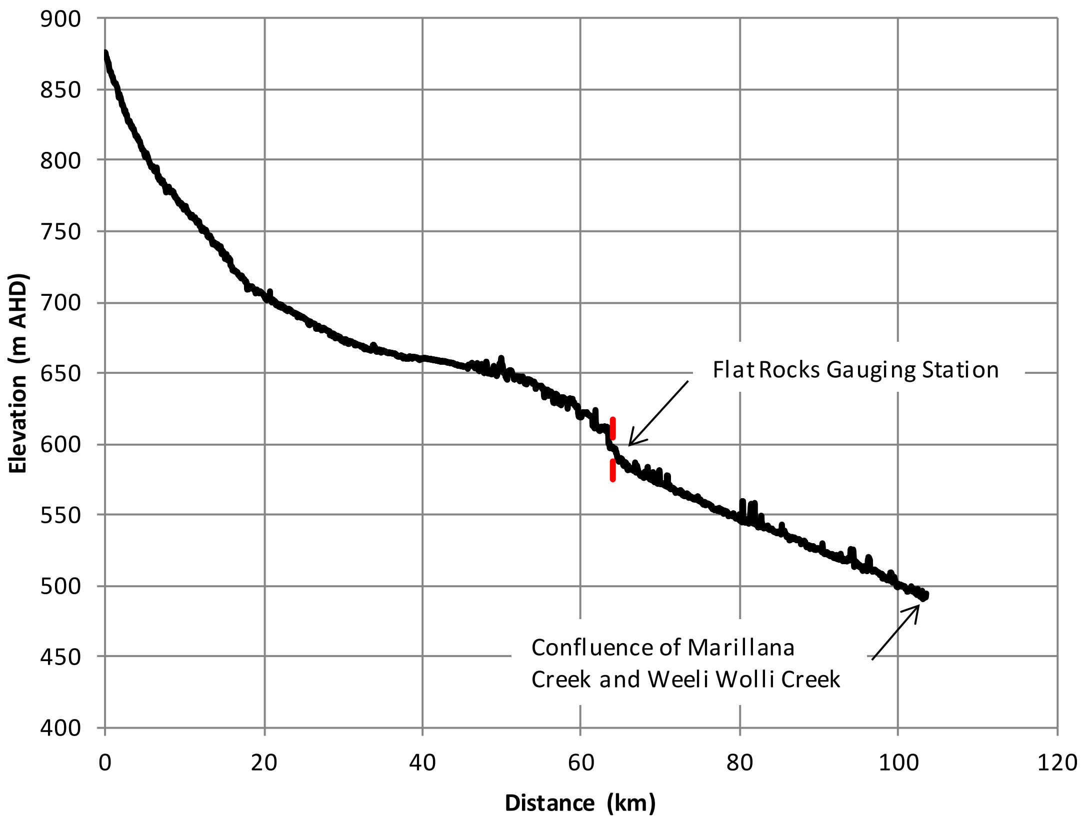


Figure 17: Marillana Creek river profile.

The only stream gauging station within the study area is located at Flat Rocks, which monitors the surface runoff contribution from around 50% of the overall Marillana Creek catchment. BHP Billiton Iron Ore has installed a number of water level monitoring sites, however, flows are unavailable at these locations. The average annual runoff is low at around 8 mm (equivalent over the entire catchment area).

Daily rainfalls during larger storm events can vary significantly across the catchment, often by a factor of up to 10 between the western and eastern boundaries of the catchment. This strongly suggests that in many instances larger floods recorded in Marillana Creek have likely resulted from partial area runoff contributions.

In terms of the available rainfall data, the average annual rainfall reduces from around 400 mm at the western boundary to around 350 mm at the Flat Rocks station. This reduction in rainfall is not considered to have a significant influence on surface runoff. The critical factors affecting the peak flood discharges and runoff volumes are more likely to be magnitude, frequency and spatial extent of storms. As noted above, the available rainfall data indicate daily rainfalls exceeding 40 to 50 mm occur on average around twice each year. Larger events exceeding 100 mm are less frequent and occur on average only once every 3 to 4 years.

Given the lack of streamflow stations in the upper reaches of the Marillana Creek catchment and other nearby catchments, a quantitative understanding of how the various areas of the catchment respond to rainfall cannot therefore be developed directly.

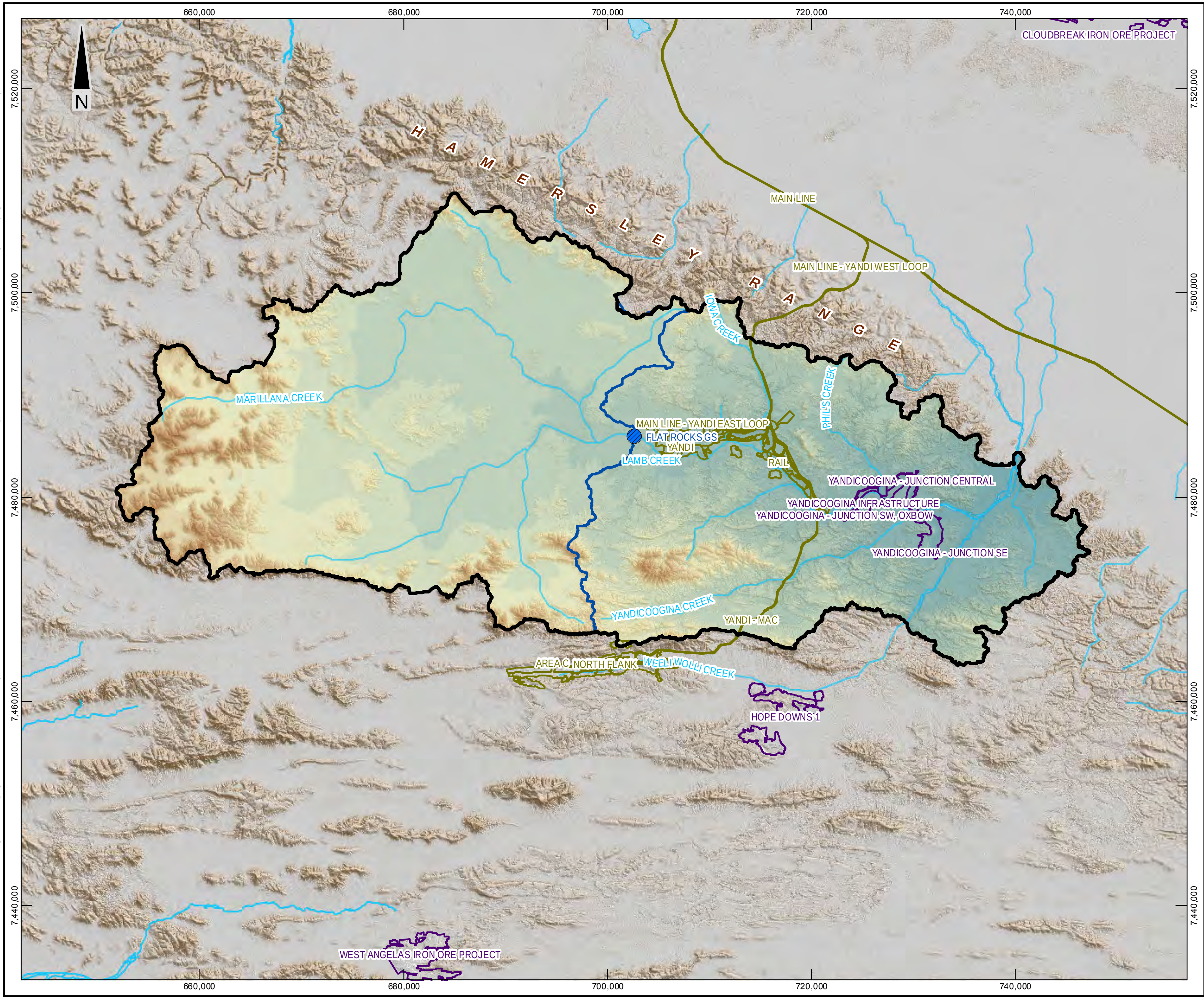
A conceptual understanding of the surface hydrology must be based on the available information for the catchment, such as topography, soils, vegetation, rainfall and streamflow as well as considering data available for stream gauging stations in adjacent catchments (e.g. Weeli Wolli Creek). In addition, some 92% of the overall area is classified as being an Upland or Transitional landscape unit where runoff generation is more likely. Taking this information in account:

- Variability in spatial extent and intensity of storm events will have the most significant influence on runoff generation and the magnitude of flows.
- If rainfall during storm events is comparable across the catchment runoff generation is expected to be generally consistent over the majority of the catchment, although it may be marginally higher in the upslope areas due to higher ground slopes and thinner topsoil resulting in reduced infiltration.
- Munjina Claypan area, characterised by low catchment slopes and numerous depressions, ponds over significant areas of the claypan following larger rainfall events. Water remains in these depressions until it is depleted through evaporation. Previous analyses (RTIO, 2010b) indicate flood peaks for ARIs less than around 10 years are attenuated in the claypans, with the level of attenuation reducing as the flow volumes increase. This suggests that although runoff as a proportion of rainfall is probably less during lower rainfalls than if the claypan area was more similar physiographically to the eastern portion of the catchment, flows continue to discharge downstream from the claypan area (via Marillana Creek). The claypan area therefore does not simply act as a shallow depression until water levels reach a threshold value. Rather, flows occur albeit with limited attenuation as the upslope runoff is conveyed through the numerous small depressions.

On this basis it is considered valid to derive runoff estimates for the various mine sites along the Marillana Creek by applying a direct area ratio to the long-term flows at the Flat Rocks station. For those sites located on tributaries of Marillana Creek, flows based on this approach are likely to be marginally underestimated, particularly for lower rainfall events.

For mine sites along Marillana Creek, peak flood discharges derived for Flat Rocks station using flood frequency analyses could be transposed based on an area ratio raised to a power (typically 0.7 is assumed). Flood estimates derived for sites on tributaries are likely to be underestimated for lower ARI storms but could be derived with more confidence for the more extreme events.

An alternative is to apply a rainfall-runoff model (e.g. RORB or similar) using model parameter values calibrated to flood events recorded at this site. For this latter approach, variations in catchment response to rainfall would better reflect variations in rainfall storm intensities and areal extent of rainfall across the catchment.



LEGEND

- Creek
- Marillana Creek project
- Current BHP Billiton Iron Ore disturbance
- Current Third Party disturbance

Surface elevation (m AHD)

- 450 - 500
- 500 - 550
- 550 - 600
- 600 - 650
- 650 - 700
- 700 - 750
- 750 - 800
- 800 - 850
- 850 - 900
- 900 - 950
- 950 - 1,000
- 1,000 - 1,050
- 1,050 - 1,100
- 1,100 - 1,150
- 1,150 - 1,200

The content of this map is conceptual only, of a general nature and does not purport to contain all information relevant to future project development associated with the Project. This map has been prepared solely for the purposes of informing environmental impact assessment pursuant to the Environmental Protection Act 1986 (WA) and Environment Protection and Biodiversity Conservation Act 1999 and is not intended for use for any other purpose. No representation or warranty is given that project development associated with any or all of the disturbance indicated on this map will actually proceed. As project development is dependent upon future events, the outcome of which is uncertain and cannot be assured, actual development may vary materially from this conceptual map.

NOTES
Coordinate System: GDA 1994 MGA Zone 50

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Mining tenements © Department of Mines and Petroleum, August 2013
Topography interpreted from SRTM Digital Elevation Model of Australia © Geoscience Australia

0 5 10 15 20
kilometres
SCALE (at A4) 1:500,000

Golder Associates

CLIENT BHP Billiton Iron Ore
DOCUMENT 137646040-002-R-Rev4
DATE 01 Sep 2015
COMPILED MS
APPROVED GRH

Marillana Creek SEA Project

VARIATION IN TOPOGRAPHY IN MARILLANA CREEK CATCHMENT

FIGURE 18

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The Munjina Claypan is a major feature of the drainage system located at the upper part of the catchment. Marillana Creek and several tributaries converge on the claypan which is, to a limited extent, an internally-draining depression with subtle internal topographic features and an area of approximately 110 km^2. The claypan is subject to periodic inundation of its local internal depressions following lower magnitude flood events (≤ 10 yr ARI) with downstream discharges being more attenuated during these events than during major floods. For larger floods, surface runoff overflows downstream with less influence/contribution of the claypan on flow volumes and peak discharges.

A number of active and proposed mines are or will be located along Marillana Creek and associated tributaries as outlined below:

- Marillana Creek: BHP Billiton Iron Ore’s Yandi operation, RTIO’s Yandicoogina operation, proposed BHP Billiton Iron Ore Munjina and Upper Marillana mines.
- Phil’s Creek: Phil’s Creek Iron Ore project.
- Yandicoogina Creek: Minister’s North (proposed) and Yandicoogina South mines.
- Weeli Wolli Creek: Iron Valley mine.

For those mines along Marillana Creek, all existing or proposed pits are or will be located either adjacent to or intersect the creek line. The mines therefore have the potential to impact on the surface runoff regime both locally as well as more regionally depending on the proposed approach to controlling and diverting surface flows. This aspect is discussed in more detail in Section 5.0 relating to the individual mining projects.

3.1.2 Catchment response to rainfall

The infrequent rainfall in the Marillana Creek catchment results in episodic catchment runoff and ephemeral flow. A summary of the longer term streamflow characteristics from the stream gauging stations in the vicinity of the Marillana Creek catchment is shown in Table 9.

Table 9: Summary of Streamflows for Available Stream Gauging Stations

Station	Catchment Area	Median/ Mean Annual Runoff	Range in Mean Annual Runoffs (mm)		Maximum Discharge
	(km^2)	(mm)	Min	Max	(m^3/s)
Marillana Creek at Flat Rocks (1967-2013)	1 370	2.4/8.0 (3.2/10.9)	0.01 (0.01)	113 (155)	1 327
Weeli Wolli Creek at Waterloo Bore (1984-2013)	3 391	0.9/8.3 (3.1/28)	0.0 (0.0)	93 (315)	4 137
Weeli Wolli Creek at Tarina (1985-2013)	1 511	4.9/12.9 (7.4/19)	0.0 (0.0)	97 (147)	2 100
Weeli Wolli Creek at Weeli Wolli Springs (1997-2008)	1 445	1.1/4.3 (1.6/6.2)	0.0 (0.0)	19 (27)	423

Note: Annual runoffs based on water year from July to June. Values in brackets are GL.

Average monthly rainfall based on the centrally located site in Marillana Creek catchment for which SILO rainfall data were obtained and mean monthly runoffs for the Marillana Creek at Flat Rocks are shown in Figure 19. The daily flow duration statistics for the site are summarised in Table 10.

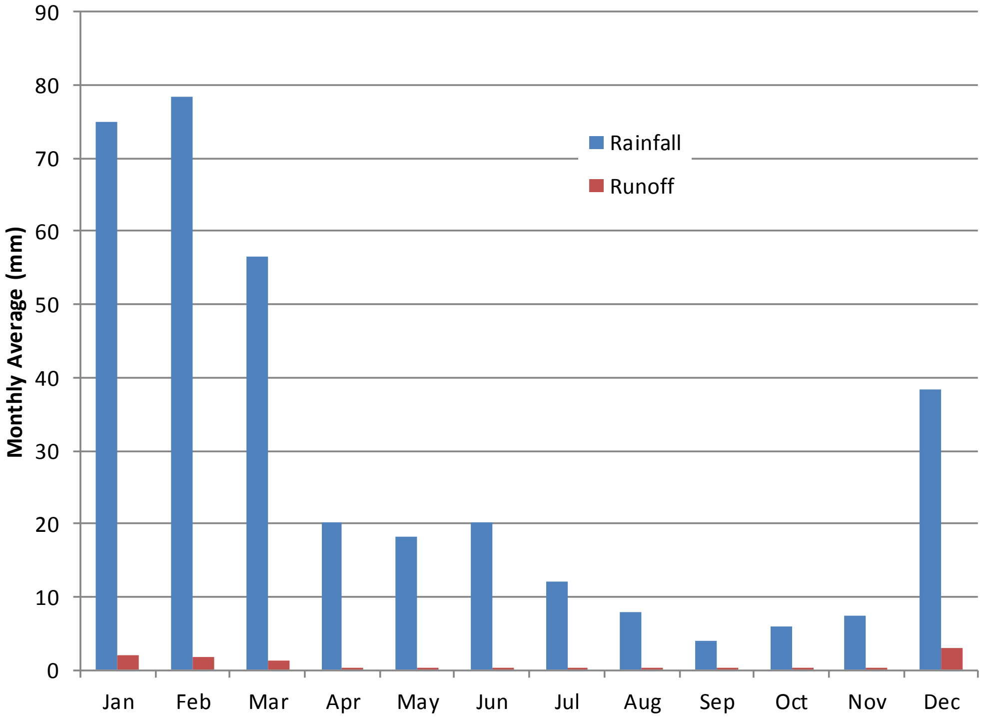


Figure 19: Comparison of average monthly rainfall and runoff for Marillana Creek catchment.

Table 10: Daily Flow Duration Statistics for Marillana Creek at Flat Rocks

Probability of Exceedence (%)	Daily Flow (m^3/s)
0.00%	838
0.05%	148
0.10%	64
0.20%	25
0.50%	10
1.00%	3
5.00%	0.1
10.00%	0.0

The above data indicate average annual runoff for the Marillana Creek catchment represents around 2% of rainfall; although, this ranges from a low of 0% to a maximum of around 20%. Flows are episodic and only occur following larger storm events of short duration. For example, the number of consecutive days in each year when flows exceed an average of 20 m^3/s at the Flat Rocks station, is generally less than two days, as shown in Figure 20. On average, there are only around six days per year when daily flows exceed 1 m^3/s.

The annual flow series is also highly skewed with a mean annual runoff of 8 mm/yr (equivalent to around 11 GL/yr) and a median annual runoff of around 2.4 mm/yr (equivalent to around 3.2 GL/yr). Significantly, about 30% of years in the available 46 year record have an annual runoff of around 1 mm or less (equivalent to around 1.4 GL/yr).

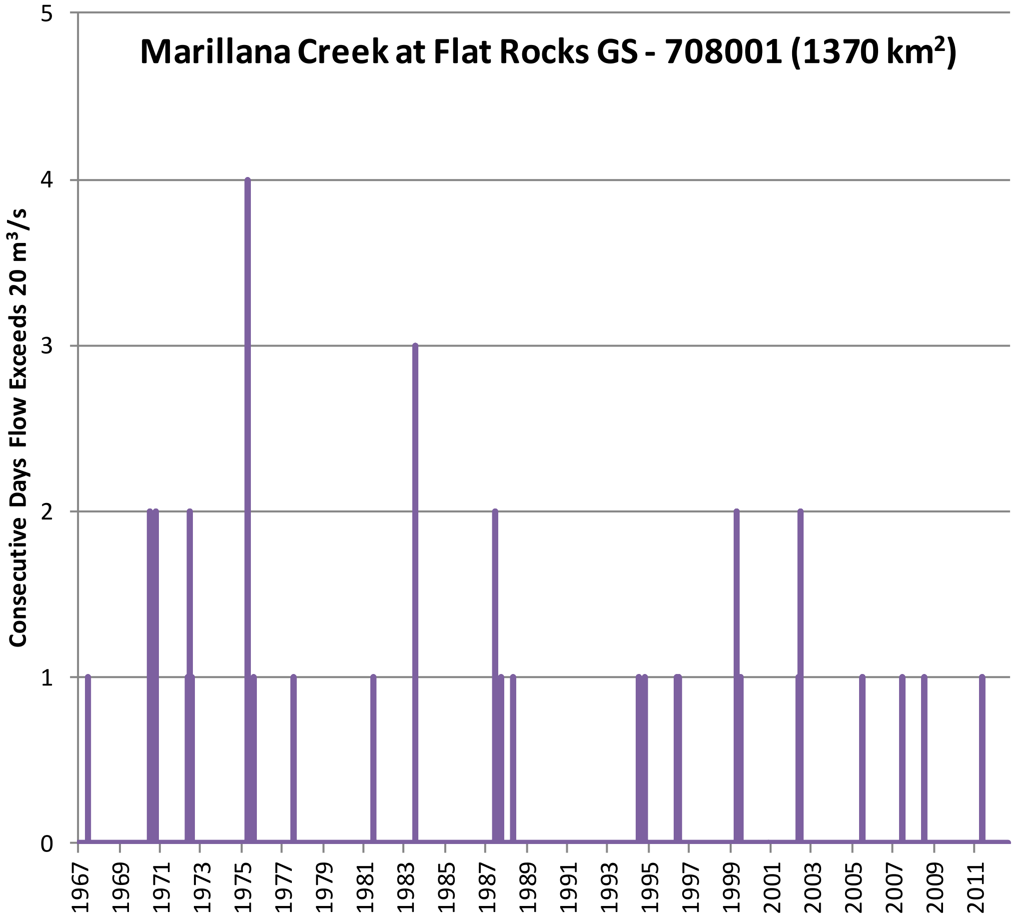


Figure 20: Marillana Creek at Flat Rocks - frequency of larger flows.

3.1.3 Flow rate and levels

The annual runoff at Flat Rocks gauging station represents less than 3% of the average annual catchment rainfall and daily flows are characterised by infrequent, short duration floods. There are, however, lengthy periods with flows less than 0.1 m^3/s. As the creek bed has outcropping rock, these extended low flow periods reflect sub-surface flows discharging to the surface as baseflow.

The average annual rainfall reduces from west to east across the catchment. The three rainfall sequences based on the SILO data were analysed to assess the variation in daily rainfalls between the sites during larger storm events. The storms selected included those where the average rainfall for the three sites exceeded 40 mm. This limit was adopted as it is comparable with the design initial loss for flood estimation procedures recommended for average recurrence intervals (ARI) from 10 to 50 years in the Pilbara Region (IEAust, 1998). It is also comparable with the daily rainfall thresholds estimated by CSIRO above which streamflows are likely to be stimulated in the Pilbara (CSIRO, 2013). On average, it is therefore unlikely that runoff will occur until the cumulative storm rainfall exceeds this value.

Estimates of design floods for the Flat Rocks gauging station were therefore derived based on the annual peak discharges for a water year (July to June) and excluding flows below 20 m^3/s (as these are not considered to reflect flood discharges). The probabilities associated with the design flood estimates (derived assuming a log Pearson III probability distribution) were then adjusted to account for the reduced sample size. The estimated discharges for a range of average recurrence intervals (ARI) are presented in Table 11.

Table 11: Estimated Design Peak Discharges for Marillana Creek at Flat Rocks

ARI (yr)	Peak Discharge (m^3/s)
2	80
5	210
10	380
20	610
50	1 120
100	1 770

3.2 Groundwater

The groundwater regime of the Marillana Creek Region has been studied and analysed in and around the existing mines and some proposed mining developments. Groundwater data and information are poor elsewhere, i.e. in most of the catchment. The information currently available is therefore skewed towards an understanding of the local hydrogeological properties of CID orebodies along Marillana Creek (Yandi and Yandicoogina operational mines) in the lower part of the catchment. As a result, there is a need to extrapolate the limited information across the catchment in different settings and to those mine areas with poorer or no data sets and which may have different geological and topographic settings.

3.2.1 Hydrogeological setting

The study area is mostly underlain by fractured rocks of generally low hydraulic conductivity. The regional groundwater system is expected to have some, mostly unidentified zones of fracturing that form local aquifers that have not been characterised. It is recharged by occasional cyclonic rainfall events and associated runoff, but the mechanisms and rates of recharge are poorly understood. Groundwater movement is generally towards the lowest parts of the catchment, i.e. to the CID deposit, Marillana Creek and its major tributaries.

The main drainage (Marillana Creek) and a few of its major tributaries are associated with both discontinuous alluvial aquifers and the older CID palaeochannel aquifer system that act as regional linear drains for the regional fractured rock groundwater system. These linear aquifers occupy the lowest part of the landscape where groundwater levels are shallow. Although hydraulic conductivities in the fractured bedrock into which the alluvial and CID aquifers are incised are low, the large area of contact (perhaps 100 km length and up to 1 000 m^2 of cross-sectional area of incision) is so large that a low rate of drainage per unit area may be sufficient to account for the rate of long-term groundwater flow in the CID aquifer. Recharge to the alluvial aquifers occurs during floods, often resulting in complete refilling of the aquifer.

The CID and alluvial aquifers are most likely in connection with surface ecological features and various groundwater dependent ecosystems, including vegetation and subterranean fauna. The main mining activities in the catchment involve the CID deposits where the ore is economic and mining will extract the main regional aquifer.

Prior to mining and at the current level of development, groundwater from the entire catchment flows in the same direction as Marillana Creek before discharging into the downstream Fortescue catchment via the CID aquifer, in and adjacent to, Weeli Wolli Creek.

The groundwater systems are recharged episodically, not seasonally, so are typically in recession most of the time. This behaviour can make difficult the separation of mining-related, or inferred hydrological change, from naturally-occurring periods of dry conditions.

The following sections describe the potential effects of mining within the catchment.

3.2.2 Groundwater systems

There are four recognised groundwater systems:

- Alluvial aquifer being discontinuous and restricted to major stream channels
- Calcrete aquifers comprising Oakover Formation with several zones of limited extent – karstic and localised
- CID aquifer being a sinuous body along the lowest part of the catchment
- A fractured bedrock system that underlies the entire catchment (Brockman Iron and Weeli Wolli Formations), but is highly localised.

The alluvial and calcrete aquifers form shallow, localised and surficial aquifers. They are treated separately as a consequence of their different locations, modes of occurrence and characteristics.

These groundwater systems are recharged by direct infiltration of rainfall and variably through surface water flow in channels and creek beds. The CID aquifer can also be recharged by leakage from the alluvium in areas where the creeks overlie and flank the CID. Exceptionally high water levels in the creek from runoff and discharge of surplus mine water can also flood areas beyond the alluvium resulting in direct infiltration to the CID. Shallow groundwater can discharge from the aquifers to Marillana Creek after a flood event. In some locations, the saturated Marillana Creek alluvium is truncated by shallow bedrock, for example at Flat Rocks, resulting in near-permanent baseflow at low rates. Recharge to the CID and alluvium is expected from the fractured rocks where hydraulic gradients exist and hydraulic continuity allow.

3.2.3 Connectivity between groundwater systems

Connectivity between the different components of the hydrological system is fundamental to understanding the groundwater processes (and groundwater-surface water interactions).

A small number of nested monitoring points have been installed recently in the vicinity of mining activities (Golder, 2013a). There is limited time series data to interpret and refine the conceptual understanding of the hydraulic connectivity between hydrostratigraphic units.

Owing to the secondary porosity characteristics and consequent high permeability of the Oakover Formation calcrete, it is likely that there is good hydraulic connection where the Oakover Formation overlies the alluvium, CID and bedrock.

The hydraulic connection between the alluvium and CID is variable depending on the thickness of the alluvium, proximity to the CID and presence of finer material in deeper horizons. There is enhanced hydraulic connection between the alluvium and CID where major creeks overly the CID, which is reflected in water level observations. Conversely, the low hydraulic conductivity of the bedrock may restrict the hydraulic connection between the alluvium and CID where the creek bed alluvium is not adjacent to the CID. Similarly, the lower hydraulic conductivity of finer material in deeper horizons of the alluvium may also limit the vertical hydraulic connection although not preventing lateral connections where the alluvium is incised more deeply along the edge of the CID (e.g. the eastern deposits at Yandi and probably RTIO’s Yandicoogina mine).

Groundwater is expected to discharge into the CID aquifer from the weathered and fractured bedrock aquifer, as the CID occupies the lowest part of the catchment landscape. Under natural conditions, it is likely that there are low rates of discharge from the bedrock and CID aquifer. The low rate of discharge is a consequence of low hydraulic conductivity of the fractured rocks and (probably) small hydraulic gradients between the hydrostratigraphic units.

Higher rates of groundwater inflow to the CID from the fractured and weathered bedrock occur where higher hydraulic gradients are induced when groundwater levels in the CID are lowered significantly due to dewatering activities.

3.2.4 Hydraulic parameters

A number of hydraulic parameters have been calculated from test pumping and slug tests; whereas others have been estimated from model calibration and experience-based judgement.

Based on bore development yields during the Marillana Creek Tree Health (MCTH) study (Golder, 2013a), the horizontal hydraulic conductivities (K_h) in the alluvium range from 0.002 to 50 m/d, with gravel lenses showing higher K. High clay content in the alluvium in the Yandi area has resulted in perched conditions to develop near areas of CID dewatering and to restrict the rate of downward movement of groundwater from the alluvium into the CID where the two units are in contact. Vertical hydraulic conductivity (K_v) is likely to range between 0.003 to 2 m/d.

The Ochreous Clay marker bed unit is a transition zone that is locally confining and includes solution channels that affect groundwater flow and facilitate dewatering of the UCID.

UCID is an unconfined aquifer having high permeability and high storage capacity. Pumping tests indicate that K_h ranges between 2 and 50 m/d. The storage parameter (specific yield – S_y) derived from previous studies (modelled values) is estimated to range between 1×10^{-3} and 0.2.

No differentiation was made between the UCID and LCID in earlier studies (see Sources: as noted under Table 12) where reported CID hydraulic conductivities range from 2 to 50 m/d.

The Basal Clay of the CID is considered an aquitard with low permeability and storage capacity.

Table 12 presents the vertical and horizontal hydraulic conductivities (K_v and K_h), transmissivity (T), specific yield (S_y), storage coefficient (S) and specific storage (S_s) data for the hydrostratigraphic units reported from field testing and adopted numerical model parameters reported by various sources.

Table 12: Hydraulic Parameters

	Vertical Hydraulic Conductivity (K_v)	Horizontal Hydraulic Conductivity (K_h)	Transmissivity (T)	Specific Yield (S_y)	Storage Coefficient (S)	Specific Storage (S_s)
	m/d	m/d	m^2/d	dimensionless	dimensionless	(m^{-1})
Alluvium	0.003 to 2	0.002 to 50	0.8 to 10	0.001 to 0.2	1×10^{-5} - 5×10^{-5}	-
Oakover Formation	-	5	-	0.05	1×10^{-4}	-
Channel Iron Deposit (CID)	-	2 to 50	150 to 3 000	0.001 to 0.2	1×10^{-5} - 1×10^{-4}	4×10^{-7} – 1×10^{-1}
Weeli Wolli Formation*	0.003 to 0.005	0.03 to 0.5	0.7 to 30	0.001	1×10^{-5}	-
Brockman Iron Formation*	0.0001 to 0.02	0.001 to 10	30	0.001 to 0.02	5×10^{-7} - 1×10^{-5}	-

Sources: (Aquaterra, 2000b, 2003b and 2009b; BHP Billiton Iron Ore, 2011c; FMG, 2012; Golder, 2012a, 2012b, 2013a; Johnson and Wright, 2001; RTIO, 2011a; RPS Aquaterra, 2011c; URS, 2012b; and Woodward-Clyde, 1995c and 1998)
*Note *Bedrock values included estimates for fractured/weathered formations.*

3.2.5 Groundwater recharge

Across the catchment, recharge is derived from rainfall within the catchment boundaries (Figure 2). The Marillana Creek groundwater catchment has been defined as the surface water catchment (apart from inflow of surface and groundwater from Weeli Wolli Creek and associated aquifers).

Rainfall either:

- directly infiltrates
- manifests itself as sheetflow

- forms ephemeral pools
- runs off into surface drainage for infiltration to alluvial sediments and, in places, into underlying hydraulically contiguous aquifers
- is lost via interception on vegetation, evaporation and evapotranspiration.

The rate of recharge to the groundwater systems is low as a proportion of average annual rainfall. This is discussed in more detail in the catchment water balance in Section 3.2.11.

Estimates have been made of recharge rates to the various formations/aquifers within the catchment (Table 13) for groundwater modelling purposes. Whilst these estimates have sometimes been expressed as percentage of annual average rainfall, recharge in the Marillana Creek catchment, as elsewhere in the Pilbara and the arid zone in general, is episodic, coming from significant cyclonic rainfall events rather than being seasonally predictable. Different derivations of “average annual rainfall” can be made, depending upon methodology and the particular gauge data included. However, recharge is used in simulations as a value of mm/year NOT as a proportion of average annual rainfall, so that uncertainty in calculating the average rainfall is of no consequence.

Table 13: Aquifer Recharge Values

Aquifer	Recharge (mm/yr)	Source
Alluvium	7	Aquaterra, 2003b
Oakover Formation calcrete	10.5	Aquaterra, 2003b
CID	0.7–10.5	Aquaterra, 2003b and Golder, 2012b and 2013b
Weeli Wolli Formation	3.5	Golder, 2013b

Zones of enhanced rainfall recharge are anticipated along the CID outcrops and also along the Marillana Creek bed especially along sections where the creek flows over the CID or is flanked by CID outcrops. River alluvium exposures are judged to receive approximately the same rainfall recharge rate as the CID outcrops.

More specifically, groundwater recharge to the CID aquifer can occur as infiltration from the ephemeral Marillana Creek into the alluvial and CID aquifers (Golder, 2012b). The recharge mechanisms comprise:

- Direct infiltration of creek water into the CID aquifers where the creek flows directly over the palaeochannel.
- Indirect infiltration from the creek that infiltrates through the alluvial aquifers into the underlying CID aquifers.
- Groundwater inflow from the sides and base of the palaeochannel from groundwater in the Weeli Wolli Formation (small contribution).
- Direct recharge from rainfall falling on the CID (probably a relatively small contribution).

A study initiated by RTIO for its Yandicoogina operation found that groundwater was recharged from intense rainfall events with little evaporative effect (Dogramaci and Dodson, 2009). The 300 to 500 mg/L increase in major ions relative to rainfall was explained as being the result of evapotranspiration of rainfall during infiltration through the unsaturated zone. Other study outcomes were that recharge events are dominated by:

- Vertical rather than horizontal flow
- Rapid recharge from significant rainfall events.

RTIO, 2010a reported on investigations into groundwater elevations for the period 1974 - 2009 in the CID and alluvial aquifers in the vicinity of its Yandicoogina operation. The estimated recharge volume calculated from water-table rise in the CID aquifer after rainfall events can reportedly be as high as 30 GL per event over a 25 km length of Marillana Creek.

It is considered that flood recharge may have been overestimated by others as there are only eight years where the annual flow at Flat Rocks exceeds this in the 46 years of record.

Where Oakover Formation occurs in outcrop or under soil cover, i.e. in the Munjina Claypan area but not where covered by thick clay, it is likely to accept groundwater recharge which may then infiltrate to underlying alluvial and CID aquifers.

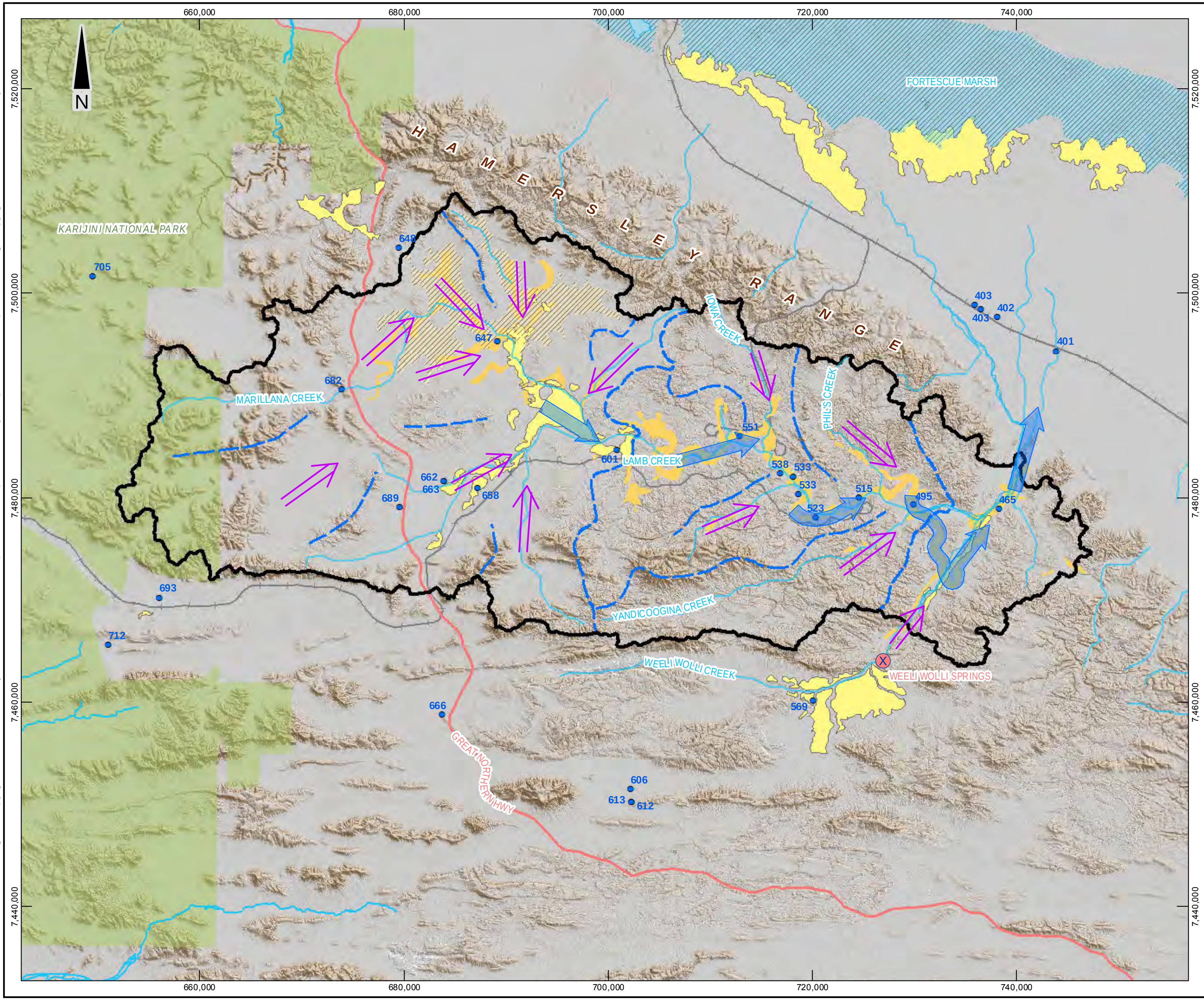
3.2.6 Groundwater levels and flow

There are few measured groundwater levels in the study area apart from along the CID aquifer in and adjacent to Marillana Creek. As a consequence, it is not possible to fully resolve catchment-scale watertable distribution. The main ridge lines that define the Marillana Creek catchment are confidently regarded as groundwater divides; a consequence of the low hydraulic conductivity of the fractured rock groundwater system. There are similar, if smaller, ridge lines within the main catchment, for example separating Yandicoogina Creek from Weeli Wolli Creek. These sub-catchment ridge lines are expected to be groundwater divides, suggesting that groundwater contours will be quite different from a simplistic representation of groundwater elevations that would be derived at the catchment scale.

The groundwater flow directions are based on regional topography and limited groundwater elevation data (pre-1996) obtained from the DoW (WinSite database) and BHP Billiton Iron Ore.

Catchment-scale groundwater elevations are generally a subdued reflection of the topography and groundwater elevation is in the range of 690 to 460 m AHD. Groundwater flow directions in the upper catchment are quite irregular reflecting the broad, low relief areas. In the lower part of the catchment, groundwater flow from the upland areas is consistently towards the CID aquifer.

Figure 21 shows the limited groundwater elevation data points available in the catchment away from the detailed information at the mine sites in the valley floor, together with an interpretation of likely groundwater flow directions.



LEGEND

- Primary road
- Railway
- Major creek
- Munjina Claypan
- National park
- Marillana Creek project
- Calcrete
- CID reserve
- Subcatchment divide
- Groundwater monitoring location
- 601 - Groundwater elevation (mAHD)
- Inferred direction of groundwater movement
- Main groundwater flow

NOTES

Coordinate System: GDA 1994 MGA Zone 50

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Geology map © Geological Survey of WA
Topography interpreted from SRTM Digital Elevation Model of Australia © Geoscience Australia

0 5 10 15 20
kilometres
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Golder Associates

CLIENT	BHP Billiton Iron Ore
DOCUMENT	137646040-002-R-Rev4
DATE	01 Sep 2015
COMPILED	MS
APPROVED	GRH

Marillana Creek SEA Project

INFERRED GROUNDWATER FLOW DIRECTIONS

FIGURE 21

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All long-term groundwater monitoring points in the catchment are concentrated in tenements of existing mining operations at Yandi and Yandicoogina (Figure 22). The database of water levels in the Marillana Creek catchment features few records which are continuous since the onset of mining and there are no time-series records in upland areas.

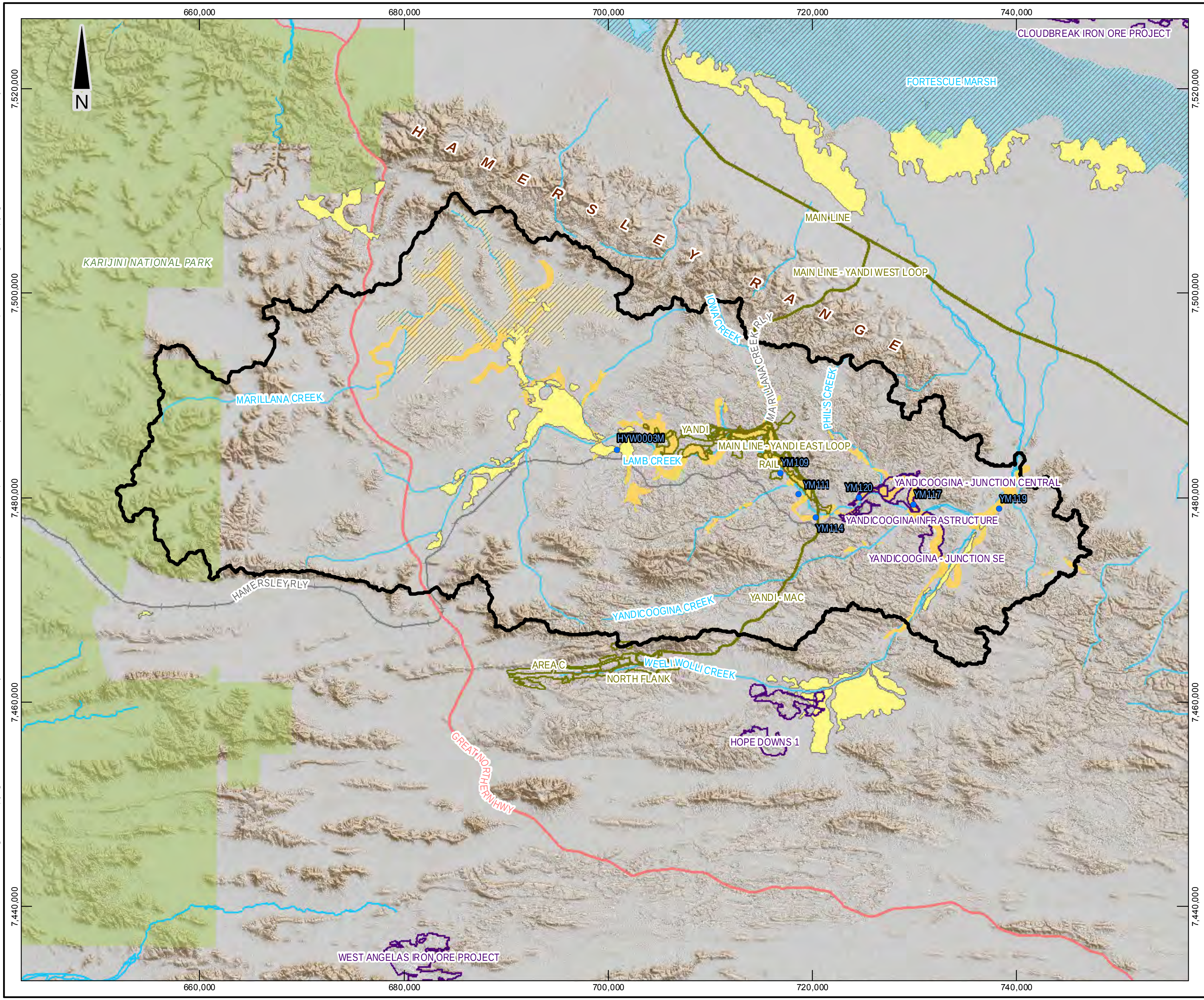
Steady-state calculated groundwater levels based on the 2013 groundwater model are shown in Figure 23 (Golder, 2013b).

Groundwater discharge into the Weeli Wolli Creek sub-catchment from the CID aquifer associated with the upstream Marillana Creek catchment is essentially the total groundwater discharge from the catchment above the confluence.

Groundwater moves along the CID aquifer in an easterly direction towards Weeli Wolli Creek with an average hydraulic gradient of about 0.2%.

The estimated groundwater flow along the CID aquifer under the regional hydraulic gradient is estimated to be approximately 3 000 m^3/d for an adopted hydraulic conductivity of 40 m/d. The alluvial aquifer associated with Marillana Creek is estimated to have a throughflow of about 5 m^3/d. Consistent with these estimates, the alluvial aquifer throughflow was estimated to be only about 0.2% of the CID aquifer throughflow (BHP Billiton Iron Ore, 2011c).

Total groundwater discharge from the Marillana Creek catchment into the Weeli Wolli Creek catchment has been estimated at between 0.7 and 1 GL/yr. Additional groundwater flow along Weeli Wolli Creek will add to that discharge to the Fortescue River catchment as discussed in the water balance (Section 3.2.11).



LEGEND

- Regional groundwater monitoring location
- Primary road
- Railway
- Creek
- Munjina Claypan
- Fortescue Marsh
- National park
- Marillana Creek project
- CID reserve
- Calcrete
- Current BHP Billiton Iron Ore disturbance
- Current Third Party disturbance

The content of this map is conceptual only, of a general nature and does not purport to contain all information relevant to future project development associated with the Project. This map has been prepared solely for the purposes of informing environmental impact assessment pursuant to the Environmental Protection Act 1986 (WA) and Environment Protection and Biodiversity Conservation Act 1999 and is not intended for use for any other purpose. No representation or warranty is given that project development associated with any or all of the disturbance indicated on this map will actually proceed. As project development is dependent upon future events, the outcome of which is uncertain and cannot be assured, actual development may vary materially from this conceptual map.

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SCALE (at A4) 1:500,000

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CLIENT	BHP Billiton Iron Ore
DOCUMENT	137646040-002-R-Rev4
DATE	01 Sep 2015
COMPILED	MS
APPROVED	GRH

Marillana Creek SEA Project

REGIONAL GROUNDWATER MONITORING LOCATIONS

FIGURE 22

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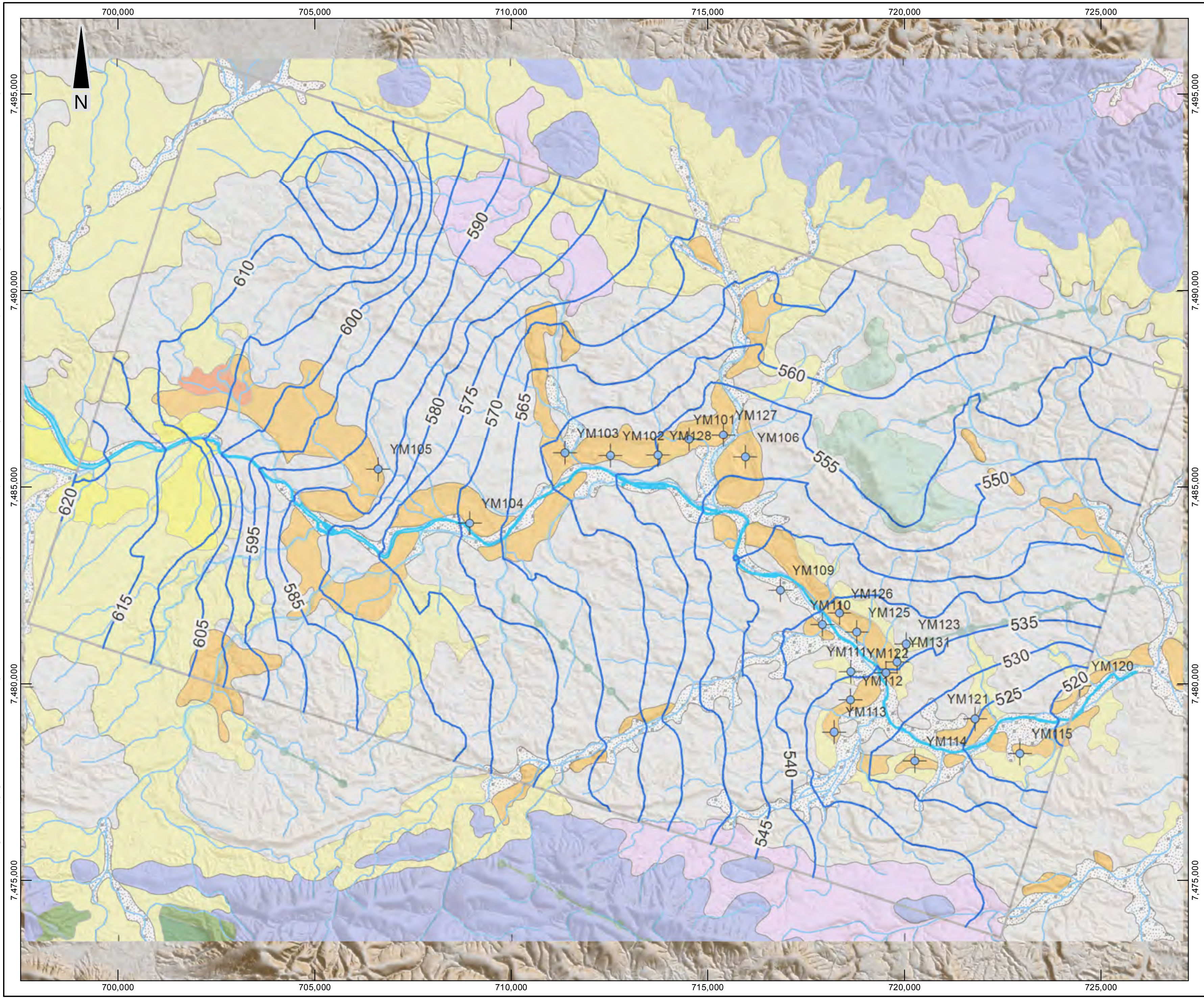

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DOCUMENT	137646040-002-R-Rev4
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COMPILED	MS
APPROVED	GRH

Marillana Creek SEA Project

MODEL-DERIVED GROUNDWATER ELEVATIONS (m AHD) FOR PRE-MINING CONDITIONS AT YANDI

FIGURE 23

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The information provided suggests that pre-mining groundwater elevations along the CID aquifer at Yandi ranged from 515 m AHD at the downstream end of the lease to 620 m AHD near Flat Rocks (Figure 23) sourced from Golder, 2013b).

A series of bores installed by BHP Billiton Iron Ore prior to 1991 monitors groundwater downstream from around Flat Rocks to the confluence of Marillana and Weeli Wolli Creeks. Groundwater level hydrographs are presented in Figure 24.

Groundwater levels in the Weeli Wolli Formation (HYW0003M) upgradient of the Yandi W1 pit range between approximately 600 m AHD and 620 m AHD. A groundwater level rise observed in mid-2000 dissipated over the next 1 to 2 years and can be attributed to large rainfall events. A small decrease in groundwater levels occurs post 2010, as a result of dewatering occurring in W1 pit.

More significant groundwater level variations in the Weeli Wolli Formation near the Yandi Eastern deposit (YM109) may be caused by its proximity to Marillana Creek when compared with YM111, which shows a more “muted” response. The results indicate that groundwater levels in the Weeli Wolli Formation, at least where measured, increase by between 7 and 10 m after episodic, high-intensity rainfall events. This response is consistent with the expectation that this formation has a small storage capacity. Despite groundwater abstraction in the CID, regional monitoring bores in the Weeli Wolli Formation show little trend in groundwater levels, suggesting poor hydraulic connection between the CID and the regional groundwater system, as well as low hydraulic conductivity within those fractured rock units.

Observations in the CID (YM114) downgradient of the Yandi Eastern deposit and the position of the BHP Billiton Iron Ore Eastern Discharge Point (pre-2007) show a slightly increasing trend over time of approximately 5 m over an 11 year period. The slight increase in water level is most likely due to recirculation of the discharge water into the CID. Similarly, increasing groundwater level trends were observed in downgradient wells YM117 and YM119, located in the Yandicoogina JSE and Billiard deposits, respectively, where there are numerous discharge outlets. Observations at YM117 ceased owing to mining of the JSE deposit, whereas water level observations at YM119 show no response to dewatering activities in up-gradient pits.

Groundwater levels in the alluvium (YM120) situated about 1 300 m downgradient of the Yandi Eastern Discharge Point show a gradual increase between 1991 and 2005, followed by a significant drawdown of approximately 10 m from 2005 to 2007. The drawdown may be the result of downstream abstraction at RTIO’s Yandicoogina mining operation.

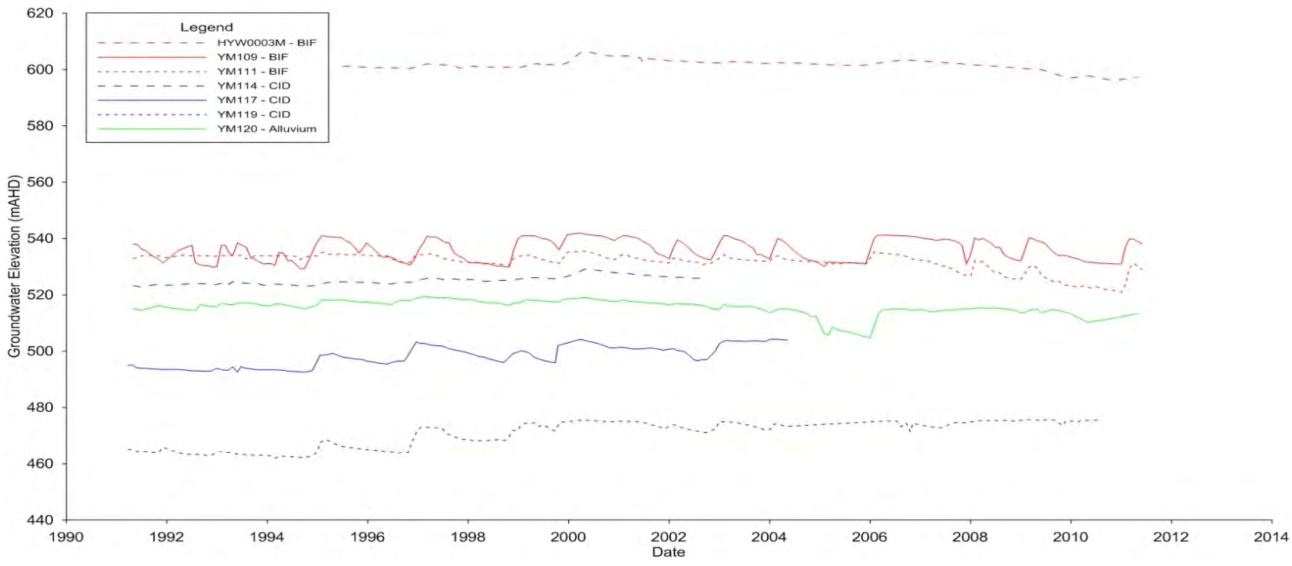


Figure 24: Selected hydrographs of regional groundwater level variations.

3.2.7 Groundwater discharge

Natural groundwater discharge occurs mostly through lateral groundwater movement out of the catchment and by evapotranspiration losses. However, groundwater can also discharge from the aquifers to Marillana Creek and Weeli Wolli Creek following large rainfall events. Evapotranspiration is concentrated in areas of abundant vegetation consisting of woodland communities, including the Riverine, Hardpan and Claypan Flats landscape units. Specific transpiration rates of vegetation in the Pilbara are not well established, but vary with vegetation type and distribution within the creek systems. Evapotranspiration rates of the species found along Marillana and Weeli Wolli Creeks were estimated to range between 530 and 1050 mm/yr (RTIO, 2012d). Higher evapotranspiration rates were estimated for riparian vegetation communities consisting of *Eucalyptus camaldulensis* (River Red Gum), *Eucalyptus victrix* (Coolibah), and *Melaleuca argentea* (Silver Cadjeput). Lower evapotranspiration rates were estimated for vegetation communities consisting of *Acacia* species (e.g. Mulga), shrublands and grasslands of the alluvial plains.

Other important discharges of groundwater are through anthropogenic processes such as groundwater abstraction for pastoral use, groundwater abstraction for pit dewatering and discharge of surplus groundwater to major creeks in support of mining operations.

Groundwater discharge will increase as existing mining operations expand and additional mining operations commence. Some of the water that is abstracted recirculates from discharge into Marillana Creek and most of the remainder evaporates, either from its use for dust suppression or from increased transpiration along the creek where it is available for plant use.

Groundwater abstraction

Current abstraction within the study area is associated with pastoral bores, BHP Billiton Iron Ore's Yandi mining operation and RTIO's Yandicoogina mining operation. Dewatering rates have increased during the development of the mines.

Approximately 17.6 GL of groundwater was abstracted from BHP Billiton Iorn Ore's Yandi mining operations in 2012. On average, about 8.8 GL/yr has been abstracted from the open pits over the past 22 years. Yandi pit dewatering requirements are projected to be up to 22 GL/yr for years 2014 to 2030 (BHP Billiton Iron Ore, 2012c).

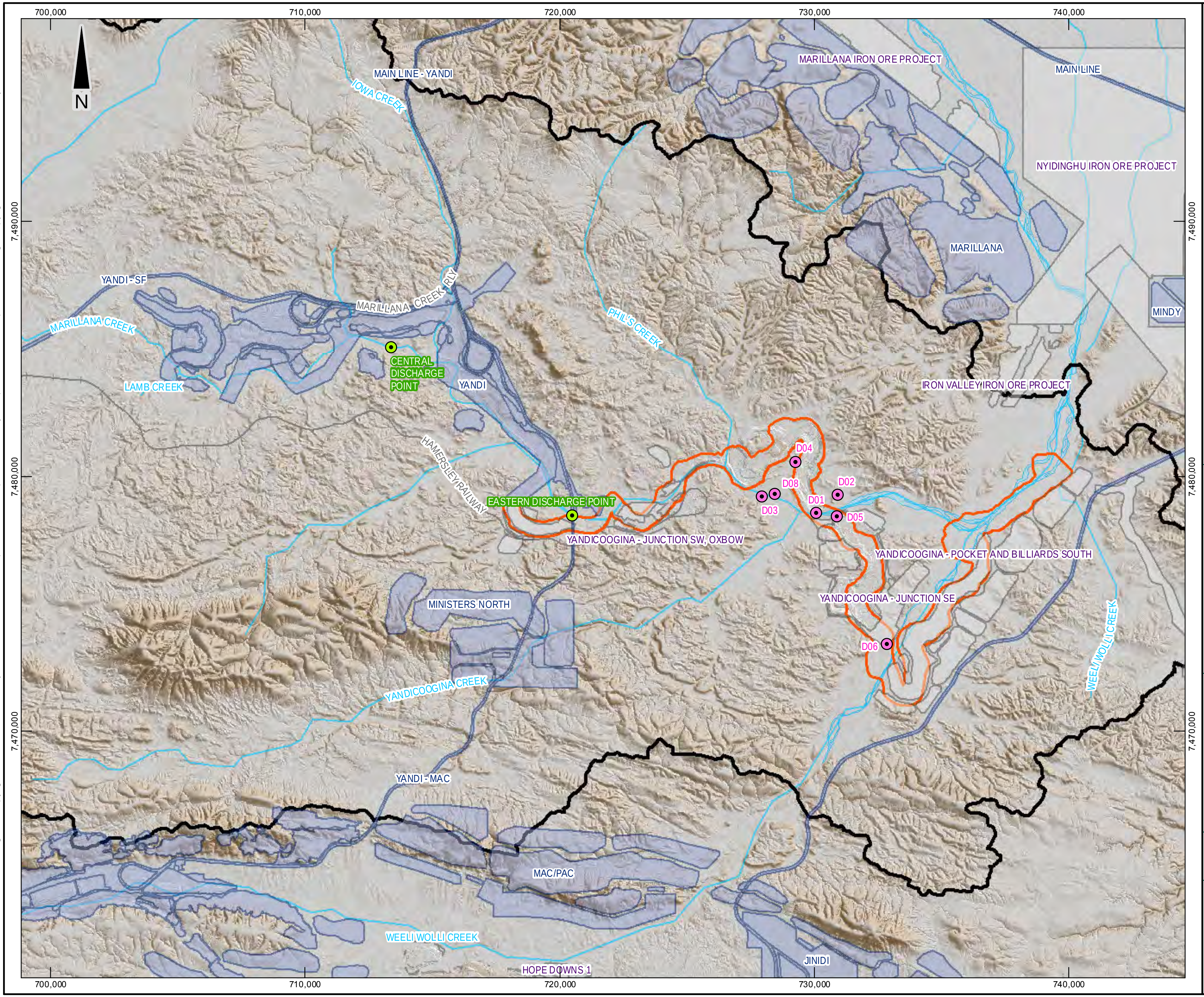
RTIO's Yandicoogina mining operations require higher dewatering rates than Yandi, approximately 35 GL/yr, in part due to recirculation of surplus water discharged upstream at Yandi. Dewatering requirements are predicted to increase up to 53 GL/yr with the expansion at Yandicoogina to include two new deposits in the next few years (RTIO, 2012e).

The number of functioning pastoral wells is unknown. Assuming all pastoral wells in the catchment are abstracting water on a daily basis at an average rate of 10 kL/day, estimated groundwater discharge from pastoral wells may be in the order of 0.1 GL/yr, i.e. a very small rate compared with the mining operations.

Surplus mine water discharge

Excess abstracted water from mining operations is discharged into Marillana and Weeli Wolli Creeks at multiple discharge points as shown in Figure 25. The current combined discharge of surplus water to the major creeks from Yandi (12 GL/yr) and Yandicoogina (14 GL/yr) mining operations is approximately 26 GL/yr. Yandi's discharge rates to Marillana Creek are projected to fluctuate in the future, ranging from 7.3 to 14.6 GL/yr for years 2014 to 2030 (BHP Billiton Iron Ore, 2012c).

Discharge rates from Yandicoogina are expected to increase by 16 GL/yr with expansion in the next few years (RTIO, 2012e).



LEGEND

- Yandicoogina discharge point
- Yandi discharge point
- Railway
- Creek
- Yandicoogina palaeochannel
- Marillana Creek project
- Indicative BHP Billiton Iron Ore disturbance
- Reasonably foreseeable Third Party disturbance

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Marillana Creek SEA Project

SURPLUS WATER DISCHARGE POINTS

FIGURE 25

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3.2.8 Groundwater – surface water connectivity

There are few, if any, natural permanent surface water features in the study area. Surface water in the catchment is associated with ephemeral creeks and areas of depression on the Munjina Claypan that are temporarily filled with water following significant rainfall events. Areas of inundation on the claypan are assessed to be separated from groundwater and their connection to groundwater is likely to be limited.

On a regional or creek system scale, surface water and groundwater interactions are broadly described as (Winter *et al.*, 1998):

- Gaining stream – groundwater flow is into the stream
- Losing stream – water is lost from the stream to the underlying aquifer and there is a saturated connection (hyporheic zone) between the surface water and groundwater systems
- Indirectly connected (or disconnected) losing stream – water is lost from the stream to the underlying aquifer and there is no hyporheic zone (i.e. an unsaturated connection exists).

In most cases, the connection between surface water and groundwater varies along a creek and temporally. The water exchange direction can alter in very short timeframes or seasonally in response to flooding or evapotranspiration.

The ephemeral creeks are characterised as a losing system where surface water is dissipated by evapotranspiration and infiltration. Smaller volume rainfall events are insignificant for groundwater recharge because the volume of water is sufficient only to replenish soil moisture or evaporate immediately after rain events.

However, the tropical cyclones and low pressure systems that occur across the catchment often produce large volumes of surface flow in a relatively short period of time provided individual events have a rainfall exceeding ~ 50 mm. These flooding events result in recharge to the alluvial and CID aquifers along the creek lines and account for the occurrence of low salinity groundwater found across the catchment. Following significant flooding events, temporary surface water pools and groundwater discharge (interflow) have been observed along certain reaches of the creek system.

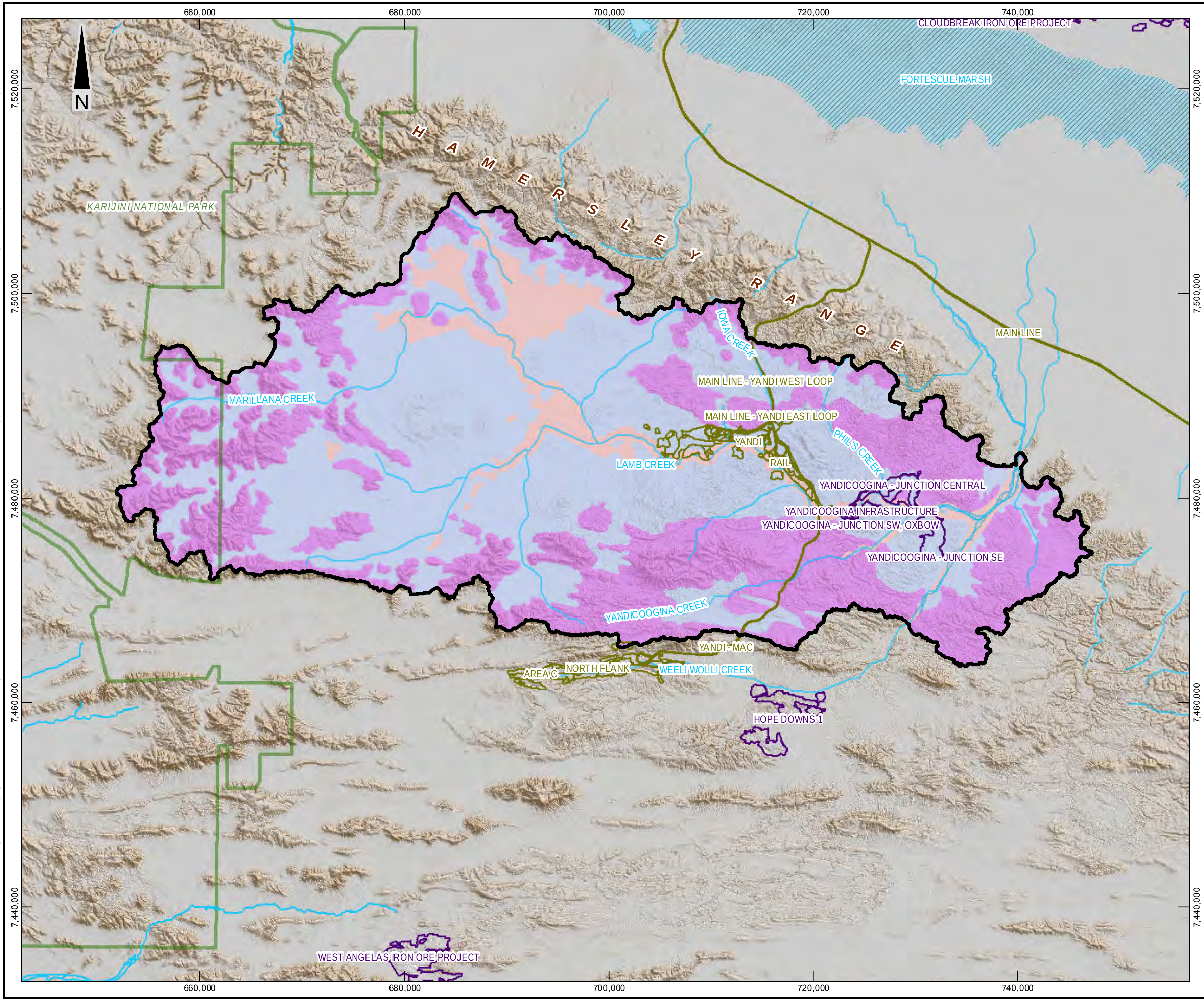
There are currently few nested monitoring sites along the creek system to assess the interaction between the surface water and groundwater systems. Nested monitoring bores have recently been installed in various geological units located in the Yandi tenement. Based on preliminary results, it is expected that temporary groundwater discharge may occur along the creek immediately following extreme rainfall events.

3.2.9 Connectivity with the environment

Connectivity of groundwater with the environment is related to the depth to the watertable. Across the study area, the depth to groundwater varies between the ground surface level (including discharging at the surface) and 100 m bgl (Figure 26). Groundwater levels in bedrock correlate well with topography. The depth to groundwater is also greatest in the upland and transitional landscape units where surface water processes dominate (runoff, sheetflow and channel drainage). Depth to groundwater is shallow in receiving landscape units where groundwater and surface water converge.

Depth to groundwater is an important factor influencing many vegetation communities. As depth to groundwater increases, vegetation communities become more xerophytic and dependent on soil moisture as observed in upland and transitional landscape units. Conversely, as depth to groundwater becomes shallower, vegetation communities become more groundwater dependent as observed in the receiving landscape units with the dominance of phreatophytes and vadophytes.

Additionally, as depth to groundwater increases so does the thickness of the unsaturated zone that must be wetted before groundwater recharge can occur. The infiltration of surface water in upland environments contributes little to groundwater recharge, but is an important contributor to soil moisture content supporting xerophytic vegetation communities. In receiving landscape units, the soil moisture deficit may be smaller, which allows increased potential for groundwater recharge. The exception is in areas of low permeability surface materials such as the Hardpan and Claypan Flats landscape unit (Munjina Claypan) that restricts vertical water movement.



LEGEND

- Creek
- Fortescue Marsh
- National park
- Marillana Creek project
- Current BHP Billiton Iron Ore disturbance
- Current Third Party disturbance

Depth to Watertable

- 30-100 m bgl
- 10-30 m bgl
- <10 m bgl

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ESTIMATED DEPTH TO WATERTABLE

FIGURE 26

3.2.10 Hydrochemistry

Most hydrochemical data is concentrated around the operating mines of Yandi and Yandicoogina, i.e. within the CID aquifer in the central and eastern parts of the catchment. Published data from work undertaken by RTIO supplements data provided by BHP Billiton Iron Ore sources. From this, a broad understanding of the groundwater chemistry can be derived, supporting in turn the conceptual understanding of the catchment hydrology.

Very little data is available across the majority of the catchment. Two groundwater samples from the upland area of the catchment provide a groundwater salinity range between 700 and 1 500 mg/L. These values are not regarded as representative.

Groundwater salinity in the CID and alluvial aquifers ranges from 100 to 1 300 mg/L. The alluvial aquifer groundwater contains higher groundwater salinity compared with the CID aquifer. The groundwater from both aquifers is dominated by bicarbonate anions. Sodium constitutes a higher portion of the major cations followed by calcium and magnesium (RTIO, 2010a).

Chloride concentration ranges from 15 mg/L for the low salinity groundwater in the CID to a maximum of 280 mg/L in the alluvium. The higher concentration of chloride in the shallow alluvial aquifer is related to direct evaporation from groundwater and also via evapotranspiration by vegetation along Marillana Creek.

Processes that influence groundwater chemistry are:

- The infiltration of ephemeral surface water from Marillana Creek to the underlying alluvium and, in places, to the CID aquifer.
- Evaporation and transpiration of shallow groundwater from the alluvial aquifer.
- Recharge to the CID aquifer through calcrete, i.e. in the Munjina Claypan area.
- More recently, discharge of CID groundwater (from dewatering) into the bed of Marillana Creek, infiltrates the alluvial aquifer and encourages vegetation growth and increased evapotranspiration.

There is evidence to suggest that there has been an increase in chloride concentration of about 20 mg/L (from 70 to 90 mg/L) in the CID aquifer at Yandicoogina over a seven year period since mining commenced in 1998. Conversely, chloride in the alluvial aquifer appeared to decrease from about 200 to 150 mg/L. The decrease in the chloride concentration of groundwater in the alluvial aquifer may be related to mixing (recharge) of surface water in Marillana Creek, derived from dewatering the CID, with ambient groundwater in the alluvial aquifer.

RTIO, 2012b undertook a sampling program to assess the potential for leaching of soluble metals and metalloids. Samples were representative of the Weeli Wolli Formation through the various ore types and alluvials. The results indicate that soluble metals/metalloids are generally below the trigger values outlined in the ANZECC water guidelines and local background values.

Figure 27 provides a plot of major ion concentrations which shows:

- A tight grouping of cation concentrations with little to no trend from upgradient (western bores) to downgradient (eastern bores).
- A greater spread of anion concentrations with an indication that bicarbonate decreases from west to east and chloride increases from west to east i.e. downgradient.
- The sump and discharge point's hydrochemistry appears mid-field being consistent with a degree of mixing of groundwater from non-point sources.

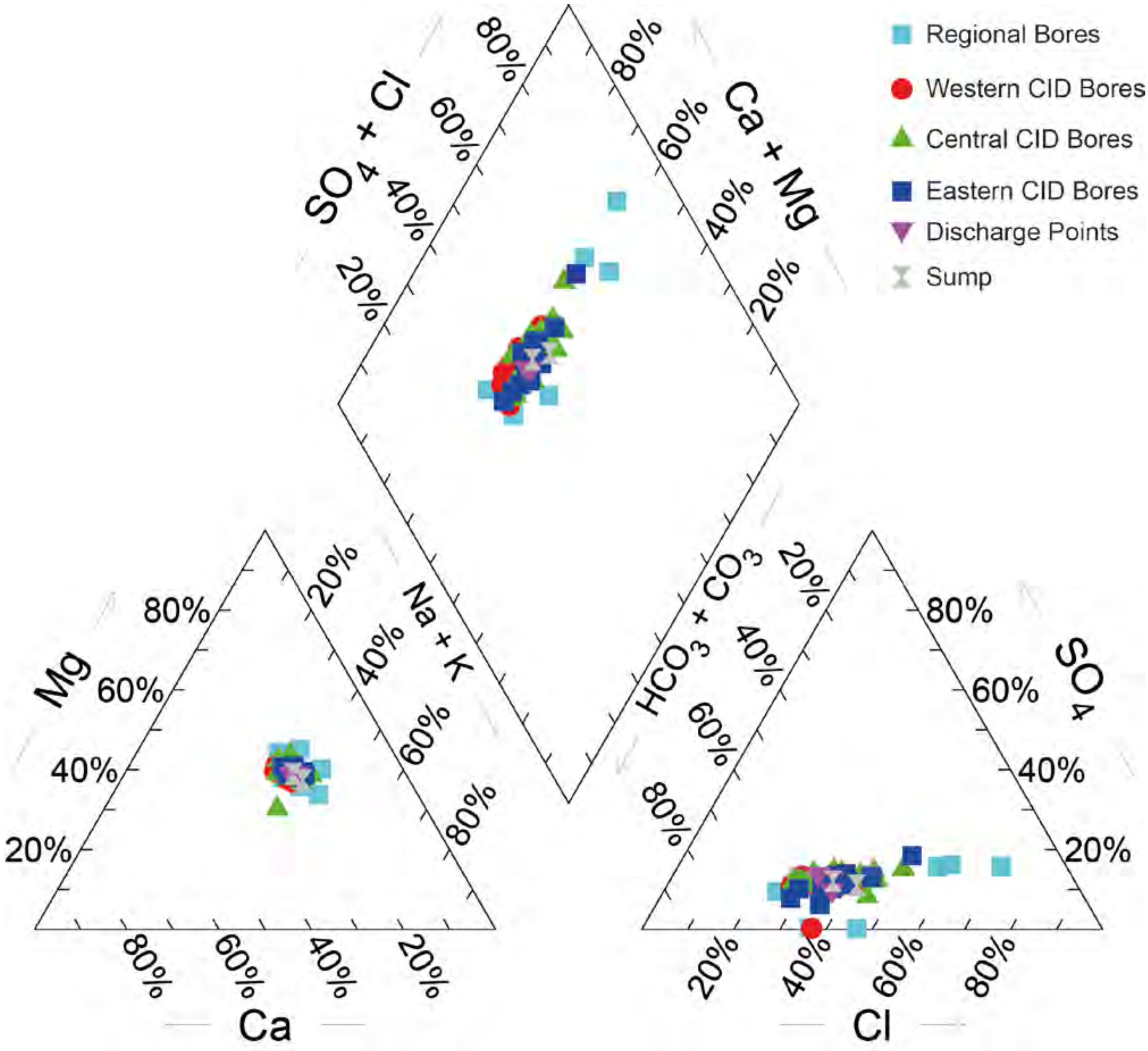


Figure 27: Piper plot of major ions.

3.2.11 Water balance

A water balance has been developed for the catchment, despite uncertainties in the estimation of some components. The water balance provides an understanding of general water availability in the catchment, as well as component uncertainties.

This water balance is based on both quantities of water, i.e. rainfall as an input and runoff, groundwater recharge and evaporation/evapotranspiration as outputs; and using the conservative tracer, chloride, which is delivered to the catchment in small concentrations in rainfall and measured in groundwater and surface water monitoring.

The approach adopted in this study is based on a simplistic “annual average” assessment, in order to provide a regional appreciation of catchment characteristics and magnitudes. In the longer term, a water balance may consider the episodic nature of rainfall and runoff in the catchment and be more probabilistic in its approach.

The Pilbara catchments are strongly influenced by large, episodic, cyclonic flooding events, which skew the statistics, particularly for runoff.

Water balance components

The components of the catchment water balance are summarised below.

Rainfall = Runoff + Recharge to Groundwater + Evaporation ± Change in Storage.

- Rainfall

  The average annual rainfall across the catchment (west to east) varies from around 400 mm to 300 mm, with an average of around 350 mm. The median annual rainfall is slightly less at around 315 mm.

- Marillana Creek runoff

  Annual runoff in Marillana Creek varies from zero in some dry years, to in excess of 200 GL when major cyclones cross the catchment. The average annual runoff is about 8 mm across the catchment, i.e. about 18 GL/yr. However, although this represents the average runoff into Marillana Creek, the median value is closer to 6 GL/yr. This disparity between mean and median reflects the skewed distribution as a consequence of infrequent large rainstorms. The skewed distribution, driven by a small number of storms and short periods of high discharge, illustrates the limitation of averages in this context. A few extreme events may dominate aspects of some processes in the water balance, which may be lost using an “average” approach.

- Groundwater throughflow

  The majority of groundwater throughflow out of the Marillana Creek catchment is via the CID aquifer, which occupies the lowest part of the landscape and collects groundwater from the entire catchment. This ultimately discharges to the Fortescue Marsh catchment via the lower section of the Weeli Wolli Creek catchment. Thus, the rate of groundwater discharge, prior to mining, can be expressed simply with an understanding of the dimensions of the CID aquifer, its hydraulic conductivity and the hydraulic gradient.

- Evaporative losses

  Typically, evaporation is the least precise estimate of the water balance components. Evaporative losses from the catchment include the following:

  - Direct evaporation from ephemeral surface water and wet ground surfaces
  - Water vapour flux from the unsaturated zone via the soil profile
  - Evaporation of water intercepted by foliage
  - Transpiration by vegetation of various types with varying access to soil water, from grasses to phreatophytic vegetation.

  It is not realistic to attempt to quantify evaporative losses from the catchment. The importance of undertaking studies in this area can be reviewed separately in the context of the entire SEA work.

- Change in storage

  - This term is included for completeness; however, it is not easily estimated for the catchment as a whole. Change in storage as a component depends entirely on the timescale over which a water balance is developed. In this case, zero values are used to develop an initial understanding. An example of a water balance for the catchment incorporating Yandi dewatering has been developed to further the understanding of dewatering in the catchment-wide context.

The ‘average’ water balance provides a straightforward consideration of water availability; for example, for consideration of closure strategies for many kilometres of open pit mining of the CID aquifer. A more sophisticated water balance, likely to have a specific objective, would consider, for example, changes in groundwater storage as a consequence of dewatering the CID aquifer.

The present situation in the catchment is that groundwater is being removed from storage (mine dewatering at Yandi and Yandicoogina) and discharged into Marillana Creek. This discharge increases storage in the alluvial aquifer and a proportion (probably large) is lost by evapotranspiration.

Table 14 provides the steady-state (pre-mining) water balance. An ‘average’ water balance is provided, accepting the compromise in such an event-based system, together with a water balance for a year with extreme rainfall and runoff.

The evaporation component of the water balance has been estimated in this instance as the difference between rainfall, and runoff plus groundwater flow. A more sophisticated analysis of evaporation and evapotranspiration could be attempted, but not realistically, within this study.

Given that the average annual rainfall adopted is 350 mm and the average annual runoff is equivalent to 8 mm, evapotranspiration accounts for most of the rainfall into the catchment. It is likely that, transpiration by phreatophytic vegetation is a very small proportion of evaporation, given the small proportion of the area of the catchment occupied by phreatophytes. This does not however, suggest that phreatophytic vegetation is not important from an ecological perspective.

Table 14: Water Balance Estimates

Feature	Steady State (Pre-mining)	Average (2000-2012)	Extreme Rainfall Year	Units	Remarks
Measured Parameters					
Catchment area	2 480	2 480	2 480	km^2	
Rainfall	350[1)]	350[1)]	560	mm/yr	[1)] average
Inflow					
Total rainfall (350 mm/yr)	868	868	1 390	GL/yr	
Change in Storage					
CID dewatering	-	10	-	GL/yr	Taken from Golder calibrated numerical model (Golder, 2013b).
Outflow					
Surface water runoff	18	13	220	GL/yr	Based on gauged data for Marillana Creek at Flat Rocks scaled to overall catchment.
Groundwater discharge (CID)	1[2)]	11[3)]	1[2)]	GL/yr	[2)] 2000 to 3000 m^3/day (EPA, 1996; RTIO, 2011a; Golder, 2013b). [3)] Average discharge from Yandi dewatering plus natural discharge from CID.
Evapotranspiration	849[4)]	834[5)]	1 169[4)]	GL/yr	[4)] Derived as difference between inflow (rainfall) and outflow as runoff and groundwater flow. [5)] Derived from pre-mining water balance, as difference between inflow (rainfall), outflow as runoff and groundwater flow and change in storage. Probably a slight under-estimate due to increased transpiration in Marillana Creek in dewatering discharge area.
Total discharge	868[6)]	878[7)]	1 390[6)]	GL/yr	[6)] Taken as equal to inflow, with inferred zero change in storage for average water balance. [7)] Taken as equal to inflow plus change in groundwater storage in CID.

The main features of the average year water balance are:

- 98% of the rainfall is lost as evaporation
- 0.1% of the water balance is groundwater flow through the catchment into the Fortescue River catchment
- 2% of rainfall, on average, discharges from the catchment.

Table 14 gives an estimated water balance for 12 years that incorporates dewatering and discharge operations at Yandi. Strictly, this is not a fully accounted water balance for the catchment, as it does not include RTIO's Yandicoogina dewatering, which might be of a similar order of magnitude. Nonetheless, it does illustrate the effects of one large mining operation on the catchment as a whole.

Table 14 also shows an annual water balance for a year of extreme rainfall. There is no reason to expect a change in groundwater outflow, as the gradients for flow cannot change significantly. In an extreme year, more water is taken up by evaporation.

The water balance for an extreme year shows a larger proportion of runoff relative to evaporation. In that year, only 84% of rainfall is lost as evaporation, with 16% of the rainfall contributing to runoff into the Fortescue River catchment. Conceptually, groundwater discharge is unlikely to change significantly from average years to wet years; although, local variations are expected.

Chloride-based water balance

Rainfall has a small but measurable concentration of sodium chloride. The chloride (Cl) component acts as a conservative tracer, provided that the processes by which it is partitioned between surface runoff and groundwater discharge from the catchment are properly conceptualised.

A benefit of a chloride balance is that it eliminates the need to include evaporation, as chloride is conservative in this context.

The chloride balance for the catchment can be expressed by the following relationship:

$$Cl_{in} = Cl_{out} \pm \text{Change in Cl Storage}$$

Where:

$$Cl_{in} = \text{Rainfall} \times \text{Cl concentration}$$

$$Cl_{out} = \text{Runoff} \times \text{Cl concentration} + \text{Groundwater discharge x Cl concentration}$$

In terms of $Chloride_{in}$, the accession to the catchment is extremely variable as a function of time, depending upon infrequent rainfall patterns, some but not all is derived from tropical cyclones. It is not known how chloride concentrations in rain vary during cyclones or from one type of rainfall to another (i.e cyclonic rain versus non-cyclonic rain). Therefore, the chloride-based water balance is based on annual average rainfall, taking an inferred average concentration from the paper of Hingston and Gailitis, 1976 of approximately 1 mg/L for rainfall north of 24^{o}S. The mass of chloride deposited annually in the catchment can therefore be calculated from the average annual rainfall of 350 mm.

$Chloride_{out}$ has two components, surface water and groundwater:

- Groundwater discharge and associated chloride content occurs as a result of near-steady movement of water through the CID aquifer under a near-constant regional gradient with a substantial buffering storage in the aquifer.
- Surface water discharge and associated chloride content occurs mostly during irregular and episodic floods within the catchment, with little or no storage of water within the catchment.

Chloride concentrations in runoff

Data for runoff along Weeli Wolli Creek, which drains from the Central Pilbara, suggests a chloride concentration for surface runoff of 20 mg/L which is used here.

The potential for change in the amount of chloride stored in the catchment may be important but cannot be quantified. For example, a series of dry years might accumulate salt that is flushed out in the first major flood event, giving an excessive chloride mass relative to a long term average. The Munjina Claypan might have potential for as-yet unrecognised salt accumulation as reflux brine, like the Fortescue Marsh, which would lead to an imbalance between $\text{Chloride}_{\text{in}}$ and $\text{Chloride}_{\text{out}}$. Such an imbalance might, however, be less than the uncertainties in the overall balance. The chloride balance is shown in Table 15.

Table 15: Average Year Chloride Balance

Chloride Balance Components	Chloride Concentration (mg/L)	Chloride Mass (tonnes/yr)	Remarks/Formula
Rainfall (average 350 mm/yr)	0.5	434	Estimate consistent with CPH study, Hingston and Gailitis, 1976 and Crosbie *et al.*, 2012.
CID groundwater throughflow	75	83	YM114, YM117 measured (avg. 05/1995 to 01/1996; range 71 to 79 mg/L)
Surface water	20	352	Chloride concentration estimated by difference

Chloride balance discussion

The chloride balance suggest, for an average year, a proportion of 19% of the total chloride mass balance leaving the catchment as groundwater discharge through the CID aquifer with the remainder contained in surface water discharge. This compares with 0.1% of the water balance for groundwater discharge from the catchment.

The chloride balance is much less reliable than the water balance given the current data availability. The large uncertainty is related to the variable concentration in runoff, which would require chloride concentrations (or electrical conductivity as a surrogate) measured in parallel with surface water discharges so as to develop a stronger understanding of the catchment characteristics.

As such, the chloride water balance has produced a result that should be used with caution.

4.0 ECOHYDROLOGICAL CONCEPTUALISATION

4.1 Regional ecohydrological assessment

A landscape ecohydrological conceptualisation of the Central Pilbara Region, including the study area, has been developed through the definition landscape of ecohydrological units (EHUs). Each EHU represents a landscape element with broadly consistent and distinctive ecohydrological attributes (see Section 1.3.3 for more detail). Factors considered in the definition of EHUs include:

- landscape position and land surface types, including soil characteristics
- landscape water balance processes
- surface drainage/redistribution processes
- connectivity and interactions between surface water and groundwater systems
- major vegetation types and their water use strategies.

Nine EHUs are represented in the landscapes of the study area (Figure 28). Upland areas comprise EHUs 1 and 2 associated with the Hamersley Range that dominates most of the project area. EHU1 typically includes dendritic networks of drainage floors and channels (EHUs 3 and 4). EHU2 includes sloping country, in some cases immediately down-gradient from EHU1, which is dissected by ephemeral creeks and drainage floors (EHUs 3 and 4). Within EHU2 these drainage lines may further coalesce before feeding into low-lying areas. The Robe Land System, part of EHU1 is notable for representing the surface expression of the palaeochannel system that hosts the CID ore deposits.

Lowland areas include alluvial plains (EHU6) associated with the broader and more extensive valley systems between the ranges. An area of calcrete plains (EHU7) occurs in the upper reaches of Marillana Creek.

Major channel systems (EHU8) are associated with sections of Marillana Creek and its major tributaries east of the Flat Rocks gauging station. An area of Marillana Creek extending approximately 7 km upstream from Flat Rocks has also been interpreted as EHU8 based on the occurrence of riparian woodland communities. EHU8 in the project area has been interpreted to include an up-gradient extension of the River Land System mapped by Van Vreeswyk *et al*., 2004 based on aerial photography of riparian vegetation communities, BHP Billiton Iron Ore vegetation mapping and depth to watertable information.

The Munjina Claypan is broadly coincident with the Brockman Land System. The area of clay flats forms an internally draining catchment which has potential to retain surface water flows associated with lower magnitude flood events (≤10 yr ARI); although, it overtops in larger floods and is classified as EHU9.

Groundwater flow follows the major valley systems at a regional scale. Zones of shallow groundwater (<20 m bgl) are associated with EHU8. Areas of calcrete, including potential habitat for stygofauna, are associated with EHUs 7 and 8. It is possible that portions of the Munjina Claypan may also be underlain by calcrete habitat for stygofauna.

Table 16: Description of EHUs within the Marillana study area

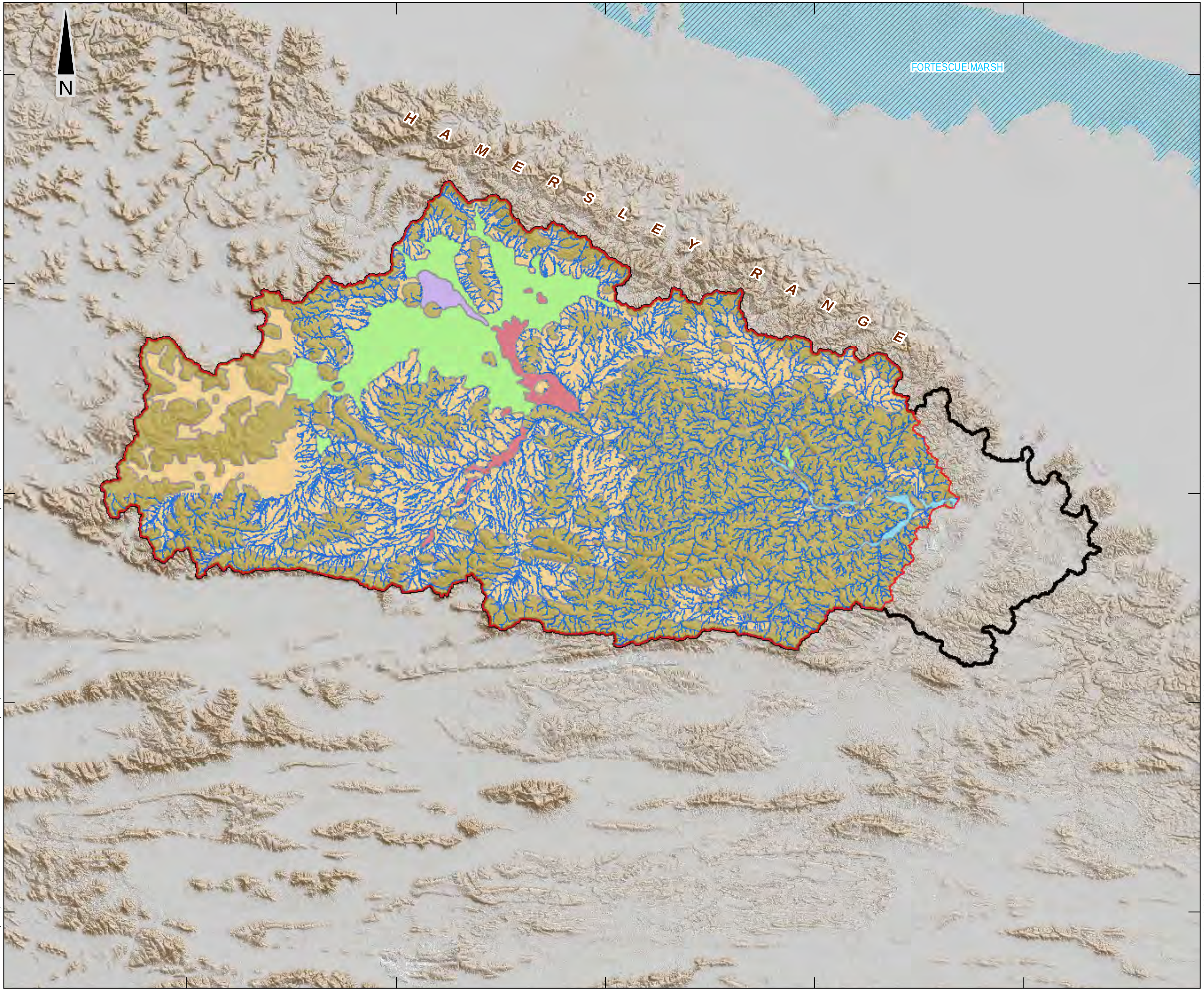
EHU	Percent project area	Distribution in project area	Component land systems
1	52%	The Hamersley Range comprising the uplands of the Study Area (predominantly the Newman Land System)	Newman; McKay (major) Oakover; Robe; Rocklea
2	27%	Foot slopes of the Hamersley Range	Boolgeeda; Platform
3	7%	Drainage floors within EHUs 1 and 2	Within EHUs 1 and 2
4	3%	Major channels within EHUs 1 and 2	
5	n/a	Sandplains in Fortescue River Valley	Not present in area
6	8%	Alluvial plains associated with major valley systems and generally adjacent to major drainage lines	Brockman; Pindering; Wannumunna
7	1%	Low calcrete platforms and plains, prominent in areas surrounding Marillana Creek between Flat Rocks and Munjina Claypan	Calcrete
8	2%	Associated with the lower reaches of Marillana Creek	River
9	0.4%	Munjina Claypan	Brockman

4.2 Local ecological assets

There are few ecological assets, and no recognised ecological receptors, in the study area.The most identifiable ecological asset is Marillana Creek itself, which is considered a Tier 3 ecological asset by BHP Billition Iron Ore as it contains no TEC or PEC and has only local conservation significance.

Other ecological assets with a low level of ecohydrological connectivity include:

- Flora species of conservation significance not associated with the key ecohydrological receptors. This includes *Lepidium catapycnon* and various priority flora taxa recognised by the Department of Parks and Wildlife.
- Fauna species of conservation significance whose habitat requirements are not strongly dependent on, or otherwise intimately associated with, the key ecohydrological receptors.
- Uplands (EHUs 1 to 4) associated with the intersection of the Karijini National Park and the study area.
- Uplands (EHUs 1 to 4), alluvial plains (EHU6) and calcrete plains (EHU7) associated with proposed 2015 pastoral lease exclusion areas within the study area.



LEGEND

- Fortescue Marsh
- Marillana Creek project
- Marillana Creek catchment
- EHU1 UPLAND Hills, Mountains, Plateaux
- EHU2 UPLAND Slopes and Plains
- EHU4 UPLAND Channel Systems
- EHU6 LOWLAND Alluvial Plains
- EHU7 LOWLAND Calcrete Plains
- EHU8 LOWLAND Major Channels and Floodplains
- EHU9 LOWLAND Munjina Claypan

NOTES
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Marillana Creek SEA Project

SPATIAL DISTRIBUTION OF EHUs

FIGURE 28

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5.0 STRESSORS

Stressors are features or developments that have potential to influence surface water flow, groundwater level and water quality. The major water-related stressors in the study area are existing, planned and potential mining operations. Most mines will extend below the watertable and may therefore involve water-related or water-affecting activities, such as:

- Dewatering, for the majority of mines
- Groundwater supply development, for potable supply, dust suppression and mineral processing
- Surplus water discharge (by redirecting to water deficit operations, injection, creek discharge, etc.)
- Surface water diversions
- Closure designs (relating to final voids).

There are also other stressors that are not related to mining activities and these include:

- Climate change
- Broadscale land use changes, for example, grazing by livestock and other feral animals
- Linear barriers to runoff, such as roads, railways, pipelines, etc.

This section of the report addresses, to the extent practicable or appropriate, water-related changes caused by actual and future proposed mining operations as outlined in the SEA schedule. They are described in their geological, hydrological and environmental contexts.

As outlined earlier in the report, there are five existing and proposed BHP Billiton Iron Ore mining areas in the study area; four existing and proposed third-party mining areas; as well as a number of potential transport corridors.

The following section provides a broad overview of the setting, mining history and level of previous hydrological investigations of these mining areas. Table 17 provides an overview of the mining areas and summarises the characteristics and status of the identified stressors within the study area (operating and proposed mining developments).

The orebody overview table includes a characterisation for each mining area based on the generic orebody type. The generic orebody types reflect the ore type and the degree of hydraulic connection with the regional aquifer. The orebody type in the Marillana Creek catchment comprises mainly CIDs which also comprises the regional aquifer. Brockman Banded Iron Formation (BIF) is targeted at Ministers North, Tandanya Sweet View, Yandicoogina South (NML) and Iron Valley (IOH/MRL).

Four generic sub-types are identified within the Marillana Creek catchment, based on the hydrogeological features, and these are as follows:

Above the Watertable

Orebodies located above the regional watertable will not encounter groundwater during mining and hence will not require dewatering. There is limited potential for direct impact on groundwater resources; however, there may need to be diversion of surface drainages and possible sourcing of a water supply from groundwater to meet water requirements. It is considered that mines above the watertable pose no potential impact risk to the regional aquifer and associated receptors. Phils Creek and Iron Valley are planned to be AWT operations and will not require dewatering.

Partially Connected

Lower in the landscape, typically within valley margins, there is potential for orebodies to extend below the watertable. The pit geometry suggests that the valley-side pit wall may intersect either saturated Tertiary detritals or fault structures that may be in connection with the regional aquifer.

Dewatering requirements are likely to be moderate at between 2 and 10 ML/d; although, groundwater inflows from localised basement aquifers would be low. Drawdown would be limited within the basement aquifer; however, there is potential for some watertable decline to extend outwards into the regional aquifer. The propagation of drawdown is most likely to develop as an elongated cone of depression along the strike of the regional aquifer and in the same alignment as the valley. Despite connectivity between the orebody and regional aquifer, the low permeability of the detrital aquifer suggests that watertable decline would be localised and be marginal with respect to the proposed mine. It is considered that partially connected mine types pose low potential impact risk on the regional aquifer and associated receptors; however, monitoring is recommended to demonstrate water level response.

Ministers North, Tandanya Sweet View and Yandicoogina South are potentially partially connected orebody systems. Further works will be required to demonstrate the extent and nature of hydraulic connectivity.

Disconnected Channel Iron Deposits (CIDs)

Disconnected CID orebodies occur within palaeochannel systems with low-permeability lithologies on both sides of the aquifer. They are not in hydraulic connection with other aquifers or surface water features and are disconnected from sensitive riparian communities. Dewatering rates may exceed 20 ML/d and groundwater drawdown may extend along the aquifer, but does not extend significantly outside the palaeochannel system.

Disconnected CIDs are associated with some Yandi and Yandicoogina orebodies. At Yandi, W1 and W4 orebodies are mostly situated in disconnected CIDs with low permeability BIF and dolerite occurring on both sides of the palaeochannel.

Connected Channel Iron Deposits (CIDs)

Connected CID orebodies occur within palaeochannel systems which are in hydraulic connection with other aquifers (calcrete or alluvium). They are in hydraulic connection with surface water features that may have sensitive riparian communities. Dewatering rates may exceed 20 ML/d and groundwater drawdown within the CID may result in drawdown in the overlying aquifers.

Munjina, Upper Marillana and some orebodies in Yandi and Yandicoogina are connected CIDs. At Munjina, the Oakover Formation calcrete aquifer overlies the CID aquifer. At Yandi, some of the CID orebodies are in hydraulic connection with the Marillana Creek and the alluvial aquifer where the creek crosses the palaeochannel (C1, C5, E2 and the ends of W1 and W4 orebodies) or flows parallel to the palaeochannel (E356).

Table 17: Orebody Overview

Operation	Yandi	Munjina	Upper Marillana	Ministers North	Tandanya	Yandicoogina	Yandicoogina South	Phil's Creek	Iron Valley	Koodaideri Corridors
Owner	BHP Billiton Iron Ore	BHP Billiton Iron Ore	BHP Billiton Iron Ore	BHP Billiton Iron Ore	BHP Billiton Iron Ore	RTIO	NML	IOH/MRL	IOH/MRL	RTIO
Ore Type	CID	CID	CID	Brockman / CID	Brockman /Marra Mamba	CID	CID/Weeli Wolli	CID	Brockman	Not Applicable
Current Status	- Operating - currently mining W1, W4, W5, C1, C5, E1, E2 and E356 - Scoping - W6 and E7.	Exploration and Mine Planning	Exploration	Exploration and preliminary Mine Planning	Exploration – only the Sweet View deposit is within the Marillana Creek SEA project area	- Operating - currently mining Junction Central and Junction South East. - Future expansion - Junction Southwest, Oxbow, Snooker, Meander and Billiards.	Exploration	Operating	Exploration and Mine Planning	Exploration and Mine Planning
Previous Hydrogeological Studies	- Drilling and testing - Numerical modelling - Groundwater management - Aquifer reviews - Closure planning - Tree health study - Ore drainage study - Detailed hydro-geological review	- Exploration drilling - Preliminary hydro-geological investigation	Exploration drilling	Exploration drilling	- Drilling and testing - Numerical modelling - Water supply investigation	- Drilling and testing - Numerical modelling - Water balance - Groundwater management - Closure planning	Exploration drilling	Exploration drilling	- Preliminary hydrogeological investigation - Numerical modelling	Not Applicable
Ore Below Watertable	75%	100%	Expect large proportion	10%	25% (10% at Sweet View)	80%	Infer less than 50%	Above water table mining	Above water table mining	Not Applicable
Maximum Saturated Thickness (m)	80	50	50	Pit and WT depths unknown	- Depth to WT possibly 100 mbgl – Pit depths unknown	80	- Depth to WT possibly 40 mbgl – Pit depths unknown	Not Applicable	Not Applicable	Not Applicable
Strike Length (km)	20	20	15+	8	15-20	26	1	1.2	3+	Not Applicable
Generic Type	Connected CID and Disconnected CID	Connected CID	Connected CID	Partially connected BIF	Partially connected BIF	Connected CID and Disconnected CID	- Partially connected BIF - Connected CID	AWT	AWT	Not Applicable
Dewatering Requirement Basis	- Aquifer storage and throughflow - Creek recharge - 15 to 22 GL/yr	- Aquifer storage and throughflow - Creek recharge - < 36 GL/yr	- Aquifer storage and throughflow - Creek recharge - < 36 GL/yr	- Aquifer storage and throughflow - < 4 GL/yr	- Aquifer storage and throughflow - < 4 GL/yr (Sweet View)	- Aquifer storage and throughflow - Creek recharge - 34 to 53 GL/yr	- Aquifer storage and throughflow - < 2 GL/yr	Not Applicable	Not Applicable	Not Applicable
Interaction with Marillana Creek	- Surface drainage - Riparian vegetation - Hyporheic zone - Subterranean fauna	- Surface drainage - Riparian vegetation - Hyporheic zone - Subterranean fauna	- Surface drainage - Riparian vegetation - Hyporheic zone - Subterranean fauna	- Surface drainage	- Surface drainage	- Surface drainage - Riparian vegetation - Hyporheic zone - Subterranean fauna	- Surface drainage - Riparian vegetation	Not Applicable	Not Applicable	Sheetflow

**Assumed 50% dewatering is discharged.*

5.1 BHP Billiton Iron Ore Yandi

5.1.1 Overview

BHP Billiton Iron Ore's Yandi mining operations comprise eight open pits located 90 km north-west of Newman within Mining Leases 270SA and 47/292 and the broad Marillana Creek valley. The mining operations target CIDs that were deposited in a meandering palaeochannel. Mining of the CID orebody along Marillana Creek commenced in 1991 with a mine life of approximately 30 years and a mining reserve of 1420 Mt.

The Yandi mining area is characterised by low ridges and hills with scree slopes rising above surrounding plains in a well-drained valley with major and minor drainage lines. There are six land systems identified in the mining area: the dominant land system comprises plateaux, ridges, and hills. The River land system includes the major drainage line, Marillana Creek. Other significant tributaries to Marillana Creek in the tenement include Iowa Creek and Lamb Creek.

The mining operations comprise the Western Deposits, Central Deposits and Eastern Deposits (Figure 29). There are currently eight operational open pits and BHP Billiton Iron Ore plans to develop 13 open pits in total, all of which will be below the pre-mining watertable. Depths to pre-mining groundwater levels are generally less than 10 m and the depths of the pits range between 55 and 80 m.

Numerous groundwater studies have been carried out at Yandi since the 1980s. The health of the riparian vegetation has been monitored since the 1990s. A "tree health study", which commenced in 2011, aims to identify the groundwater controls on the riparian vegetation and assess the potential interactions between mine dewatering and riparian vegetation health (Golder, 2013a).

5.1.2 Yandi Conceptual Model

5.1.2.1 Surface Water

The mine comprises a number of pits extending a distance of around 20 km along and adjacent to Marillana Creek. A significant proportion of the deposits are located below and directly adjacent to Marillana Creek and diversion and bunding along sections of the watercourse is therefore required to minimise the risk of inundation during flooding.

In addition to the diversion channels, the existing creek line also passes adjacent to and between several proposed pits (W1/W2 and E3/5/6/E7). Protection bunds have been or will be constructed to minimise the risk of inflow to the pits along these creek sections. The designs are based on the control of floods associated with a 100 yr ARI.

The specific surface water requirements relating to the Yandi mine are:

- Maintaining drainage corridors of existing watercourses to the extent possible
- Where diversions are required these are designed to convey, as a minimum, the 100 yr ARI peak flood discharge
- For those areas where upslope runoff is impeded, convey flows around the infrastructure wherever possible
- Consideration of the volumes of continuous dewatering discharge relative to the frequency and magnitude of surface water flows.

5.1.2.2 Groundwater

The conceptual model features a palaeochannel aquifer, which contains the CID deposits, with fresh to marginally fresh groundwater. An alluvial aquifer is incised into weathered and fractured bedrock and in places is hydraulically connected with the palaeochannel. Schematics depicting the understanding are presented in Figure 30 and Figure 31.

The main recharge mechanisms for the CID aquifer are throughflow and creek recharge from episodic floods in Marillana Creek. Hydraulic tests in the bedrock, field observations of the rock mass and general experience all indicate that the bulk hydraulic conductivity of the bedrock is very low, which will limit the rate of groundwater movement through bedrock.

BHP Billiton Iron Ore commissioned a "Tree Health Study" (Golder, 2013a) which aimed to better understand the hydrological dependence and interaction between the Marillana Creek riparian vegetation and the open pits, situated in the palaeochannel. The Tree Health Study comprised installing about 30 monitoring bores at crucial sections along Marillana Creek and continuously monitoring water level and quality using data loggers. The fieldwork assisted the development of the conceptual hydrological model along the creek.

A number of hydrological zones can be identified along Marillana Creek. Each of these zones is associated with a distinct geological, hydrological and ecohydrological setting. The zones are described in more detail below.

Zone 1: Shallow groundwater underlain by alluvium and bedrock

Over much of the Yandi tenement, especially in the western part, Marillana Creek is remote from the palaeochannel. The creek is underlain by alluvium and bedrock, the latter comprising low permeability BIF and dolerite. The alluvial aquifer is hydraulically separated from the palaeochannel by the low permeability BIF and dolerite. The groundwater in this zone is shallow and the zone supports phreatophytic vegetation types such as Silver Cadjeput (*Melaleuca argentae*) as well as facultative groundwater users such as River Red Gum (*Eucalyptus camaldulensis*) and Coolibah (*Eucalyptus vitrix*). Groundwater levels are sustained by creek flows which periodically infiltrate the creek bed.

The vegetation is susceptible to groundwater drawdown, but since the creek is hydraulically separated from the palaeochannel, drawdown does not generally extend to the alluvial aquifer. Groundwater levels can also be sustained by discharging excess dewatering water into the creek, such as at the Central Discharge Point.

Zone 2: Creek crosses palaeochannel

Marillana Creek crosses the meandering palaeochannel at many sites. In these areas, the creek is underlain by alluvium and CIDs. As with Zone 1, the groundwater in this zone is typically shallow hence the zone supports phreatophytic vegetation types. Groundwater is more susceptible to drawdown from dewatering activities which have lowered groundwater levels over large parts of the palaeochannel. Shallow, perched groundwater may still be sustained in the alluvium in parts of Zone 2 occurring on low permeability clay bands in the alluvium or CID.

Zone 3: Creek flow adjacent to palaeochannel

In some portions of the catchment, Marillana Creek flows adjacent to the palaeochannel. In these areas, there is a good hydraulic connection between the creek and palaeochannel.

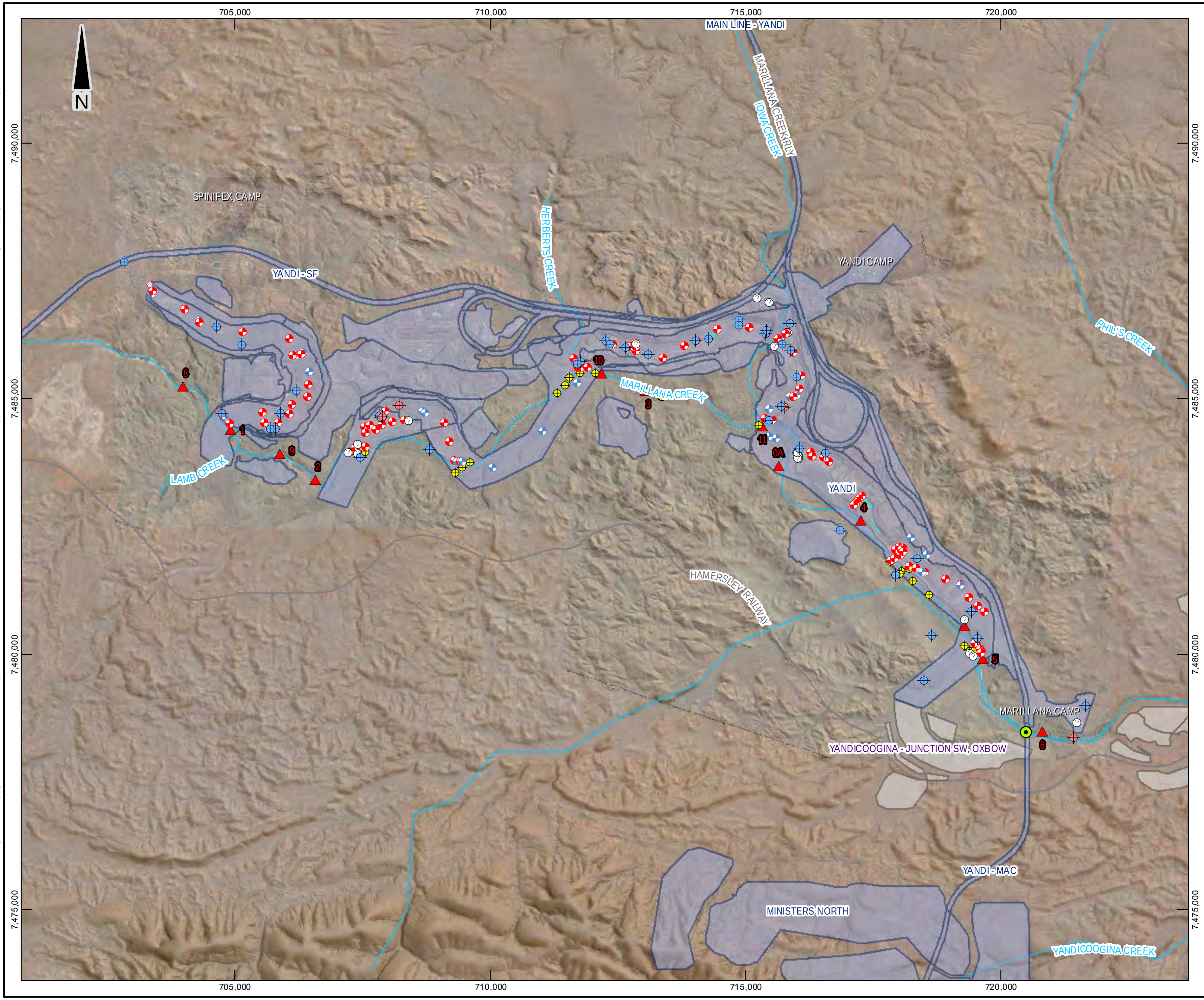
In Zone 3, groundwater levels are not sustained by creek flows, because groundwater flows to the higher permeability CIDs. Groundwater levels are typically more than 10 m bgl. The groundwater is often too deep to sustain obligate phreatophytic vegetation, and the riparian woodland comprises vadophytic and facultative groundwater users.

Dewatering activities from nearby mining operations have lowered groundwater levels in areas where the creek flows parallel and adjacent to the palaeochannel. Since vegetation in this zone is less dependent on groundwater, drawdown may only affect a small portion of facultative vegetation.

Zone 4: Discharge Zones

Excess dewatering water is being discharged mainly at the Eastern Discharge Point, close to the southern tenement boundary. Some excess water is also occasionally discharged at the Central Discharge Point. The discharge of excess dewatering has created a permanent surface water expression at and directly downstream of the discharge points. This surface water flows along the creek and then infiltrates the alluvial aquifers. The artificially higher groundwater levels support riparian woodland with more abundant vegetation and an increase in vegetation densities and foliage cover.

Once the discharge of excess water stops, the vegetation will revert back to the pre-discharge conditions, which implies a decrease in vegetation abundance, density and foliage cover. The vegetation will require time to adapt to the lower water availability.



LEGEND

- Monitoring well without borelog
- Dewatering well without borelog
- Monitoring well with borelog
- Dewatering well with borelog
- Other
- Marillana borelog
- Discharge point
- Tree health monitoring site
- Creek
- Railway
- Sump
- Indicative BHP Billiton Iron Ore disturbance
- Reasonably foreseeable Third Party disturbance

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NOTES

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0 1 2 3 4
kilometres
SCALE (at A4) 1:100,000

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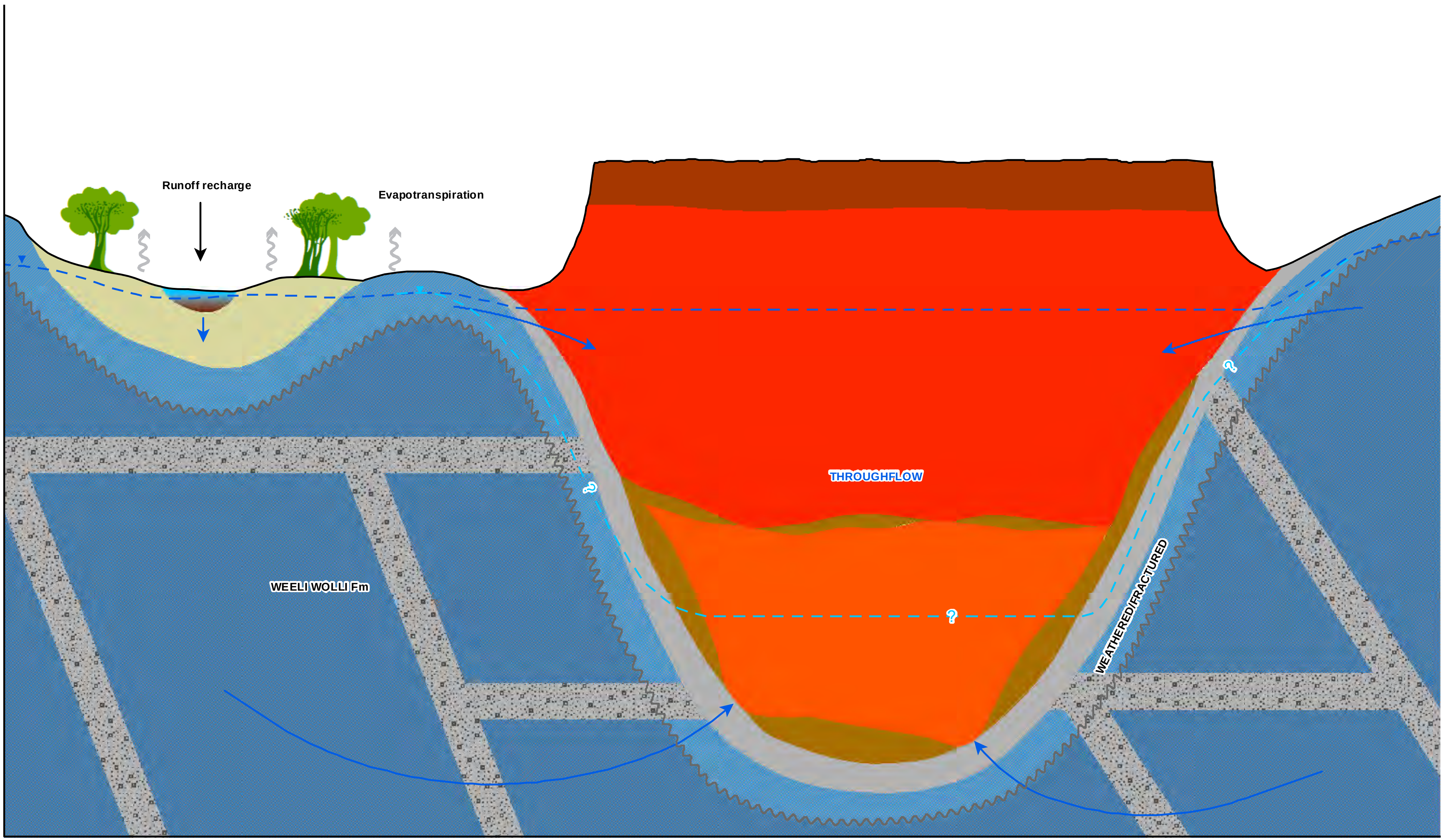
CLIENT	BHP Billiton Iron Ore
DOCUMENT	137646040-002-R-Rev4
DATE	01 Sep 2015
COMPILED	MS
APPROVED	GRH

Marillana Creek SEA Project

YANDI SITE OPERATIONS

FIGURE 29

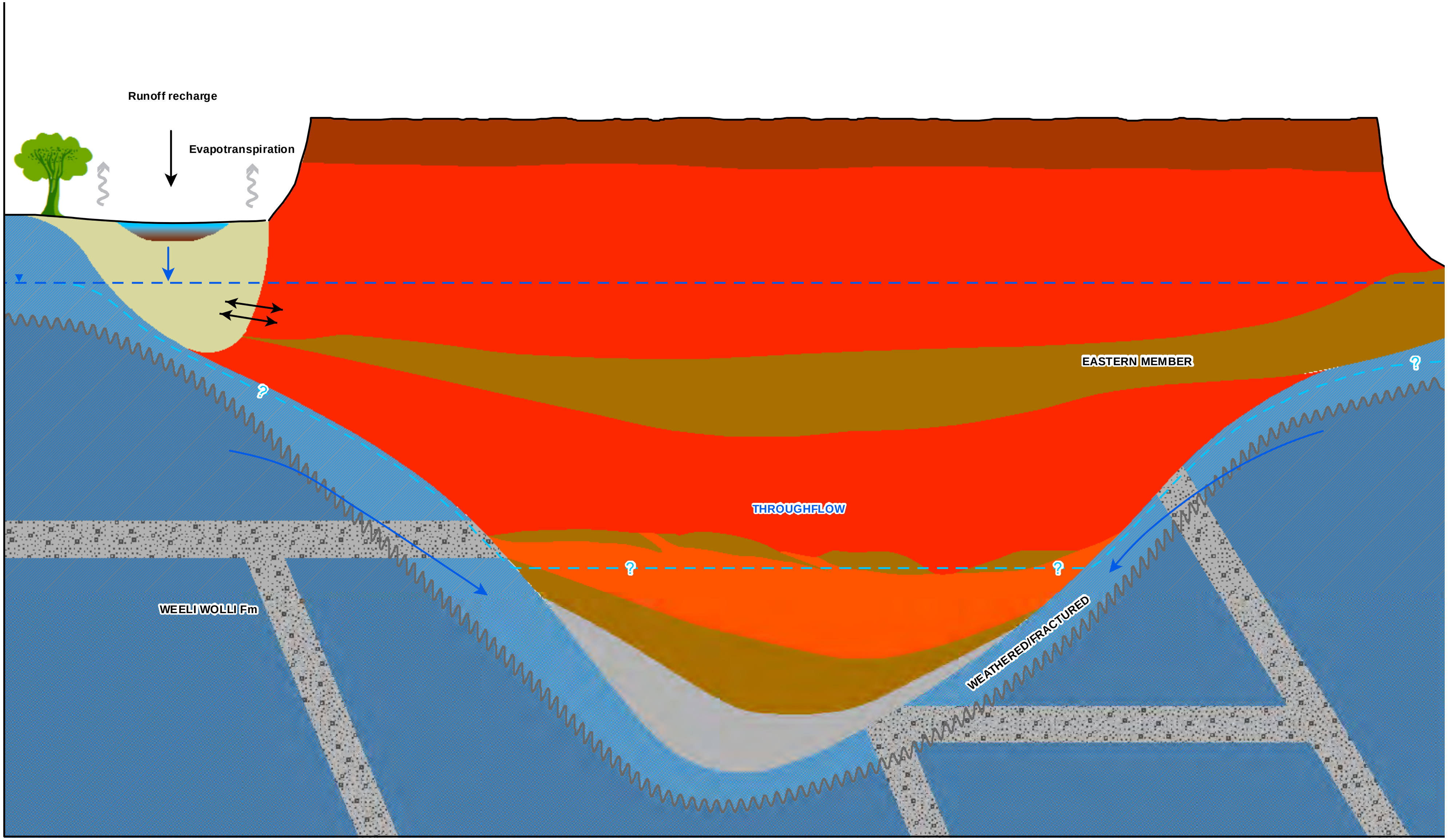
File Location: G:\Spatial_Information_Group\GIS_WORKSPACE_AUSTRALIA\01_WA\SF5012_ROY_HILL\137646040\Projects\002-R\Rev4\137646040-002-R-F029-Rev4_YandiSite.mxd



LEGEND

Surface	FERRICRETE	CLAY
Pre-mining water level	ALLUVIUM	CONGLOMERATE
Mining water level	LCID	MARILLANA CREEK (EPHEMERAL)
Groundwater flow	UCID	DOLERITE DYKE/SILL

CLIENT BHP Billiton Iron Ore		PROJECT Marillana Creek SEA Project	
DRAWN MS	DATE 01-Sep-2015	TITLE SCHEMATIC CROSS-SECTION WHERE BEDROCK RESTRICTS THE HYDRAULIC CONNECTION BETWEEN THE ALLUVIUM AND CID	
APPROVED GRH			
SCALE NOT TO SCALE	A4	PROJECT No 137646040-002-R-Rev4	FIGURE 30



LEGEND

- Surface
- Pre-mining water level
- Mining water level
- Groundwater flow
- FERRICRETE
- ALLUVIUM
- LCID
- UCID
- CLAY
- CONGLOMERATE
- MARILLANA CREEK (EPHEMERAL)
- DOLERITE DYKE/SILL

Golder Associates

CLIENT	BHP Billiton Iron Ore
PROJECT	Marillana Creek SEA Project
DRAWN	MS
APPROVED	GRH
DATE	01-Sep-2015
TITLE	SCHEMATIC CROSS-SECTION SHOWING MARILLANA CREEK ALLUVIUM INCISED INTO CID MATERIAL
SCALE	NOT TO SCALE A4
PROJECT No	137646040-002-R-Rev4
	FIGURE 31

File Location: G:\Spatial_Information_Group\GIS_WORKSPACE_AUSTRALIA\01_WA\SF5012_ROY_HILL\137646040\Projects\002-R\Rev4\137646040-002-R-F031-Rev4_Section.mxd

5.2 BHP Billiton Iron Ore Munjina and Upper Marillana

5.2.1 Overview

The proposed Munjina and Upper Marillana mining areas are located in the upper reaches of the Marillana Creek catchment approximately 50 km north-west of the Yandi mine. Upper Marillana borders the Munjina project (Figure 32). The projects are currently in exploration and mine planning phases with Upper Marillana within the Exploration Lease 47/1222 and Munjina within the State Agreement Lease M270SA. The mining operations will consist of open pits targeting CIDs which are situated in the same palaeochannel system that is mined at Yandi. All the proposed open pits will be mined below the watertable.

The Munjina Preliminary Hydrogeological Review (BHP Billiton Iron Ore, 2012) developed a conceptual hydrogeological understanding of the Munjina (and Upper Marillana) mining areas, based on preliminary groundwater level and geological data collected during exploration activities. Upper Marillana has a similar geological and hydrogeological setting to Munjina, and the findings of the Munjina review can be inferred to apply across both tenements.

No studies have investigated the relationship between groundwater and the riparian vegetation at Munjina and Upper Marillana. However, as with Yandi, there may be localised zones of groundwater dependent phreatophytic vegetation where groundwater levels are shallow. The calcrete and CID aquifers may host subterranean fauna.

5.2.2 Conceptual Model

The conceptual hydrogeological model for the Munjina mining area is provided in Figure 33 which is similar to the conceptual model for the Upper Marillana mining area.

5.2.2.1 Surface water

The mining areas are mostly located in a broad, flat valley flanked by low ridges and hills with scree slopes. The Munjina claypan is anhydrological feature that occurs where Marillana Creek and several tributaries converge. The claypan is subjected to periodic inundation following lower magnitude flood events (<10 yr ARI) which attenuates downstream discharge. Larger flood events are less affected by the claypan.

Riparian vegetation is established along the Marillana Creek and its tributaries. The pits will cross Marillana Creek and a northern tributary, resulting in the loss of a small portion of the riparian vegetation. It is likely that extensive flood control work will be required to minimise the risk of pit inundation.

5.2.2.2 Groundwater

Munjina is in an area where several tributary palaeochannels containing CIDs converge. The main water bearing units are the alluvium, CID aquifers, and the Oakover Formation (calcrete) thatoverlies the CID. The calcrete is about 20 m thick with outcrops in central and southern Munjina tenements. The Oakover Formation is also present in the north east area of the Upper Marillana tenement.

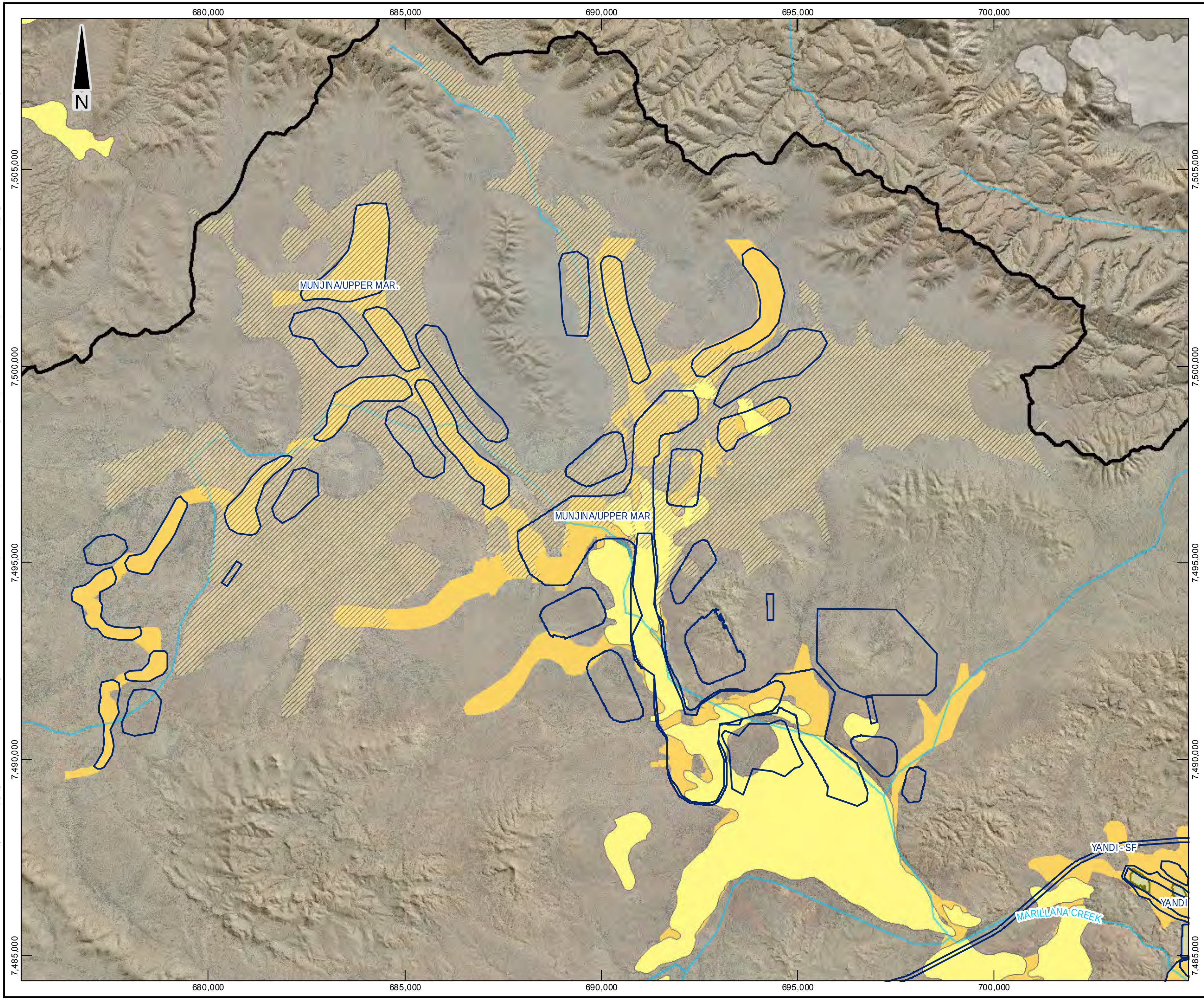
The calcrete is likely to have a high permeability. Where the creek flows over the calcrete outcrop, there is also likely to be good hydraulic connection between the creek and calcrete aquifer resulting in high recharge rates during periods of creek flow.

Groundwater elevations in the CID aquifer range from 650 m AHD in the north to 640 m AHD in the southern portion of the Munjina mining area. The general groundwater flow direction is to the south-east and groundwater flows mainly along the high permeability CID and calcrete aquifers.

Groundwater levels in the alluvium and calcrete aquifers are likely sustained by creek recharge which is episodic. Groundwater losses are mainly through transpiration of the riparian vegetation and direct evaporation from the Munjina claypan. Groundwater throughflow is possibly a small component of the groundwater water balance. There may be a small contribution to groundwater flow in the CID aquifer from the weathered/fractured bedrock.

Dewatering is required to enable mining below the watertable, which will result in drawdown around the open pits, extending into the calcrete aquifers. Where groundwater levels are shallow, riparian vegetation may be influenced by drawdown (i.e. the lowering of groundwater levels). The drawdown may also influence a portion of the subterranean fauna habitat. Preliminary dewatering estimates are about 100 ML/d or 37 GL/yr. The excess dewatering volumes are unknown and will depend on mine water requirements and the vertical rate of mining.

There is currently insufficient information to determine whether the vegetation that occurs on the Munjina claypan is dependent on groundwater.



LEGEND

- Creek
- Munjina Claypan
- CID reserve
- Calcrete
- Marillana Creek project
- Indicative BHP Billiton Iron Ore disturbance
- Reasonably foreseeable Third Party disturbance
- Current BHP Billiton Iron Ore disturbance

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NOTES
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0 1 2 3 4 5
kilometres
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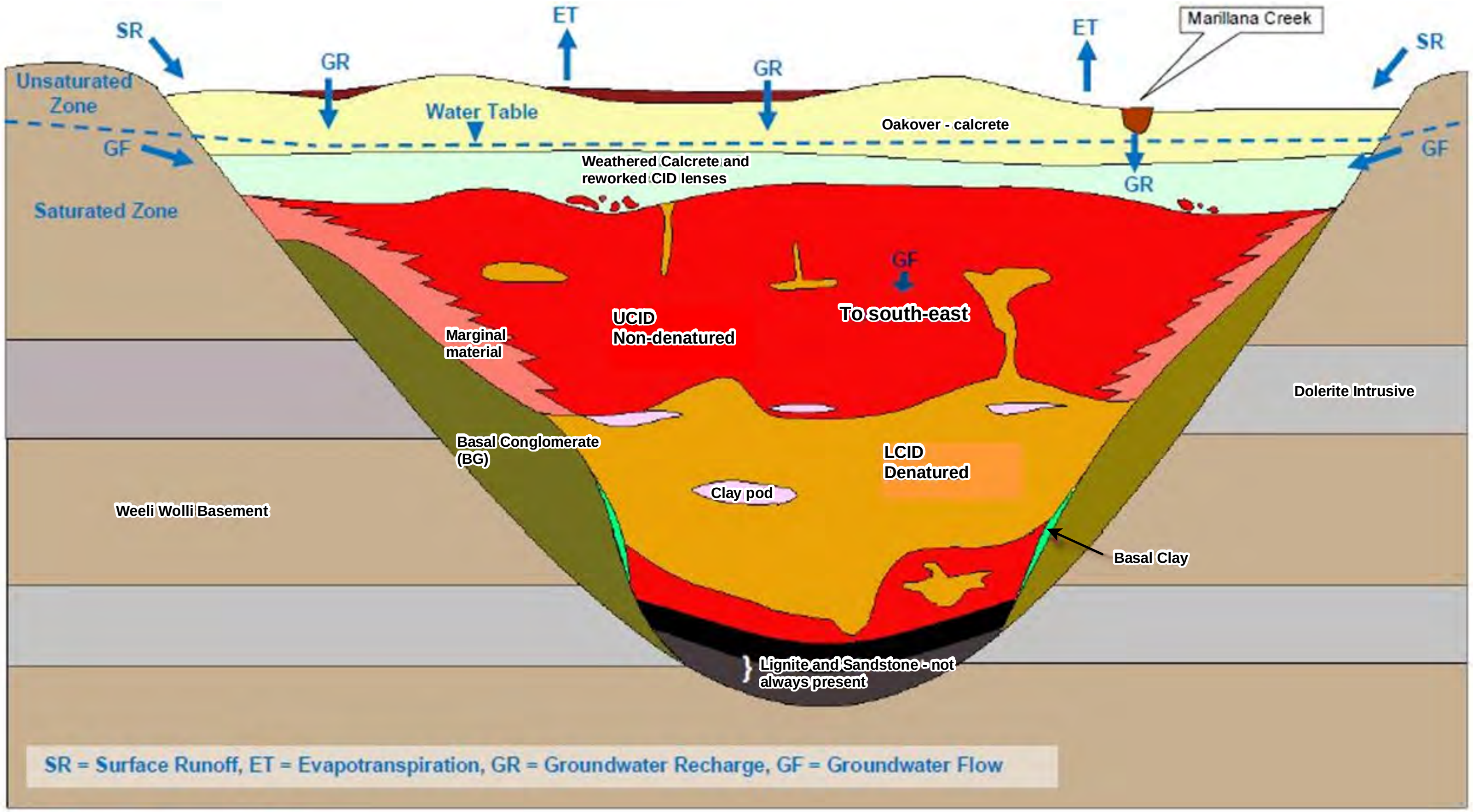
Marillana Creek
SEA Project

MUNJINA AND UPPER MARILLANA PROJECT LAYOUT

FIGURE 32



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Marillana Creek SEA Project

MUNJINA OREBODY CONCEPTUAL MODEL

FIGURE 33

5.3 BHP Billiton Iron Ore Ministers North

5.3.1 Overview

Ministers North tenement E47/(mining area) 0628 is located 10 km south of the main BHP Billiton Iron Ore Yandi camp and straddles the ephemeral Yandicoogina Creek (Figure 34). Yandicoogina Creek is a major tributary of Marillana Creek and flows in a north-easterly direction, before joining Marillana Creek in the RTIO Yandicoogina tenement.

The dominant land system in the mining area is an upland landscape unit comprising rugged plateaux, ridges and mountains with steep scree slopes and gently inclined lower slopes associated with the Hancock Range. There are moderately spaced dendritic tributary drainage patterns of narrow valleys and gorges that feed into the major Yandicoogina Creek drainage line.

Mining operations will comprise a number of pits of which one is aligned along or adjacent to Yandicoogina Creek (CID ore). Several other larger and a number of smaller isolated pits are located along ridgelines further to the west (Brockman Iron Formation ore). Overall, the pits cover a total area of around 3 km^2.

5.3.2 Ministers North Conceptual Model

The mining area is underlain by Brockman Iron Formation to the south and Cainozoic haematite-goethite deposits on BIF or scree slopes on its northern flank. The hydraulic properties of the Brockman Iron Formation BIF are expected to be similar to the Weeli Wolli Formation, which underlies the northern scree slopes.

At deposit scale, the zone of mineralisation is within a gently dipping, east-west plunging anticline with shallowly dipping limbs in a north-south orientation. No major faults have been identified but current drill spacing is not sufficient to clearly define fault location or geometry (BHP Billiton Iron Ore, 2014).

Generally, the BIF formations forming the upland areas have low permeability possibly enhanced locally by structure (faulting, shears and joints) and contribute to a groundwater system that drains towards the CID aquifer system low in the valley landscape. Recharge to this partially interconnected groundwater system is by rainfall infiltration during years of high cyclonic rainfall and surface water recharge along Yandicoogina Creek.

5.3.1.1 Surface water

The catchment area of Yandicoogina Creek upstream of the mine is around 150 km^2. The overall area disturbed by mining is estimated to be around 5 km^2 which represents around 3% of the overall upstream catchment area.

The proposed pit along Yandicoogina Creek is within an incised valley generally around 60 to 70 m wide at the base rising steeply adjacent to both river banks. Using design discharges derived for Yandicoogina Creek in the vicinity of the mine area, the 100 yr ARI peak flood discharge is estimated to be around 380 m^3/s. Proposed pits located to the west of Yandicoogina Creek are generally located along ridgelines and it is unlikely any significant diversions will be required in these areas apart from bunding.

5.3.1.2 Groundwater

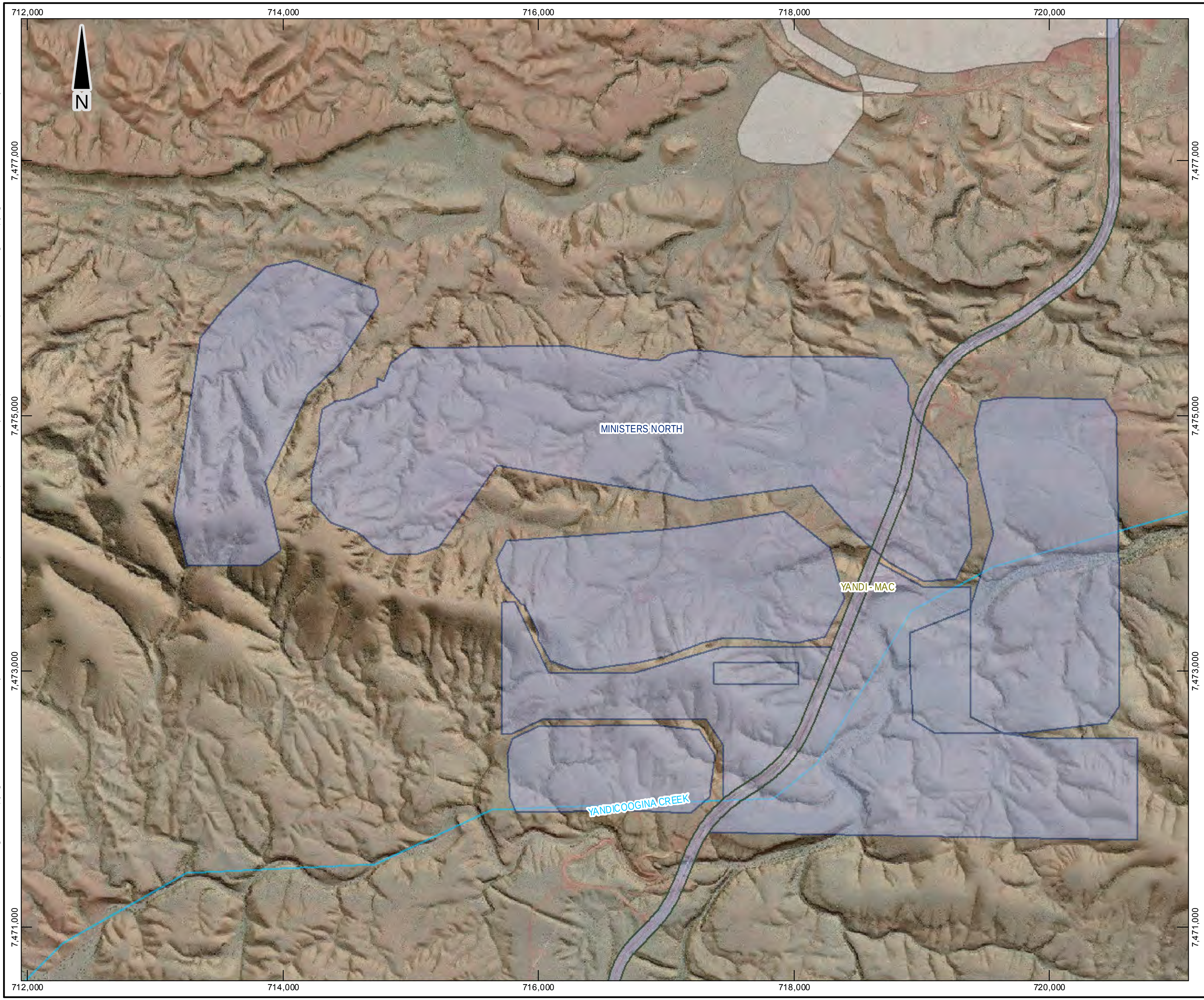
It is estimated that only 10% of the BIF pits will intersect the watertable and the orebody aquifer will likely be bound along strike and in the footwall and hanging walls by unmineralised BIF (similar to Tandanya). The orebody aquifers will have little hydraulic connection with aquifers outside the pit areas, being hydraulically isolated. It is unlikely that local faulting would provide connection to the main aquifer systems.

Dewatering will be required at Ministers North and pit dewatering requirements will be low to moderate (<10 ML/d or <4 GL/yr) for the BIF pits.

The implications of dewatering on the local and regional hydrogeology from the Ministers North orebody are:

- Localised drawdown of the watertable (i.e. reduction in groundwater storage) within the BIF and CID as the orebody aquifers are dewatered.
- Where the orebodies (and pits) are bounded by unmineralised BIF or other lithologies on all sides, as is likely the case, there will be little to no drawdown away from the individual pits.
- Natural groundwater recharge and throughflow will be minor in comparison with expected dewatering rates, and it is likely that there will be little groundwater outflow from the mining area during active dewatering.

Development of Ministers North will result in a set of Brockman Iron Formation pits high in the landscape and a pit or series of pits along the CID adjacent to Yandicoogina Creek. Impacts from the BIF deposits are expected to be local, provided that acid generating materials, if present in the host rocks, are managed appropriately.



LEGEND

- Creek
- Indicative BHP Billiton Iron Ore disturbance
- Reasonably foreseeable Third Party disturbance
- Current BHP Billiton Iron Ore disturbance

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NOTES

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Marillana Creek SEA Project

MINISTERS NORTH BIF RESERVES

FIGURE 34

File Location: G:\Spatial_Information_Group\GIS_WORKSPACE_AUSTRALIA\01_WA\SF5012_ROY_HILL\137646040\Projects\002-R\Rev4\137646040-002-R-F034-Rev4_MinistersNorth.mxd

5.4 BHP Billiton Iron Ore Tandanya

5.4.1 Overview

The bulk of BHP Billiton Iron Ore's Tandanya tenement (mining area) lies within the Central Pilbara Region (RPS Aquaterra, 2013). However, an 81 km^2 portion of the tenement comprising a portion of the Sweet View orebody area lies within the south-western part of the Marillana Creek catchment near its southern divide.

The geomorphology of the Sweet View orebody area is described as rugged plateaux, ridges and mountains with dissected slopes, stony lower slopes and plains below hill systems. A southern unnamed tributary to Marillana Creek flows through this portion of the mining area.

Potential development of the Tandanya mining area will see mining of both Brockman Iron Formation and Marra Mamba Iron Formation orebodies (Figure 35). At various periods of its development, the mine will be in water surplus and at other times in water deficit. In water deficit periods, water for dust suppression, ore processing and camp use will be required from water supply bores or from dewatering borefields of nearby mines with water surpluses.

Groundwater investigations were undertaken south of the Sweet View orebody prior to acquisition of the project by BHP Billiton Iron Ore. Work included exploratory drilling, a trial groundwater production bore, monitoring bore installation, test pumping and groundwater modelling. For the Sweet View orebody, no specific groundwater or surface water investigations appear to have been carried out. Observations from similar orebodies have been used to assess the characteristics of the orebody.

5.4.2 Tandanya Conceptual Model

The surface geology consists of Brockman Iron Formation, which hosts the orebody and forms part of the southern ridge and boundary to the Marillana Creek catchment. The Brockman Iron formation is overlain by Cainozoic colluvial and alluvial deposits. A small outcrop of Weeli Wolli Formation is located to the north of the deposit. The Marra Mamba Formation occurs low in the landscape.

The Sweet View orebody is located on the northern limb of an anticline in Brockman Iron Formation. The pit may intersect the watertable, but the orebody aquifer is bounded along strike and in the footwall and hanging walls by unmineralised BIF (and/or Mt McRae Shale/Mt Sylvia Formation in the footwall). The pits will intersect groundwater with little hydraulic connection with aquifers outside the pit areas; hence, the Sweet View orebody is considered to be an isolated system.

5.4.2.1 Surface water

The proposed pit within the Marillana Creek catchment has an impacted area of around 13 km^2. An unnamed tributary to Marillana Creek rises within the Sweet View tenement and initially flows easterly then east-north-easterly towards Marillana Creek. The associated catchment upstream of the proposed pit has an area of around 112 km^2.

Although the catchment area upslope of the pit is not large, discharge for the 100 yr ARI peak flood is estimated to be about 370 m^3/s. Options to convey this flow downstream of the pit will be developed during mine planning. Given the magnitude of the flows, one option would be to maintain the existing drainage lines crossing the pit provided suitable bunding around the pit is established to minimise the risk of inflows and flooding of the pit. This would require leaving several sections of the pit unmined as adopted at the Yandi mine.

There are unlikely to be any additional upslope areas within the study area isolated as a result of mine infrastructure.

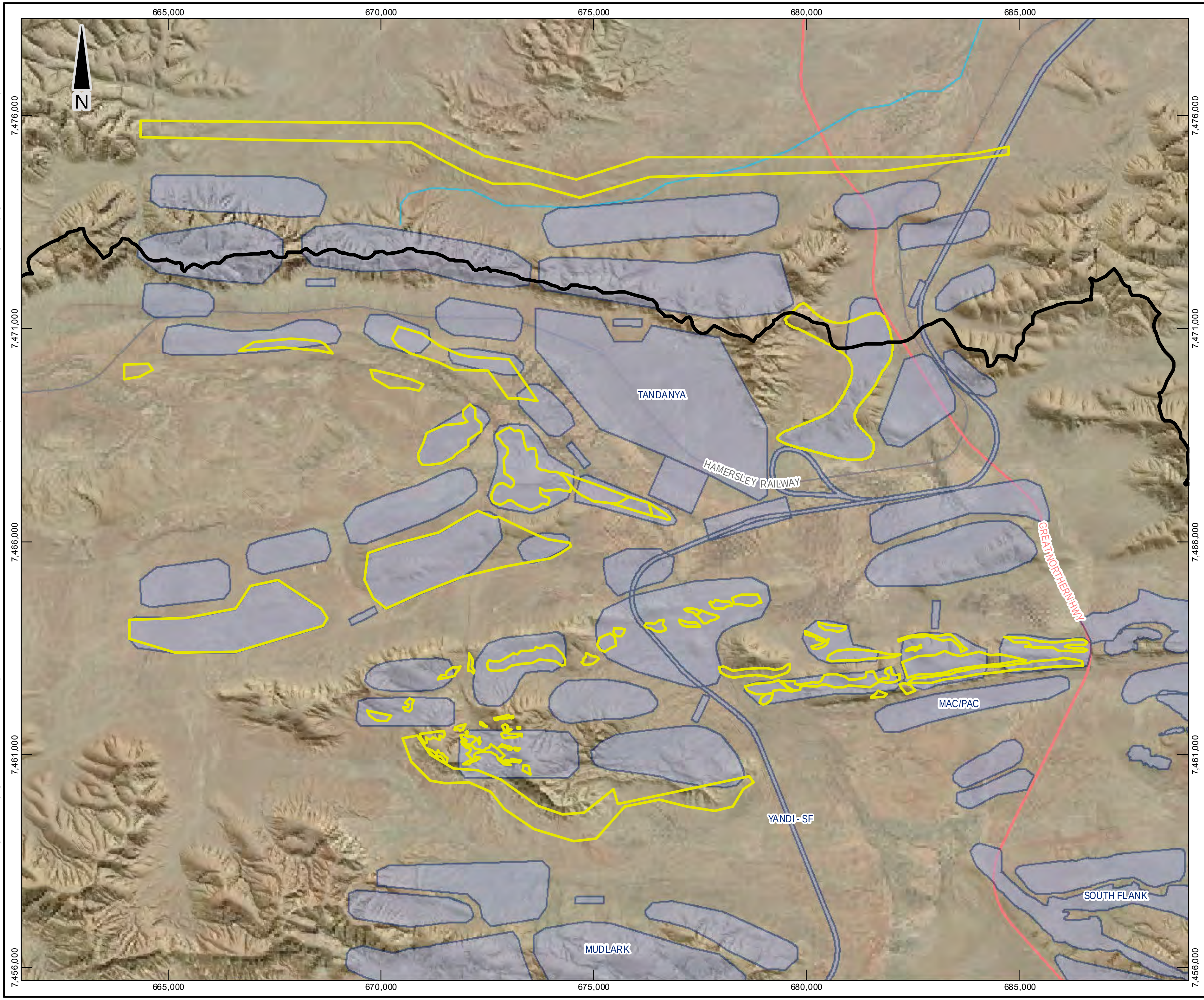
Mine dewatering has not been assessed in detail. However, annual dewatering requirements are likely to be low at around 10 ML/d or about 4 GL/yr. It is likely a proportion of this would be required for dust suppression. Any dewatering discharge to the local drainage system in excess of around 1 GL/yr would, however, be significantly larger than the local surface runoff during most years.

5.4.2.2 Groundwater

Groundwater levels could be up to 100 m bgl beneath the ridges at the Sweet View orebody site. Groundwater flows from the west to east within the valley to the north of the Marra Mamba Formation orebodies. Most groundwater appears to flow northwards through a break in the range to the north and into the Marillana Creek catchment.

Bores south of the Sweet View orebody have hydrographic records from 2006 to 2011. The bores are all located in an area interpreted to be a groundwater divide and with very low rates of groundwater flow. The hydrographs show very little seasonal or longer term watertable fluctuation; although a very slight and steady trend in rising watertables is apparent. The data suggest that groundwater recharge that occurs in the mining area is limited and indirect (RPS Aquaterra, 2014).

A site specific dewatering assessment was undertaken relating to a pit in the Marra Mamba Formation; it predicted dewatering rates of up to 22 ML/d over a 15 year mine life (BHP Billiton Iron Ore, 2012c). For the elevated Brockman Iron Formation pits (e.g. Sweet View), where the orebody aquifers are constrained by low permeability materials, it is concluded that BHP Billiton Iron Ore's generic estimates are probably over-estimates. The Sweet View pit dewatering requirement is estimated as being low to moderate (<10 ML/d).



LEGEND

- Primary road
- Railway
- Creek
- BIF reserve
- Marillana Creek project
- Indicative BHP Billiton Iron Ore disturbance

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Marillana Creek SEA Project

TANDANYA BIF RESERVES

FIGURE 35

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5.5 RTIO Yandicoogina

5.5.1 Overview

The Yandicoogina project is located adjacent to BHP Billiton Iron Ore's Yandi lease, downstream in the same CID. The project is owned and operated by RTIO and is within Mining Lease 274SA situated at and upstream of the intersection of the Marillana and Weeli Wolli Creeks (Figure 36).

The mining area includes three main landforms: low stony hills, broad valleys and the two major creek systems of Marillana Creek and Weeli Wolli Creek. Significant tributaries to Marillana Creek, upstream from the Weeli Wolli confluence, include Yandicoogina Creek and Phil's Creek.

The operations mine the CID orebody which is situated in the same palaeochannel system as Yandi. Approximately 80% of the ore is situated below the watertable. The deposits occur in the same broad valley in which the Marillana and Weeli Wolli Creeks flow.

A staged mining approach is followed whereby the voids of previously mined pits are partially filled with overburden material from developing pits.

Early water related work was undertaken in the 1980s with investigations focused on; obtaining aquifer parameters at the new mining deposits, surface water and groundwater interaction, and estimates of dewatering volumes for the proposed expansion sites. Subsequently, a regional groundwater numerical model was developed with the purpose of predicting dewatering scenarios for current and future Yandicoogina operations. Later studies have included water balance modelling, geochemical characterisation, catchment scale surface water investigations, tree health studies and the effect of discharge water on Marillana Creek riparian vegetation amongst others.

5.5.2 Yandicoogina Conceptual Model

The conceptual hydrogeological model features a principal aquifer comprising the CID and overlying/abutting alluvium and colluvium, with hydraulically-connected, fractured and weathered basement rock in an envelope around the palaeochannel CID. The basement rocks of the Weeli Wolli Formation have a low permeability, but localised geological structures in these rocks may provide localised conduits for groundwater flow. The hydraulic connection between the alluvium and the CID is consistent throughout the area. A thick alluvial aquifer occurs throughout the RTIO lease which contributes significant volumes of water to the CID aquifer.

Although Yandi and Yandicoogina are in a similar hydrogeological setting, there are also significant differences. At Yandicoogina, a thick layer of alluvium underlies most of the Marillana Creek with a high hydraulic connection with the CID aquifers. In contrast, portions of the Marillana Creek at Yandi are underlain by shallow alluvium and bedrock, with less hydraulic connection to the CID aquifer.

5.5.2.1 Surface water

Surface water flow is estimated to average about 19 GL/yr immediately downstream of the Yandicoogina mine under pre-mining conditions with a high degree of variability from 0 to in excess of 200 GL/yr.

Dewatering needs exceed water demand and excess dewatering discharge volumes have varied but annually have been around 1 GL/yr into both Marillana Creek and Weeli Wolli Creek, although this may increase with 14 GL/yr from the Junction South West mine and 8 GL/yr from the Junction Central mine. A portion of excess dewatering water is also re-injected in the Billiard South section of the CID aquifer.

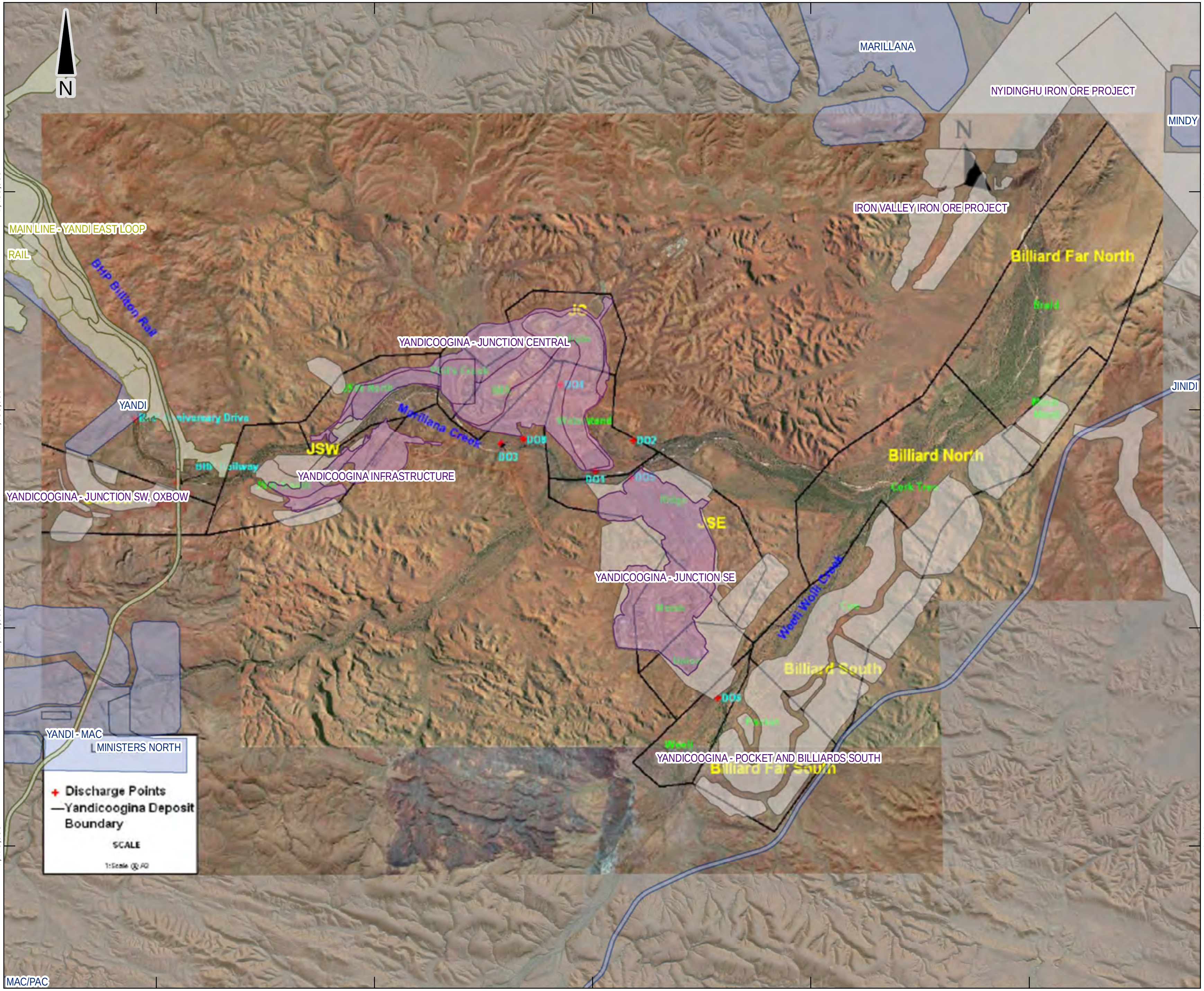
5.5.2.2 Groundwater

Mine pit dewatering requirements at Yandicoogina are approximately 35 GL/yr from currently mined deposits JC and JSE. The expansion of two additional deposits (JSW and Oxbow) is predicted to increase dewatering to up to 53 GL/yr. It is expected that the future expansion of the Billiard, Meander and Snooker deposits will also have a high dewatering requirement.

Water level drawdown within the CID resulting from dewatering activities extends 12 km downstream of Junction Central. Beyond this point, the watertable elevation has remained stable since observations commenced. The expansion of the mine to include the JSW and Oxbow deposits will increase water level drawdown with an area of influence extending to a distance of ~2 km downgradient of the JSW pit and ~1.5 km upgradient of the Oxbow pit.

The main potential impacts of Yandicoogina are much the same as for Yandi. The combination of dewatering and discharge into Marillana Creek results in:

- a degree of groundwater level reduction in nearby areas, particularly where the alluvial aquifer has a direct connection with the CID, with consequent effects on phreatophytic vegetation
- dramatic growth of phreatophytic vegetation in discharge areas that become permanently wet.



LEGEND

- Indicative BHP Billiton Iron Ore disturbance
- Reasonably foreseeable Third Party disturbance
- Current BHP Billiton Iron Ore disturbance
- Current Third Party disturbance

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Marillana Creek SEA Project

YANDICOOGINA PROJECT AREA

FIGURE 36

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5.6 MRL Phil's Creek

5.6.1 Overview

MRL's Phil's Creek mine exploits a tributary CID in the vicinity of BHP Billiton Iron Ore's Yandi and RTIO's Yandicoogina operations in the north-eastern corner of the Marillana Creek catchment.

There are three land systems identified in the Phil's Creek tenement; Newman, Robe and McKay.

The geology of the mining area consists of Brockman Iron Formation high in the landscape to the north, conformably overlain by Weeli Wolli Formation. Low in the landscape, incised into Weeli Wolli Formation, is the Phil's Creek CID, part of a tributary palaeochannel that is continuous with the trunk palaeochannel deposit being mined at Yandicoogina. The Phil's Creek mine is shown in Figure 37.

5.6.2 Phil's Creek Conceptual Model

The Phil's Creek mine is positioned above the watertable and does not require dewatering. Water supply is provided by a small wellfield for mining operations and potable water use. The predicted water use for the accommodation village is low at 34 kL/d (12 ML/yr). Water requirements for dust suppression are not known but are likely to be low.

5.6.2.1 Surface water

The proposed Phil's Creek mine is located immediately adjacent to Phil's Creek some 3.5 km upstream of its confluence with Marillana Creek at the RTIO Yandicoogina mine. The mine pit and associated infrastructure has an impacted area of around 1.4 km^2.

The catchment area of Phil's Creek upstream of the mine is around 73 km^2. The 100 yr ARI peak discharge for Phil's Creek at the mine site is estimated to be 230 m^3/s. Flood depths in Phil's Creek adjacent to the pit could be around 2 m. No dewatering is anticipated, so dewatering discharge to Phil's Creek is not required.

5.6.2.2 Groundwater

The hydrogeological setting of the CID orebody at Phil's Creek is similar to the setting at the abutting Yandicoogina and Yandi operations, where three main aquifers are recognised:

- weathered/fractured bedrock aquifer
- CID aquifer
- thin and unconfined alluvial aquifer.

The unconfined alluvial aquifer associated with Phil's Creek mine is likely composed of superficial sand, gravel to boulder size with potentially finer materials (clays and silts) increasing with depth. The alluvium thickness is likely less than 20 m with variable permeability depending on the presence of gravel lenses. The distribution of alluvial sediments relative to the CID may facilitate or restrict recharge to the orebody from Phil's Creek.

The CID aquifer is a narrow meandering tributary palaeochannel incised into weathered/fractured bedrock. The aquifer is heterogeneous with variable but overall increasing permeability with depth formed by solution channels and cavity features.

The weathered/fractured bedrock aquifer consists of Weeli Wolli Iron Formation with a variable permeability largely dependent on structural features such as fractures and dolerite intrusions. Regionally, the bedrock aquifer has a low permeability and very low storage. Dolerite intrusions with low to high permeability may act as barriers or facilitate groundwater flow dependent on the degree of weathering associated with them. Hydraulic connection with the orebody is anticipated to be limited under natural groundwater conditions due to the relatively low hydraulic conductivity of the bedrock and low hydraulic gradients.

Exploration drilling indicated a depth to groundwater of around 14 to 24 m bgl in the vicinity of the mine pit area and that local groundwater levels are below the ore body (i.e. dewatering will not be required). Local groundwater movement is expected to be towards the main CID aquifer at Yandicoogina, i.e. along the tributary valley.

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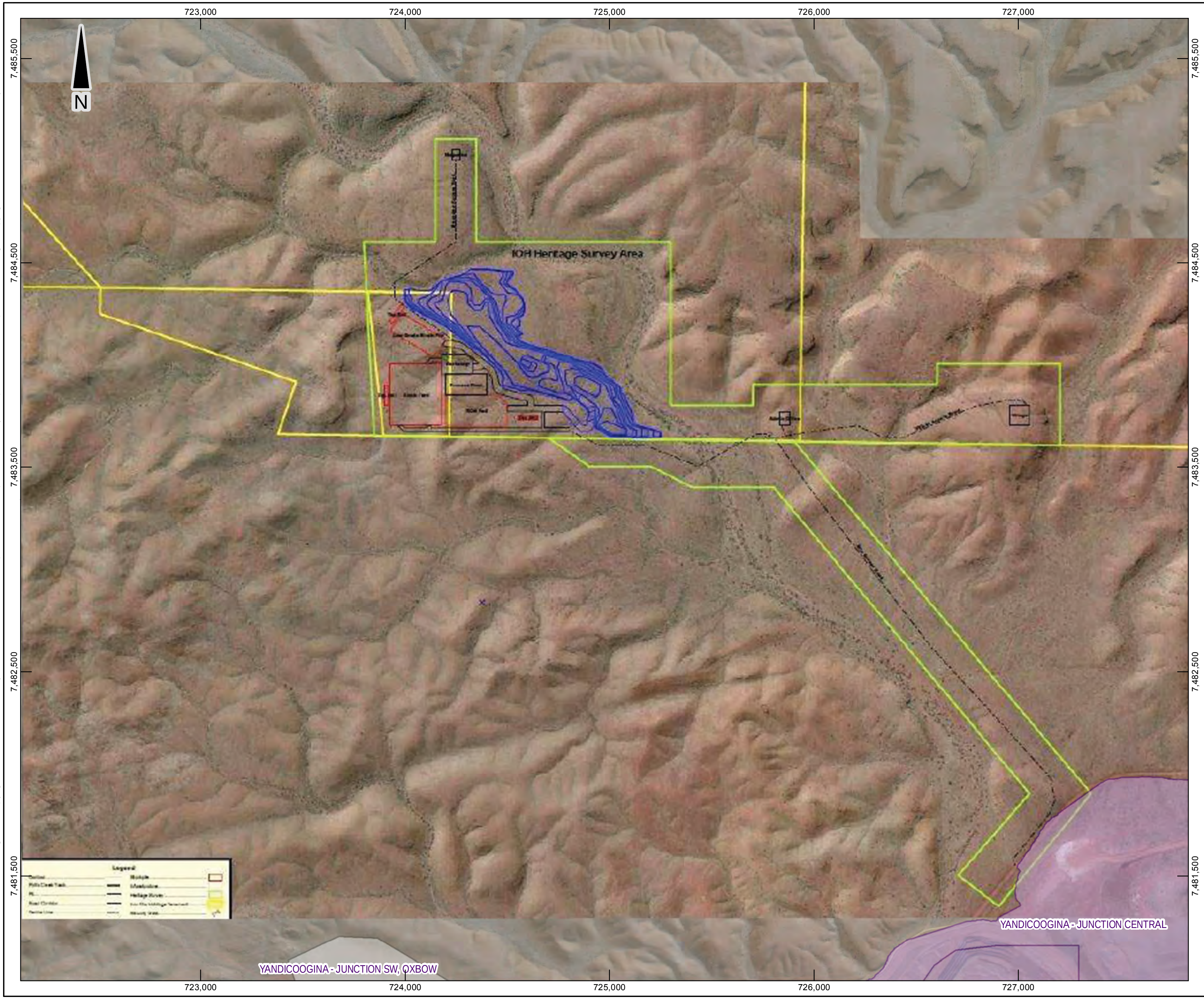

LEGEND

Current Third Party disturbance

Reasonably foreseeable Third Party disturbance

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Marillana Creek SEA Project

PHIL'S CREEK PROJECT LAYOUT

FIGURE 37

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5.7 MRL Iron Valley

5.7.1 Overview

The proposed Iron Valley project is within Exploration Lease E47/1385 and Mining Lease M47/1439 north east of Yandi and Yandicoogina (URS, 2012b). The project area is located towards the mid-eastern area of the Hamersley Ranges, which typically consists of rocky hills, small gorges, ephemeral watercourses and gravelly loam valleys. The project area is at an elevation of between 500 and 600 m AHD and lies within the physiographic unit known as the Hamersley Plateau. The project layout is presented in Figure 38.

Mining operations are expected to occur over seven years with additional time for pre-mining construction, post-mining decommissioning and closure.

Water supply will be from a production bore (or production bores) and used for mineral processing, dust suppression and potable water needs. Annual average water demand is estimated at 360 ML.

5.7.2 Conceptual Model

The orebody is within the Brockman Iron Formation with proposed extraction via an open pit. Other on-site infrastructure will include waste rock piles, a ROM pad, waste management plant and other supporting facilities. Total project footprint is estimated to be 7 km^2.

The project area crosses the northern boundary of the Marillana Creek catchment with a small open pit and waste rock dump within the catchment. The main pit of the mine is within the Fortescue River catchment. A southern pit ore body was wholly below the water table but following a project review, it was decided to reduce the Project scope to above the water table mining. Because of this decision the southern pit was removed from the project.

5.7.2.1 Surface water

The project will comprise two pits with the overall area to be disturbed estimated to be around 7 km^2. The main drainage lines in the vicinity of the mine site comprise:

- unnamed creek located around the southern boundary of the south pit
- three minor, unnamed watercourses that convey runoff from the elevated rocky outcrops to the west of the mine directly through the project footprint.

The overall catchment area upstream of the mine is around 64 km^2 (URS, 2012a) and runoff currently discharges into Weeli Wolli Creek some 200 m east of the north east corner of the site. The catchment area of Weeli Wolli Creek at this location is around 4 000 km^2.

Studies undertaken for the project indicate flood levels for the 100 yr ARI design discharge along Weeli Wolli Creek and the larger watercourse draining around the southern boundary of the pits will not flow into the project area. The minor local watercourses immediately to the west of the site are likely to be diverted around the pits and infrastructure, and discharge directly towards Weeli Wolli Creek.

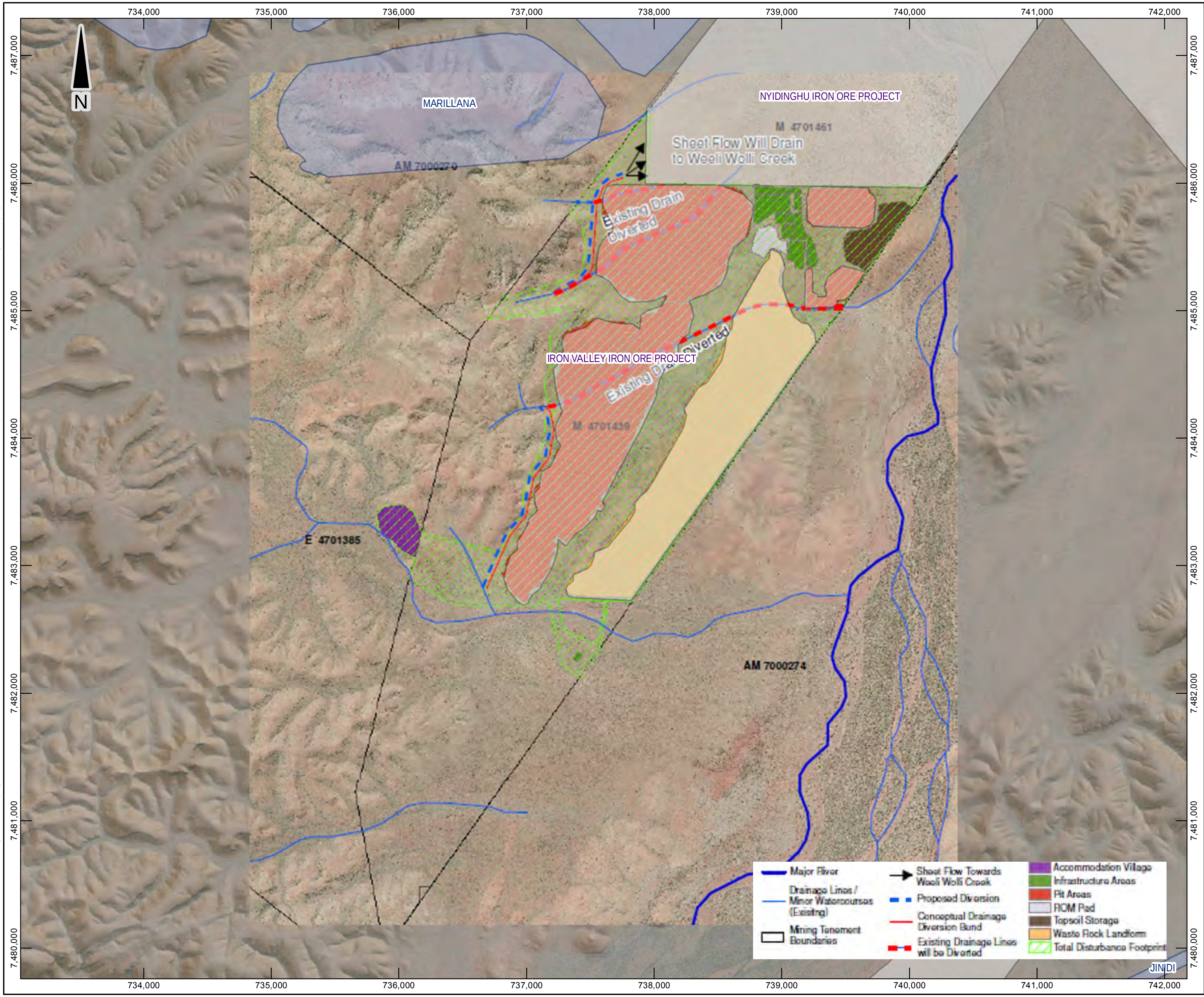
No dewatering is anticipated for the mine, so no discharge of excess water to Weeli Wolli Creek would be required.

The proposed surface water drainage diversions shown in Figure 38 will result in negligible change in runoff volume reaching Weeli Wolli Creek as runoff along all but 7 km^2 will continue downstream.

Studies indicate a low risk of acid metalliferous drainage generated from the site. However, it is predicted that surface water quality will cause minimal change to the downstream environment as there will be no requirement for water discharge to the environment from the mine area.

5.7.2.2 Groundwater

Predictive groundwater modelling indicates that drawdown within the ore zone at the water supply bores will be between 2 to 8 m, with drawdown preferentially propagating along the orebody fault to the north and throughout the mineralised Brockman Iron Formation to the south of an identified dyke. Predictions showed limited drawdown to the east and no drawdown below Weeli Wolli Creek. This drawdown would be experienced during the mine life and is estimated to recover to within 4 m of pre-mining levels within three years after abstraction ceases, and to within 1 m, ten years following cessation of abstraction.



LEGEND

Indicative BHP Billiton Iron Ore disturbance

Reasonably foreseeable Third Party disturbance

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Marillana Creek SEA Project

IRON VALLEY PROJECT LAYOUT

FIGURE 38

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5.8 NML Yandicoogina South

5.8.1 Overview

The Yandicoogina South project is within exploration lease 47/1903 located about 5 km south of RTIO's Yandicoogina mine. The project is located in close proximity to established infrastructure and existing major iron ore operations. It is understood that the project is still in the exploration phase.

The dominant land system is the Newman land system associated with the Hancock Range representing predominantly an upland landscape unit. With decreasing elevation to the east, the geomorphology of the area evolves to the McKay land system. There are moderately spaced dendritic tributary drainage patterns of narrow valleys and gorges that feed into the major drainage line on the northern boundary of the project area, namely Yandicoogina Creek.

5.8.2 Conceptual Model

5.8.2.1 Surface water

The proposed Yandicoogina South pit (Figure 39) is located immediately adjacent to Yandicoogina Creek. The indicated CID resource is located immediately adjacent to the creek while the targeted CID and BIF reserves are further to the south.

The catchment area of Yandicoogina Creek at the mine site is around 195 km^2. The design flood for the 100 yr ARI is estimated to be around 450 m^3/s. The Yandicoogina Creek channel is around 200 m in width adjacent to the mine area, widening substantial immediately downstream. Preliminary hydraulic analyses indicate flood depths for this design event are likely to be less than 1 to 1.2 m although flow velocities will be in excess of 2 m/s. The need for protection bunding adjacent to the river can only be confirmed when the pit extents are finalised. Bund requirements will not change the local flow conditions significantly.

No upslope areas will be isolated as a result of currently proposed mine development.

Although no information on mine dewatering is available, given the relatively small pit areas, it is likely dewatering volumes will not be large. An assumed dewatering rate of 10 ML/d would result in a likely dewatering discharge of around 2 GL/yr.

5.8.2.2 Groundwater

There are two ore body types to be developed at the Yandicoogina South site:

- CID orebody adjacent to Yandicoogina Creek
- Weeli Wolli Formation BIF orebody to the south.

The Yandicoogina South CID orebody extends from ground surface to a depth of 28 m bgl (HRL, 2011a). The orebody setting is similar to the CID described at similar mining operations at Yandi, Yandicoogina and Phil's Creek. Three main groundwater systems are recognised:

- weathered/fractured bedrock
- CID aquifer
- thin and unconfined alluvial aquifer.

The unconfined alluvial aquifer associated with Yandicoogina Creek is likely to comprise sediments of sand, gravel up to boulder size, with potentially finer materials (clays and silts) increasing with depth.

The CID aquifer is a narrow palaeochannel tributary incised into weathered/fractured bedrock. The aquifer is heterogeneous with variable but overall increasing permeability with depth formed by solution channels.

The target BIF orebody is located on a plateau with surface water runoff directed towards drainage channels on breakaways. There are potentially three aquifers associated with the orebody:

- valley-fill aquifers (alluvials and colluvials)
- weathered/fractured bedrock groundwater systems
- ores of the Weeli Wolli Formation.

The valley-fill aquifers are located beneath drainage channels on the flanks of the plateaux. The thickness of the sediments is likely to be variable (0 to 30 m). There is direct infiltration from surface water runoff and the aquifers are likely to be in partial hydraulic connection with the underlying weathered and fractured bedrock.

The mineralised zones of the Weeli Wolli Formation are likely to have higher hydraulic conductivities than the unmineralised sections, due to silica removal during the ore forming processes, fracturing and brecciation. The orebody may be completely encapsulated by low permeability unmineralised BIF or there may be zones with enhanced connection to other orebodies and aquifers through local fracturing.

LEGEND

- Creek
- Current indicated CID reserve
- Target CID reserve
- Target BIF reserve
- Current Third Party disturbance
- Reasonably foreseeable Third Party disturbance

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Marillana Creek SEA Project

YANDICOOGINA SOUTH RESERVES

FIGURE 39

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5.9 RTIO Koodaideri

5.9.1 Overview

RTIO's Koodaideri Project is located about 30 km north-west of its Yandicoogina operation and has a proposed life of 30 years. The resource is to be obtained from Brockman Iron Formation ore. Only the infrastructure corridor options are included in this study (Figure 40), as the mining operations themselves are located outside (north of) the study area.

Several options for connecting with the existing RTIO rail network require evaluation and one or a combination of the following options could be used:

- Western corridor
- Southern corridor – consisting of several branch options
- Eastern corridor.

Two of the three corridor options lie within the study area and are therefore considered in this assessment (Figure 40). The major drainage line, Marillana Creek, and multiple tributaries are present within the footprint of the proposed corridor options. The Eastern corridor option crosses two drainage lines, Marillana Creek and Phil's Creek.

5.9.2 Koodaideri Conceptual model

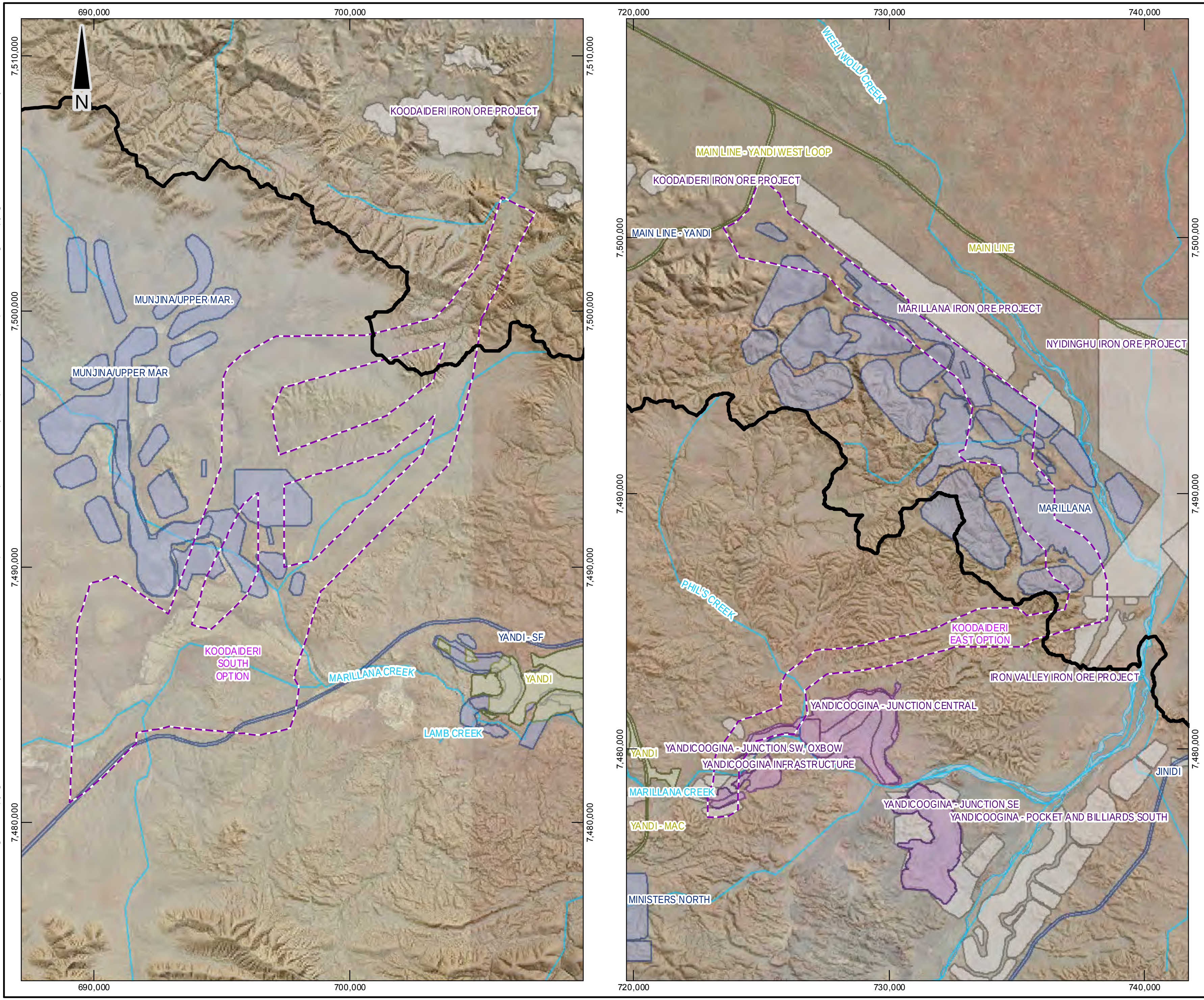
5.9.2.1 Surface water

The Koodaideri East option enters the Marillana Creek catchment near the Iron Valley mine area and traverses the north-eastern section of the catchment through hilly terrain, crossing Phil's Creek immediately north of RTIO's Yandicoogina mine. It then continues generally parallel with, and on the northern side of Marillana Creek, crossing to the south of the creek at the upstream end of Oxbow Pit at RTIO's Yandicoogina mine.

The initial section of the alignment is within the catchment that ultimately discharges directly to Weeli Wolli Creek immediately to the south of Iron Valley mine. This section of the corridor would therefore have no impact on flows within the Marillana Creek catchment. The section closer to Phil's Creek and to the end of the corridor south of Marillana Creek is initially along a valley section and infrastructure within the corridor should have negligible impact on runoff and flood discharges to Marillana Creek. In the section immediately to the north of Marillana Creek, the corridor crosses a number of minor sub-catchments. Infrastructure such as roads would need to be constructed with suitable hydraulic structures to minimise catchment runoff and peak discharges from these minor sub-catchments.

The Koodaideri South Option (with several alternative routes) enters the study area north-east of the Munjina project area. All alternative routes cross wide, flat valley floors with some areas of the corridor within the Munjina Claypan. The corridor also extends further south, crossing Marillana Creek downstream of the Munjina orebody.

Runoff on the flatter areas is likely to be predominantly sheetflow and impacts on surface runoff could occur if infrastructure is constructed that disrupts this flow such as, for example, roads being raised above ground level with insufficient drainage infrastructure to allow discharge downslope. Failure to incorporate such design features could result in significant ponding upslope of the linear infrastructure and reductions in downstream flow volumes as this ponded water infiltrates or evaporates.



LEGEND

- Creek
- Marillana Creek project
- Koodaideri corridor
- Current BHP Billiton Iron Ore disturbance
- Indicative BHP Billiton Iron Ore disturbance
- Reasonably foreseeable Third Party disturbance

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Marillana Creek SEA Project

PROPOSED KOODAIDERI INFRASTRUCTURE CORRIDORS

FIGURE 40

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5.10 RTIO Pocket and Billiard South Mine

5.10.1 Overview

RTIO's Yandi Pocket and Billiard South (PBS) deposits occur at the eastern limits of the 80 km long CID palaeochannel mined by both BHP Billiton and RTIO, which is characterised by relatively continuous iron mineralisation (channel iron deposits) (Rio Tinto, 2014). The site is located approximately 90 km north-west of Newman (Figure 41).

The PBS operation will mine the last stages of the CID palaeochannel through the Hamersley ranges, prior to entering and fanning out onto the Fortescue River Valley. To the east, the palaeochannel follows a north-east trending path, remaining within the confines of the Weeli Wolli valley prior to entering the Fortescue River Valley to the north. The PBS deposits have a total length of 7 km and are situated to the east, and running parallel to, the floodplain of the current Weeli Wolli creek.

The project would result in the construction and operation of a new open pit mine, associated infrastructure (e.g. ore stockpiles, overburden storage areas and haul roads) and additional dewatering of the CID aquifer as part of the existing Yandicoogina Operations (Rio Tinto, 2014). RTIO plans to undertake mining by way of a single, below water table pit along the CID palaeochannel. The project is planned to have a life of more than 16 years, with the current resource estimated by RTIO at 452 Mt (production rate of 70 Mtpa).

The key infrastructure is as follows:

- Flood protection levee
- Weeli Wolli crossing
- Ore handling and processing infrastructure
- In-pit waste fines storage facilities
- Supporting mine infrastructure.

5.10.2 Conceptual Model

5.10.2.1 Surface water

Weeli Wolli Creek is the main drainage line in the PBS project area and enters from the south of the PBS deposits. It runs approximately parallel to the deposit in a predominantly north-easterly direction and then traverses a more north-west path downstream of the deposits and of the Marillana Creek confluence. It drains into a fluvial outwash fan and finally into the Fortescue River Valley.

RTIO has recognised that the PBS project area will cause some local changes to surface hydrological flow pathways and behaviours. RTIO has identified a number of surface water management structures that will need to be put in place to protect mining operations and related infrastructure, as follows:

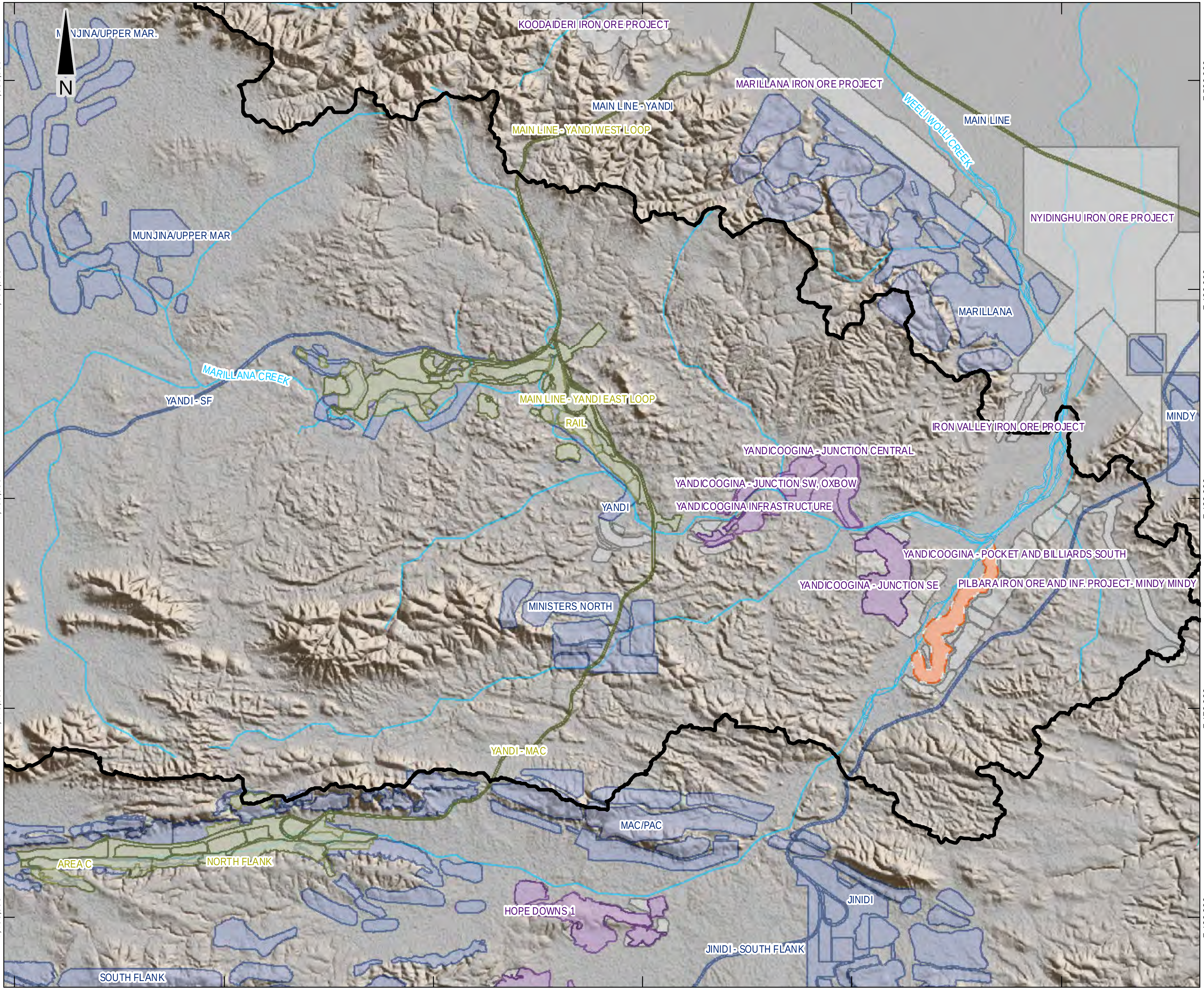
- A 10 km long surface water interception levee will need to be constructed. It will occur along the western margin of the main PBS pit and run adjacent to Weeli Wolli Creek (RTIO has indicated that the levee will necessarily need to be located within the Weeli Wolli Creek floodplain in some areas).
- A number of creek crossings will need to be constructed to facilitate light vehicle access, heavy vehicle access (via bridge and/or floodway across Weeli Wolli creek) and/or permit overland ore conveyors.
- Maintaining a low flow channel in Weeli Wolli Creek near the PBS pit within the existing Weeli Wolli braided creek channel (during operations).

5.10.2.2 Groundwater

The key groundwater unit is the CID aquifer found within a narrow palaeochannel tributary incised into weathered/fractured bedrock. As has been shown elsewhere, the aquifer is heterogeneous with variable but overall increasing permeability with depth formed by solution channels.

RTIO reports that the PBS deposits are situated almost entirely (~99%) below the water table and will require dewatering to commence approximately 12 months before mining activities start. Dewatering will be facilitated by vertical dewatering wells completed in curtain or cluster arrangements within or adjacent to the mine pits.

Dewatering will be fully integrated with site water demand. However, a significant volume of surplus water (ranging from the existing Yandicoogina Operations approved ~47 GL/a up to ~77 GL/a) is likely to be generated over the life of RTIO's Yandicoogina Operations. Some of the groundwater extracted during dewatering is expected to be used for dust control, camp usage and ore processing. The remainder will be discharged into the Marillana and Weeli Wolli Creek systems at controlled, release discharge points.



LEGEND

- Creek
- Pocket and Billiard South
- Marillana Creek project
- Current BHP Billiton Iron Ore disturbance
- Current Third Party disturbance
- Indicative BHP Billiton Iron Ore disturbance
- Reasonably foreseeable Third Party disturbance

The content of this map is conceptual only, of a general nature and does not purport to contain all information relevant to future project development associated with the Project. This map has been prepared solely for the purposes of informing environmental impact assessment pursuant to the Environmental Protection Act 1986 (WA) and Environment Protection and Biodiversity Conservation Act 1999 and is not intended for use for any other purpose. No representation or warranty is given that project development associated with any or all of the disturbance indicated on this map will actually proceed. As project development is dependent upon future events, the outcome of which is uncertain and cannot be assured, actual development may vary materially from this conceptual map.

NOTES
Coordinate System: GDA 1994 MGA Zone 50

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Golder Associates

CLIENT BHP Billiton Iron Ore
DOCUMENT 137646040-002-R-Rev4
DATE 01 Sep 2015
COMPILED MS
APPROVED GRH

Marillana Creek SEA Project

YANDICOOGINA POCKET AND BILLIARD SOUTH PROJECT LAYOUT

FIGURE 41

6.0 CONCLUSIONS

The major water-related stressors are existing, planned and potential mining operations, including Yandi, Munjina, Upper Marillana, Ministers North, Tandanya, Yandicoogina, Yandicoogina South, Phil's Creek, Iron Valley, Koodaideri Corridors and Pocket and Billiard South. Most mines will extend below the watertable and may therefore involve water-related or water-affecting activities, e.g. dewatering, groundwater supply development, surplus water discharge, surface water diversions and closure designs.

The type of orebody being (or proposed to be) mined and the operation's interactions with surface water flows within Marillana and Weeli Wolli Creeks define the stressor. Changes to surface flows are also important because they define the behavioural responses of creek flora/fauna.

The ecohydrological conceptualisation has characterised the interactions between ecological and hydrological systems, and identifying the interactions between these systems and identified stressors.

The main findings are:

- The average annual quantity of surface water discharging from the entire catchment is about 18 GL which represents around 2% of average incident rainfall of 868 GL/yr (350 mm/yr). The median annual surface flow is only around 6 GL, highlighting the extremely skewed flow distribution in the region. The skewed distribution is a consequence of a few extreme flood events. These runoff estimates are of a similar order of magnitude to those recorded at gauging stations in the adjacent Weeli Wolli Creek catchment.
- Surface water flows are almost exclusively the result of remnant cyclonic rainfall events and large flows in excess of 20 m^3/sec do not persist for more than a few consecutive days. Larger flood events occur irregularly, on average around once every three to four years. Around 30% of years can expect negligible streamflow in the Marillana Creek catchment.
- The annual volumes of surface flow are inadequate for use in void filling or flushing post-closure.
- Unless Marillana Creek is permanently diverted away from final voids, even if they are backfilled, there would be a substantial decrease in downstream surface discharge, probably with no discharge at all from the catchment for all but the largest storm events.
- Groundwater discharge from the Marillana Creek catchment moves largely through the CID aquifer to the lower part of the Weeli Wolli Creek catchment, thence to sub-surface discharge into the Fortescue River catchment.
- The groundwater component of catchment discharge is extremely small, approximately 1 GL/yr out of 868 GL/yr annual average rainfall (about 0.1%).
- Dewatering from projects to be mined beneath the watertable will result in the discharge of significant volumes of water back to the surface drainage system. In most cases, these dewatering volumes are comparable with or greater than the average annual flows in Marillana Creek adjacent to the mines. Importantly, these dewatering discharges will be generally continuous seasonally and from year to year, in contrast with the rainfall induced streamflow pattern which is highly episodic.
- The final mine footprint (pits, infrastructure and upslope minor catchments isolated as a result of the mining) may reduce the overall surface runoff contributing area within Marillana Creek catchment by around 6%. This may marginally reduce flood peaks but this will be highly dependent on the spatial distribution of the associated storms within the catchment.
- The development of the final mining voids after closure will require careful consideration to ensure that groundwater salinity is maintained. CID mining will deplete much of the CID aquifer that drains the regional groundwater system towards the Fortescue River valley.

Report Signature Page

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APPENDIX A

Water Data Inventory

Appendix A provides information related to data acquisition for the Marillana Creek SEA Project report.

Topography and drainage

A DEM file with resolution of 5 m was made available by BHPBIO and a digital topographic and elevation model were retrieved from Geoscience Australia (GA) – resolution 30 m.

Landscapes in the catchment were classified on the basis of topography, geology, soils and vegetation into three main landscape units (Upland, Transitional, and Receiving) using the land systems surveyed by the Western Australian Department of Agriculture and Food (DAFWA; Van Vreeswyk *et al.,* 2004).

Climate

The primary climatic data utilised in the study included:

- Daily rainfall series for selected stations available from the Australian Bureau of Meteorology (BoM) and Western Australian Department of Water (DoW)
- Daily rainfall data extracted from the enhanced SILO climate data bank hosted by Science Delivery Division of the Department of Science, Information Technology, Innovation and the Arts (DSITIA, 2013)
- Evaporation data from Western Australian Department of Agriculture and the SILO database
- Daily streamflow for a number of stream gauging stations in the Marillana Creek and Weeli Wolli Creek catchments operated by the DoW.

Additional information was also obtained from the ongoing studies to assess the climatic changes in the Pilbara region being undertaken by CSIRO (CSIRO, 2013).

It is noted that the SILO data are based on complex interpolation and extrapolation procedures. The database is, however, widely used within Australia and the records are considered to be generally reliable. The locations were selected to provide an indication of the variation in annual rainfalls from west to east across Marillana Creek catchment.

A summary of the available information outlining location and periods of available rainfall and evaporation data are presented in Table A1 and Table A2, respectively. The locations of the stations are shown in Figure A1.

Table A1: Available Rainfall Data

Station Name	Station	Location		Period of Record
	Number	Latitude	Longitude	
BoM				
Wittenoom	005026	22.24°S	118.34°E	1951 - 2012
Marillana	005009	22.63°S	119.41°E	1936 - 2013
Newman Aero	077176	23.42°S	119.80°E	1971 - 2013
Ethel Creek	055003	22.90°S	120.17°E	1907 - 2013
SILO				
West Marillana	-	22.78°S	118.45°E	1887 - 2013
Central Marillana	-	22.78°S	118.90°E	1887 - 2013
East Marillana	-	22.78°S	119.35°E	1887 - 2013

Table A2: Available Evaporation Data

Station	Station	Location		Period of Record
	Number	Latitude	Longitude	
DoA				
Jiggalong	-	23.41°S	120.62°E	-
Newman	-	23.27°S	119.56°E	1965 - 2003
SILO				
West Marillana	-	22.78°S	118.45°E	1887 - 2013
Central Marillana	-	22.78°S	118.90°E	1887 - 2013
East Marillana	-	22.78°S	119.35°E	1887 - 2013

Groundwater bore locations, waterways, hydrographic catchment and basin boundaries were downloaded from the DoW GIS database.

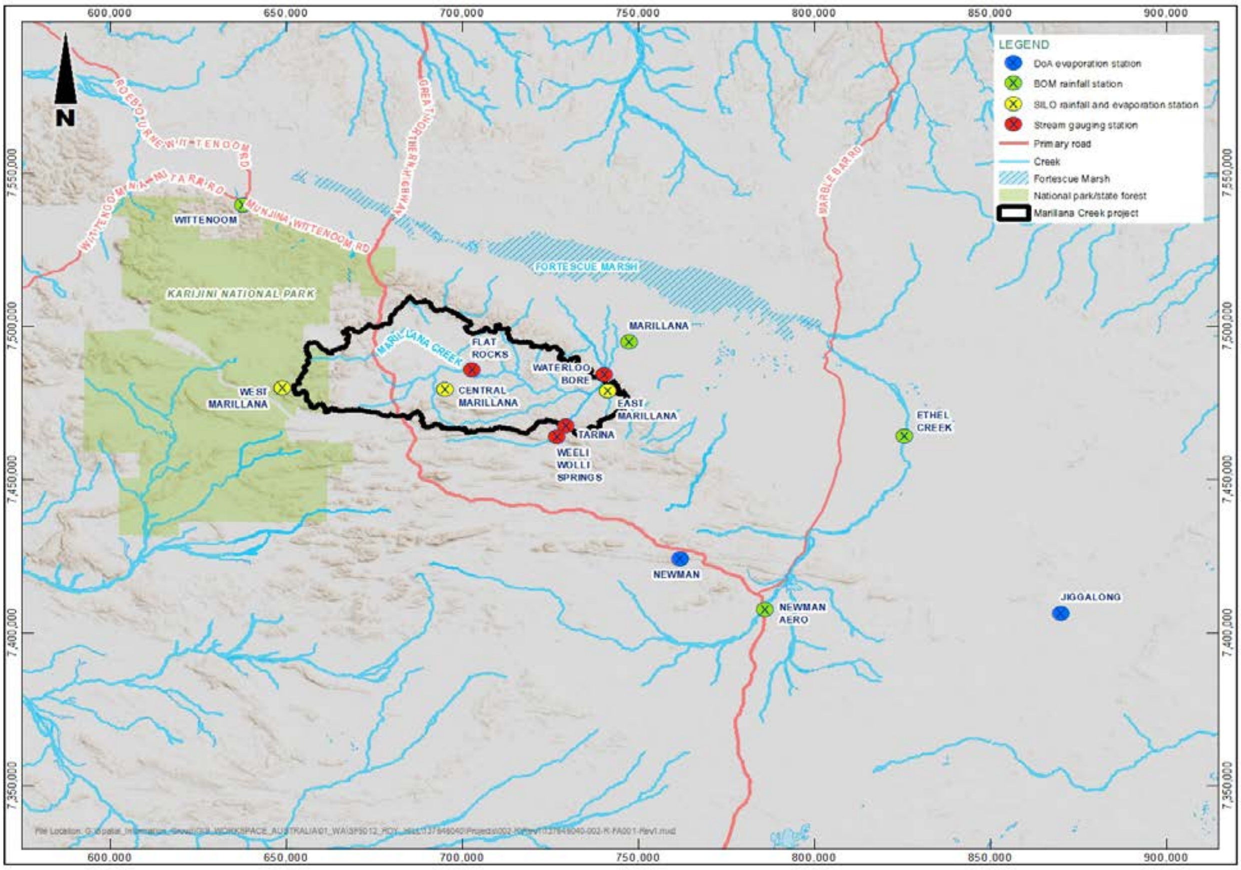

Figure A1: Climate and stream gauging stations.

Geology

The geology of the Hamersley Province, the rocks of which underlie the Marillana catchment, has been well documented by a number of authors with a useful syntheses and reference lists presented in Kneeshaw (2004 and 2008; 'The Blue Book', 1st and 2nd Editions, respectively). Much of the geologic description is derived from Kneeshaw (2004 and 2008) and the Explanatory Notes of the Roy Hill 1:250 000 geological sheet (Thorne and Tyler, 1997).

Additionally, the BHPBIO Exploration team provided a 3D GoCAD model of the Marillana catchment including geologic surfaces and faults. This information was used to interpret the geologic sections across the Marillana catchment and incorporate into the 3D block diagram. At the time of this study, the model was a work in progress, so not all surfaces may be deemed as a correct representation of the geology and the depth and dip of the faults were speculative.

Hydrology

Surface water

A limited number of stream gauging stations have been operated by the DoW in the Marillana Creek and adjacent Weeli Wolli Creek catchments for a number of years. A summary of the available stations is presented in Table A3 and the locations are shown in Figure A1. Daily flow series were available for each station while limited water quality information is also available for a number of water quality parameters. However, water quality measurements have only been recorded at relatively low discharges at all sites and reliable assessment of changes in water quality at different flow rates or over time is not possible.

Table A3: Available Streamflow Data

Station	Station	Catchment	Location		Period of
	Number	Area (km^2)	Latitude	Longitude	Record
Marillana Creek at Flat Rocks	708001	1 370	22.723°S	118.973°E	1967 - 2013
Weeli Wolli Creek at Waterloo Bore	708013	3 991	22.732°S	119.339°E	1984 - 2013
Weeli Wolli Creek at Tarina	708014	1 512	22.883°S	119.235°E	1985 - 2013
Weeli Wolli Creek at Weeli Wolli Springs	708016	1 445	22.916°S	119.212°E	1997 - 2008

Groundwater

Groundwater data was obtained from the Department of Water (DoW) WinSite database together with reports and publications from existing and proposed company operations sourced from BHPBIO or from other company sources including websites. Editable groundwater data was made available by BHBPIO.

It is recognised that the DoW WinSite groundwater data has been developed utilising information from a wide variety of sources: private landholders, companies, government sources with varying levels of reliability. For example, locations can be in error by kilometres and elevations cited in inappropriate columns. Units of measure have also been noted to be in error.

An extensive list of data and information sources is available in the References section.

Ecology

Reference materials (maps, publications and reports on related topics for similar projects) were consulted to support the understanding of the geologic setting, regional groundwater flow system, groundwater recharge estimates and hydrochemistry, the region's vulnerability to climate change, riparian ecological water requirements, subterranean fauna, risk assessment tools for groundwater dependent ecosystems (GDE), and assessment of cumulative effects of mining.

The BHPBIO Biodiversity team provided input regarding the current understanding of species' ranking, ecological significance and environmentally sensitive areas. Spatial data was provided for the receptors identified within the study area including critical biodiversity areas, high biodiversity assets, PEC buffers, proposed DEC exclusion areas, and locations of wetlands. At the time of this study, the "Wetland Values of the Eastern Pilbara" project was ongoing, as well as additional biodiversity surveys and may identify other receptors within the study area for future consideration.

Dan Huxtable, Equinox Environmental contributed Sections 1.3 Ecohydrology, 2.6 Landscape and Environment and Section 4.0 Ecohydrological Conceptualisation to the report main text.

Mining Operations

BHPBIO was consulted over the course of the study and supplied various documents related to existing and proposed operations within the Marillana Creek study area. BHPBIO provided input regarding LoA water planning, groundwater management strategies, and mine planning.

The BHPBIO Mine Planning team provided spatial data of the overburden storage areas (OSA) and resource range analysis (RRA) for BHPBIO proposed operations. Spatial data for the Yandi mine infrastructure and operations were available. Pit shells and roads for Munjina were also provided.

The majority of the available BHPBIO information is focused on the existing Yandi operations, with substantially less information for the proposed operations Munjina, Upper Marillana and Ministers North (listed in order of available information).

All mining tenement boundaries were downloaded from the Department of Mines and Petroleum (DMP) website.

Active mine sites

Yandi

The Golder team has been involved at Yandi extensively on various hydrogeology and water balance studies. Much of the conceptual understanding for Yandi was based on Golder knowledge from previous studies and studies that were currently being carried out. Hydrogeological studies that were being carried out simultaneously as the SEA project included:

- Marillana Creek Tree Health (MCTH, draft report November 2013)
- Yandi Operations Groundwater Flow Model (draft report November 2013) and
- W5, W6 and E7 drilling programs.

Electronically available data included:

- locations and borehole logs of existing wells and installations
- Yandi creek and pit discharge volumes
- Yandi historical data including regional water levels, water quality, and flow volumes
- Yandi mine abstraction and discharge.

Reports and general datasets:

- Biodiversity studies
- Recommendations and conditions of the EPA for the Yandi operation
- Yandi operation licences and monitoring requirements
- Surface water studies undertaken at and management strategies for Yandi
- Groundwater supply, dewatering and management strategies for Yandi
- Yandi drilling and well testing
- Yandi groundwater models
- Yandi aquifer reviews
- Yandi LoM environmental management and closure plan
- Yandi mine decommissioning and final rehabilitation plan.

Yandicoogina

Numerous reports for the existing RTIO operation, Yandicoogina, were available either through the internet or provided by BHPBIO. These reports included relevant information regarding:

- Biodiversity surveys and management
- Environmental impact assessments (including cumulative) and management plans
- Site specific and catchment scale detailed hydrology
- Geochemistry and hydrochemistry
- Groundwater, surface water and salt balance modelling
- Closure options.

Phil's Creek

Limited information was available on the internet for the MRL operation, Phil's Creek. The bulk of the information available was from previous tenement holders, Iron Ore Holdings Ltd. and Process Minerals International Ltd. This included the DEC's conditions and environmental assessment report, proposed mine infrastructure and investigations described in ASX announcements.

Proposed mining projects

Munjina

Preliminary hydrogeological review for Munjina

Biodiversity studies

Exploration data – reserve estimates and preliminary mine plan.

Upper Marillana

Biodiversity studies

Exploration data – reserve estimates.

Minister's North

Extrapolation of data from sites in similar terrain

Exploration data – reserve estimates.

Tandanya

Incorporated information from the Central Pilbara SEA project (RPS, 2013).

Iron Valley

Information available on the internet for the proposed Iron Valley operation (MRL) included site layout, potential environmental impacts (including cumulative), management options, hydrogeology and hydrology studies, and biodiversity surveys.

Yandicoogina South

Nexus Minerals Ltd. (formerly Hemisphere Resources Ltd) ASX announcements.

Koodaideri corridors

Koodaideri Iron Ore and Infrastructure Project EPA referral document and supporting information including fauna and vegetation surveys.

The data register is presented in Table A4.

Table A4: Data Register

Data Type	File Type	Date	Description	Reference	No. of Sites
Water Asset Ranking	excel	14/06/2013	Biodiversity Team's ranking of species, ecological significance, sensitive areas within Management Areas (i.e. Marillana Creek)	Supplied Information; BHPBIO	17
Wetlands & Stygofauna Sites	pdf	2001	Figure 4.2 p 24 in the Central Pilbara Groundwater Study by Johnson & Wright	Johnson, S. L. and Wright, A. H. 2001. Central Pilbara Groundwater Study, Water and Rivers Commission, Hydrogeological Record Series. Report HG 8. 102 p.	
Survey Sites	pdf	2012	Map showing sites surveyed for Stygofauna as part of the Pilbara Region Biological Survey	DEC; https://informationcentre.environment.wa.gov.au/our-environment/science-and-research/animal-conservation-research/invertebrates/stygofauna-of-the-pilbara.html?showall=&start=5	
Rainfall Gauging	pdf	1/07/2013	Marillana Monthly Rainfall (mm); 1936 - 2013	Product code: IDCJAC0001 reference: 12815837 Created on Mon 01 Jul 2013 17:44:52 PM EST © Copyright Commonwealth of Australia 2013, Bureau of Meteorology. Prepared using Climate Data Online, Bureau of Meteorology http://www.bom.gov.au/climate/data	
SILO Climate	excel	1/10/2013	Daily temperature, rainfall, evaporation, humidity	Queensland Government Department of Science, Information Technology, Innovation and the Arts (DSITIA); http://www.longpaddock.qld.gov.au/silo/	3
Daily Rainfall (mm)	excel	min date: Jan 1969 max date: May 2013	Meteorological sites: 505004, 505011, 505014, 505020, 505035, 505040, 505041 [Various date ranges for each site]	WA Department of Water; received 16/07/2013	7
Stream Gauging (Daily Stage and Flow)	excel	min date: Aug 1967 max date: May 2013	Stream Gauging sites: Marillana Creek (Flat Rocks - 708001) and Weeli Wolli Creek (Waterloo Bore - 708013; Tarina - 708014; WW Springs - 708016) [Various date ranges for each site]	WA Department of Water; received 16/07/2013	4

Data Type	File Type	Date	Description	Reference	No. of Sites
Surface Water Quality	excel	min date: 1968 max date: 2008	WQ for all stream gauging sites includes: Al, Alkalinity, C (org), Ca, Cl, colour, conductivity, discharge rate, F, Fe, hardness, K, Mg, Mn, N, Na, NO3, P, pH, S, SiO2, SO4, Suspended solids, TDSalt, TDSolids, Temp, TSS, Turbidity	WA Department of Water; received 16/07/2013	4
Groundwater Bores and Quality	excel	min date: 1967 max date: 2008	Well coordinates, construction details, stratigraphy, lithology. Water quality includes: conductivity, pH, TDSolids, Temp	WA Department of Water; received 16/07/2013	751
Groundwater Levels	excel	min date: 1968 max date: 2008	Various measurement datums, some include surveyed datum, some water levels, some converted to elevation	WA Department of Water; received 16/07/2013	458
GIS	Shapefile	07-Jun-13; revised 20-Sep-13	Project, OSA, RPD and RRA boundaries; Memo: WAIO Disturbance Polygons for Approvals to support SEA	Supplied Information; BHPBIO	
GIS	Shapefile		Yandi mine pits	Supplied Information; BHPBIO	
GIS	Shapefile	2/11/2012	BHP All bores 2009 dxf; MGA50	Supplied Information; BHPBIO	~82
GIS	Shapefile	2/11/2012	BHP All bores 2010 dxf; MGA50	Supplied Information; BHPBIO	~36
GIS	File Geodatabase Feature Class		Existing Installations		
GIS	File Geodatabase Feature Class		Proposed Installations		
GIS	Shapefile		Topography; Pilbara, WA		
GIS	Shapefile	5/03/2013	Tenements, WA (All Companies)	WA Department of Mines and Petroleum	
GIS	Shapefile		Groundwater and Surface water Information	WA Department of Water	
GIS	Shapefile		Hydrographic subcatchments	WA Department of Water	
GIS	Shapefile		Hydrographic basins	WA Department of Water	
GIS	Shapefile		Surface water allocation subareas	WA Department of Water	
GIS	Shapefile	Apr-07	Pre-European Vegetation	WA Department of Agriculture	
GIS	Shapefile		Towns, Highways	WA Gov	
GIS	Shapefile	Apr-09	Streets	WA Gov	

Data Type	File Type	Date	Description	Reference	No. of Sites
GIS	Shapefile		Railways	WA Gov	
GIS	Shapefile	Apr-09	Parks	WA Gov	
GIS	File Geodatabase Feature Class		DIVA Surface Water Creeks	WA Gov	
GIS	Shapefile		WA Creeks	WA Gov	
GIS	Shapefile	Apr-09	WA Surface Water Areas	WA Gov	
GIS	Raster Catalog		Pilbara Index Map	WA Gov	
GIS	Raster Catalog		WA Geology (250K)	WA Gov	
GIS	Shapefile	2012	Munjina Clay Pan	Supplied Information; BHPBIO	
GIS	Layer file	17/07/2013	Critical Biodiversity Assets - Pilbara – which are areas protected by legislation (National Parks, TEC's, threatened fauna, and declared rare flora)	Supplied Information; BHPBIO	
GIS	Layer file	17/07/2013	DEC Threatened and Priority Ecological Community Buffers – the Fortescue Marshes and Weeli Wolli buffer zones are partly located in the Marillana catchment model boundary	Supplied Information; BHPBIO	
GIS	Layer file	17/07/2013	DEC_2015_PL_Exclusion_areas – tenure proposed to be included in the conservation reserve in 2015 when the pastoral leases lapse	Supplied Information; BHPBIO	
GIS	Layer file	17/07/2013	High Biodiversity Assets - Pilbara – includes priority flora and fauna records, mulga, significant rivers, important wetlands, and the Munjina Claypan	Supplied Information; BHPBIO	
GIS	Layer file	17/07/2013	Important Wetlands - Pilbara – nearby/adjacent areas include Karijini and Fortescue Marshes	Supplied Information; BHPBIO	
GIS	Layer file	17/07/2013	Regional Biological Survey Data – this provides the boundaries of all known biological surveys undertaken, along with a link to the associated survey report on 1Doc/Webtop.	Supplied Information; BHPBIO	
GIS	Layer file	17/07/2013	Significant Communities – TEC's, PEC's and Environmentally Sensitive Areas (mulga, groundwater dependent vegetation)	Supplied Information; BHPBIO	

Data Type	File Type	Date	Description	Reference	No. of Sites
Geology Map	pdf	1996	Roy Hill Geological Survey of Western Australia	THORNE, A. M., and TYLER, I. M., 1997, Roy Hill, W.A., Sheet SF 50Ý-12 (2nd edition): Western Australia Geological Survey, 1:250,000 Geological Series	
Geology Map	pdf	1990	Newman Geological Survey of Western Australia	1990, Newman, W.A., Sheet SF 50-16 (2nd edition): Western Australia Geological Survey, 1:250,000 Geological Series	
Geology Cross-Sections	pdf	13/11/2002	Marillana formation long-section down palaeochannel; includes stratigraphic column	Supplied Information; BHPBIO	
Geology Cross-Sections	pdf	19/08/2004	Schematic Cross-section through channel iron deposit; includes stratigraphic column	Supplied Information; BHPBIO	
Geology Cross-Sections	pdf		Schematic Cross-section through Dignum Gorge NNW (Fortescue River Catchment), Marillana Creek Catchment, and Tandanya SSE (Coondewanna Catchment).	Supplied Information; Received from Una Roberts (BHPBIO) 28/06/2013	
GIS	Raster Catalog		Australia Topography (250K)	Geoscience Australia	
GIS	Shapefile		Map Grid (250K)	Geoscience Australia	
GIS	Shapefile		National Map Grid	WA Gov	
GIS			International UTM zones	ESRI	
GIS	Raster		Aerial Imagery	Bing Maps	
GIS	Shapefile	10/07/2013	Fortescue Marsh SEA Project Boundary	Supplied Information; BHPBIO	
GIS	Shapefile	10/07/2013	Central Pilbara SEA Project Boundary	Supplied Information; BHPBIO	
GIS	Shapefile	23/08/2013	Eastern Pilbara SEA Project Boundary	Supplied Information; BHPBIO	
GIS	Shapefile	17/09/2013	Marillana Creek and Weeli Wolli Creek CID boundary	Supplied Information; BHPBIO	
Map	pdf	10/07/2013	Central Pilbara Hub Study Area and Sub Areas	RPS-Aquaterra; Supplied Information - BHPBIO	
Map	pdf	11/2011	Canopy condition of riparian woodland along Marillana Creek	Supplied Information; BHPBIO	

Data Type	File Type	Date	Description	Reference	No. of Sites
Map	pdf	11/2011	Relationship between alluvial and CID aquifers and the location of Melaleuca argentea trees and regeneration along Marillana Creek	Supplied Information; BHPBIO	
Map	pdf	22/04/2013	Marillana Creek Riparian Vegetation Management Zones; dead Melaleuca trees	Supplied Information; BHPBIO (18/07/2013)	
Map	pdf		Yandicoogina modelled water impact figures (2014 - 2028), predicted groundwater drawdown.	Rio Tinto	
Map	pdf	05/2012	Interim Biogeographic Regionalisation for Australia, Version 7. IBRA regions represent a landscape based approach to classifying the land surface, including attributes of climate, geomorphology, landform, lithology, and characteristic flora and fauna. Specialist ecological knowledge combined with appropriate regional and continental scale biophysical data sets were interpreted to describe these regions.	Department of Sustainability, Environment, Water, Population, and Communities	
Map	pdf	05/2012	Subregions	Department of Sustainability, Environment, Water, Population, and Communities	
Map	pdf	04/2012	Terrestrial Ecoregions in Australia	Department of Sustainability, Environment, Water, Population, and Communities	
Map	pdf	04/2012	National Reserve System IBRA region protection level	Department of Sustainability, Environment, Water, Population, and Communities	
Map	pdf	04/2012	National Reserve System IBRA subregion protection level	Department of Sustainability, Environment, Water, Population, and Communities	
Map	pdf	04/2012	Location of reserves in the National Reserve System	Department of Sustainability, Environment, Water, Population, and Communities	

Data Type	File Type	Date	Description	Reference	No. of Sites
Map	pdf	04/2012	National Reserve System IBRA regions with less than 10% protection	Department of Sustainability, Environment, Water, Population, and Communities	
CAD	dxf	11/07/2013	Munjina Life of Mine pits, dumps, roads	Supplied Information; BHPBIO	
GoCAD	MPEG-2 TS Video	12/07/2013	Marillana Catchment 3D Model: faults, Basement, box canyon, Brockman, Jeerinah, Marra Mamba, Poonda. Marillana surfaces: Sylvia, Wittenoom, Weeli Wolli. The base map used for the regional model is the GSWA 500k geology, the projection is GDA 1994 MGA zone 50.	Supplied Information; BHPBIO	
GoCAD	pdf				
Yandi Discharge Volumes (Creek)	excel	July '97 to Dec '08	Downstream discharge volumes from the central discharge point and eastern discharge point	Supplied Information; BHPBIO	2
Yandi Discharge Volumes (pits)	excel	Oct '07 to Jun '13	E6 and C1 Discharge volumes	Supplied Information; BHPBIO	2
Yandi Historical Data	excel	Various dates	Regional monthly water levels ('91 to '00); Monthly water quality testing (E2, C5, C1); Monthly flow volumes (C1, E2); Creek water quality ('00)	Supplied Information; BHPBIO	
Yandi Chemistry Analysis	Database	1995 - 2012	Water quality data for bores, wells, pumping wells, sumps, discharge outlets. Includes pH, Ca, EC, K, Mg, CO_3, Na, Cl, HCO_3, SO_4. There are two tables one with selected analyses and the second with all chemical analyses.	Supplied Information; BHPBIO	91 (338 records)
Yandi Abstraction	excel	1995 - 2003	Mine usage	Supplied Information; BHPBIO	
Yandi Discharge	excel	2003 - 2004	Mine discharge	Supplied Information; BHPBIO	
Yandi Bore Maps	pdf	2012	Bores piezometers and active areas for each pit (C1, C5, E1, E2, E3, E5/E6, W1, W4)	Supplied Information; BHPBIO	8
Yandi Bore Maps	pdf	2011	Bores piezometers and active areas for each pit (C1, C5, E1, E2, E3, E5/E6, W1, W4, W5)	Supplied Information; BHPBIO	9
Marillana Creek Logs	pdf and excel		Marillana Creek Logs in pdf format; GIS locations in excel format	Supplied Information; BHPBIO	22
Yandi Bore Logs	pdf, tiff, jpeg, excel		Borehole logs for existing installations	Supplied Information; BHPBIO	151

Data Type	File Type	Date	Description	Reference	No. of Sites
Yandi Bores	excel	2012	Yandi compiled borehole list	Supplied Information; BHPBIO	218 piezometers; 178 production wells; 116 monitoring wells; 45 borehole logs
Yandi Pumping Data	excel		2010 and 2011 pumping data; HYD YAN 2010213 RPRT Yandi Monthly Water Data.xlsx; HYD YAN 20110101 DTB Yandi Well Production All May 2012.xlsm	Supplied Information; BHPBIO	
Yandi Water Level Monitoring	excel		1995, 1996, 2010-2012 Water Levels	Supplied Information; BHPBIO	
Yandi Well Locations	excel	7/08/2012	MGA50 and Yandi94 coordinates	Supplied Information; BHPBIO	149
Grid Conversion	excel	15/09/2007	Conversion of MGA94 to Yandi Mine Grid	Supplied Information; BHPBIO	
Grid Conversion	excel	21/09/2007	Conversion of Yandi Mine Grid to MGA94	Supplied Information; BHPBIO	
Presentation	ppt	2/09/2013	Fortescue Marsh SEA project model	Supplied Information; BHPBIO	

References

Discrete geological and mine planning data packages provided by BHP Billiton Iron Ore (Commercial in Confidence).

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