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Strategy, Development & Planning

SEA Hydrology

Ecohydrological Change Assessment

Statement of limitations

This report 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 (Cth) 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 in this report 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 report.

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Glossary

Term	Definition
Backfill	The placement of overburden that had been stored ex-pit back into the pit.
Conceptualisation	A descriptive representation of a system, which consolidates the current understanding of key system elements and interactions between these elements. The system is depicted in the simplest possible way, whilst retaining sufficient detail to adequately assess the influence of stresses and understand the effect of possible future changes.
Connectivity	A qualitative measure of connection between and within ecological and hydrological regimes.
Derived Proposal	Future proposal, identified in the strategic proposal, to be referred to and considered by the EPA.
Ecohydrology	The study of interactions and relationships between surface water, groundwater and ecosystems.
Ecohydrological conceptualisation	A conceptualisation of relationships between surface water, groundwater and ecosystem elements in a defined landscape setting.
Ecohydrological unit	A landscape element with broadly consistent and distinctive ecohydrological attributes.
Ecohydrological study area (study area)	The spatial extent of ecological and hydrological interactions / influences relevant to all proposed mine developments within the Strategic Proposal.
Ecohydrological change	Significant and sustained change to an ecosystem associated with modified groundwater and surface water regimes.
Ecohydrological change potential	A qualitative measure of the potential for hydrological change to cause a negative effect on ecological values.
Ecological asset	A type of environmental asset defined by key environmental, biodiversity and/or ecological values.
Ecohydrological receptor	Ecological asset with hydrological dependency and high sensitivity to groundwater or surface water change.
Environmental Asset	A specific component of the biophysical environment which supports one or more environmental and/or social values. Examples include the Karijini National Park and Fortescue Marsh.
Hydrological change	Modification(s) to the groundwater regime (e.g. drawdown) and/or surface water regime (e.g. loss of catchment) that change the timing, magnitude, duration and/or relative importance of water inputs, outputs and storage within a defined area.
Infill	The in-pit placement of overburden as per normal business practices.
Landscape	A spatially heterogeneous area of land, scaled relative to the process of interest. Within landscapes it is usually possible to define a series of different ecosystems, landforms, habitats and natural or man-made features.
Managed aquifer recharge	The purposeful recharge of water to aquifers for subsequent recovery or environmental benefit (Dillon *et al*, 2009).
Mining area	A group of existing or proposed deposits, mines and orebodies within BHP Billiton Iron Ore tenure located within a unified operational area.
Normal business management practices	The normal execution of operations within BHP Billiton Iron Ore.
Predictive modelling	Predictive modelling is a process whereby a numerical computer model is developed for the purpose of predicting system hydrological responses to a change in hydrological conditions.
Region	A collection of landscapes, typically including multiple ecological assets and mining areas, that is defined by surface water catchment divides and a set of

Term	Definition
	unified management considerations.
Regional scale	At the scale of the region (refer to definition for ‘region’).
Regional Management Strategy	A strategy-level document that defines the standardised, business-wide approach to management of the key EPA Factors. The RMS identifies regional management objectives, guiding principles, adaptive management approach and business management toolbox to avoid, mitigate or offset significant impacts.
Sensitivity	A qualitative measure of the sensitivity of a landscape element or ecological asset to hydrological change
Strategic Proposal	The proposal for future mine infrastructure developments within a region including all mines, OSAs and railway corridor
Surplus water	A volume of water that is excess to requirements for mine usage and/or ore processing, and therefore requires appropriate disposal
Threatening processes	Processes with the potential to cause ecohydrological changes that negatively affect the values of ecological assets.
Tier 1 ecological asset	Ecological assets that are directly protected under Federal or State legislation, or otherwise recognised as having specific conservation significance under a formal international ranking system. They contain species that are known to be under threat being listed under IUCN Red-list categories and/ or the 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 (e.g. Declared Rare Flora).
Tier 2 ecological asset	Ecological assets that have a formal level of protection for conservation purposes or foreseeable level of future protection. They include Environmental Sensitive Areas (ESAs), State-listed Threatened and Priority Ecological Communities, wetlands listed in the Directory of Important Wetlands in Australia, and the Department of Parks and Wildlife (DPaW) proposed 2015 pastoral lease excision areas. This tier may contain species that are listed under international conventions (e.g. JAMBA, CAMBA), as Marine or Migratory under the EPBC Act, in Schedule 3 of the WC Act or as a priority species, and IUCN Category V and VI depending on the values and objectives of the specific reserve.
Tier 3 ecological asset	Ecological assets that have no formal level of protection for conservation purposes or foreseeable level of future protection. The tier may contain native species subject to the WC Act, but without any special protections (e.g. as schedule listed species) or other traits that may confer elevated conservation significance (e.g. range outliers, novel and/or undescribed species).
Unmitigated	In the absence of management controls
Value	Any particular benefit of use of the environment that is important for a healthy ecosystem or for public benefit. Values are not quantifiable and cannot be directly monitored, measured or assessed.

Abbreviations

Term	Definition
AMD	Acid and Metalliferous Drainage
AMP	Asset Management Plans
AWT	Above the water table
BIF	Banded-iron formations
BOM	Bureau of Meteorology
BRK	Brockman
BWT	Below the water table
CAMBA	China-Australia Migratory Bird Agreement
CID	Channel iron deposit
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Department of Environment and Conservation
DEM	Digital elevation model
DET	Detritals
DoW	Department of Water
DPaW	Department of Parks and Wildlife
DRF	Declared rare flora
EHU	Ecohydrological unit
EMP	Environmental Management Plan
EPA	Environmental Protection Authority of Western Australia
EP Act	*Environmental Protection Act 1986 (WA)*
EPBC	Environment Protection and Biodiversity Conservation
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cmth)
ESA	Environmental Sensitive Area
FMG	Fortescue Metals Group
GDE	Groundwater-dependent ecosystems
GIS	Geographic Information Systems
HPPL	Hancock Prospecting Pty Ltd
IBRA	Interim Biogeographic Regionalisation for Australia
IUCN	International Union for Conservation of Nature
JAMBA	Japan-Australia Migratory Bird Agreement
Lidar	Light and radar
LoA	Life of Assets
m bgl	Metres below ground level
MAC	Mining Area C
MAR	Managed aquifer recharge – referring to the injection, infiltration or return of water into the aquifer

Term	Definition
MM	Marra Mamba
MRL	Mineral Resources Limited
NDVI	Normalised Difference Vegetation Index
OSA	Overburden storage area
PAF	Potential acid forming
PBS	Pilbara Biodiversity Study
PEC	Priority ecological community
RMS	Regional Management Strategy
RTIO	Rio Tinto Iron Ore
SEA	Strategic Environmental Assessment
SRE	Short Range Endemic species
TD	Tertiary Detritals
TDS	Total dissolved solids
TEC	Threatened ecological community
WC Act	*Wildlife Conservation Act 1950* (WA)
WW	Weeli Wolli Formation

Executive Summary

BHP Billiton Iron Ore is undertaking a regional strategic environmental assessment (SEA) for its Strategic Proposal, which comprises construction and operation of a number of new operational iron ore mining areas, expansion of existing operational iron ore mining areas, and capacity upgrades to the main Newman to Port Hedland rail line and associated spur lines to existing and proposed mining areas. The SEA provides a regional-scale appreciation of how mining proposals within the Strategic Proposal, individually or in combination with other BHP Billiton Iron Ore and third-party projects, may affect the environment.

This report describes the potential hydrological change (both surface water and groundwater) associated with the Strategic Proposal. The basis of the change assessment is an ecohydrological conceptualisation of Pilbara landscapes, which characterises the landscape hydrological regime with a focus on understanding the connectivity between water resources and major ecosystem components. This has provided a framework for evaluating the potential effects of hydrological change at a regional scale and for selected environmental receptors, through consideration of key threatening processes associated with current and proposed mining operations for BHP Billiton Iron Ore and third parties. The assessment informs BHP Billiton Iron Ore's SEA process, with particular relevance to the key environmental factors of hydrological processes and inland water environmental quality.

Study area

The study area included all areas potentially subject to hydrological influence by the proposed mine, overburden storage areas (OSAs) and infrastructure footprints within the Strategic Proposal. Given the large scale and complexity of the study area, it was segregated into four regions defined on the basis major catchment boundaries including:

- Eastern Pilbara - current operations around Newman and towards Jimblebar. Proposed mining areas under the Strategic Proposal include Homestead, Eastern Ridge, Whaleback, Shovelanna, Wheelarra (and Jimblebar), Caramulla, Ophthalmia, and Prairie Downs and the proposed third party operations include Davidson Creek to be operated by Atlas Iron;
- Central Pilbara - current operations at Mining Area C and mines at Hope Downs 1, Hope Downs 4 and West Angelas operated by Rio Tinto's Iron Ore business (RTIO). Proposed mining areas under the Strategic Proposal include Jinidi, South Flank, Mudlark, Mudlark Well and Tandanya;
- Marillana Creek - current operations at Yandi and as well as the RTIO operation at Yandicoogina. Proposed mining areas under the Strategic Proposal include Munjina, Upper Marillana and Tandanya as well as the proposed RTIO Yandicoogina expansion and additional third-party operations;
- Fortescue Marsh - current mines at Cloudbreak and Christmas Creek operated by Fortescue Metals Group (FMG). Proposed mining areas under the Strategic Proposal include Marillana, Mindy, Coondiner and Roy Hill and additional proposed third-party operations at Roy Hill to be operated by Hancock Prospecting (HPPL), Koodaideri (RTIO), Nyidingu and Mindy Mindy (FMG), and Marillana (Brockman Resources).

Objectives

The change assessment included the following objectives:

- Provide an understanding of the prevailing hydrological regime (surface and groundwater, and considering hydrological variability), including relationships with ecosystem components and processes;
- Identify and classify ecological assets with consideration of their ecohydrological functioning and connectivity with surface water and groundwater systems. Ecological assets with a high level of hydrological dependency and connectivity are considered to be 'ecohydrological receptors';

- Understand the influence of current and proposed mining projects on hydrological conditions, including hydraulic connectivity with the regional groundwater system and the potential for reductions in surface water flow.
- Evaluate the potential for ecohydrological change associated with proposed mining development in the study area. This includes consideration of BHP Billiton Iron Ore and third-party mining projects, where information is available, in order to gain an appreciation of potential cumulative impacts;
- Describe the management approach for addressing potential change at ecohydrological receptors within the context of the BHP Billiton Iron Ore's Water Regional Management Strategy (RMS); and
- Present the Ethel Gorge ecohydrological case study as an example of a quantitative evaluation of changes in groundwater conditions under proposed mining scenarios in the vicinity of the Ethel Gorge Threatened Ecological Community (TEC).

Assessment approach

The change assessment methodology was developed assess ecohydrological change at a regional scale. It consists of three broad elements depicted in Figure ES1 and summarised as follows:

- conceptualisation and characterisation of landscape ecohydrological elements and processes, ecological assets and generic mine types.
- Identification of ecological assets and water resources that may be sensitive to hydrological change,
- Identification of key threatening processes contributing to ecohydrological change potential, and
- Consideration of management approaches addressing ecohydrological change potential within the context of BHP Billiton Iron Ore's adaptive management framework (Water and Closure RMS').

For the purpose of the assessment, hydrological change refers to modifications to surface water and groundwater regimes caused by the activities of BHP Billiton Iron Ore and third parties. Ecohydrological change refers to material change1 in ecosystem structure, function and/or biodiversity resulting from hydrological change. 'Ecohydrological change potential' is a precautionary measure of the potential for hydrological change to cause material environmental change in the absence of targeted management.

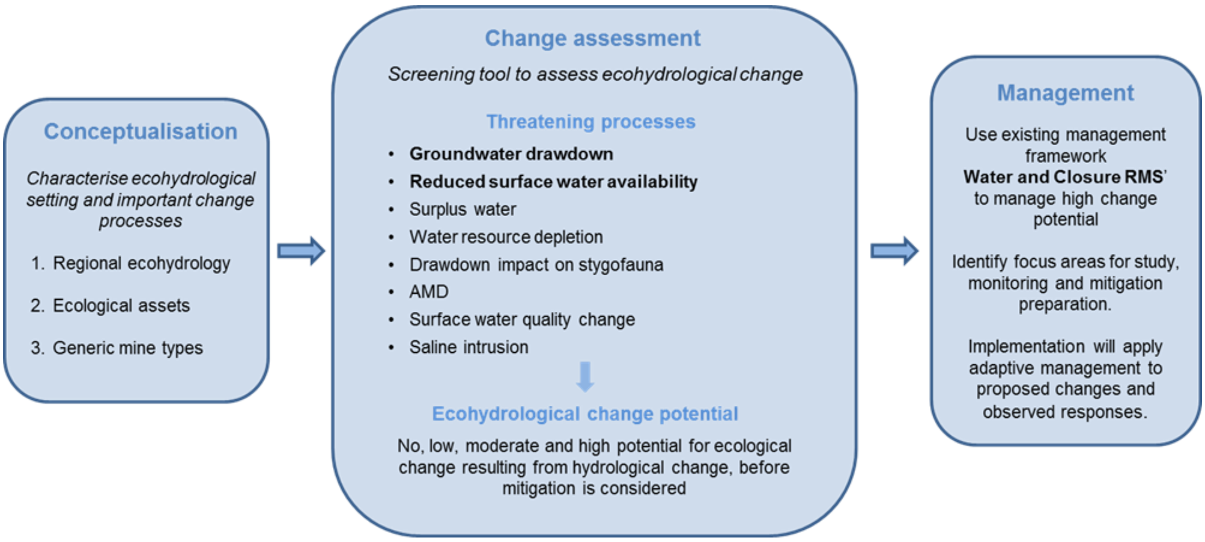

Figure ES1 Stepwise methodology used in the ecohydrological change assessment

[1] Material change is considered to include persistent, measurable change over annual or longer timescales.

Ecohydrological conceptualisation

The landscape water regime influences the nature and distribution of ecosystems in the inland Pilbara Region. The ecohydrological conceptualisation provides a regional-scale appreciation of landscape elements with similar ecological characteristics and water-related processes. It underpins the identification of landscape elements with higher susceptibility to changes in the water regime, and key ecohydrological processes relevant to particular ecological assets.

The inland Pilbara Region experiences a semi-arid climate with infrequent but intense rainfall events associated with tropical cyclones and rain depressions. This rainfall produces short-duration, high-energy streamflow within networks of ephemeral creeks, which is rapidly concentrated into major drainages and low-lying areas. Floodwaters that accumulate in drainage termini are mainly lost to evapotranspiration, associated with storage and release processes, but may also contribute to groundwater recharge in certain situations. In a few places, groundwater interacts with surface ecosystems and flows into ephemeral drainage lines; this occurs primarily in riparian settings.

A regional groundwater system comprising Tertiary detritals and underlying Wittenoom Formation dolomite is bound within low-permeability lithologies. The host rocks have been subject to various geological processes including folding, faulting and doleritic intrusions; all of which may influence groundwater system connectivity. Regional aquifers are associated with Tertiary-infilled palaeochannels and karstic dolomite units that forms part of the Wittenoom Formation. Localised aquifers occur in zones of higher permeability associated with orebody mineralisation , which can be hydrogeologically isolated or variably connected to the regional groundwater system. The level of connection has an important influence on mine dewatering requirements and the magnitude of groundwater drawdown at environmental receptors. Under certain geological conditions, these groundwater systems can support diverse stygofauna communities, particularly where the depth to groundwater is shallow.

With consideration of the above processes, nine landscape-ecohydrological units (EHUs) defined as ‘landscape elements with broadly consistent and distinctive ecohydrological attributes’ were described and their distributions mapped across the study area. These include:

- EHU 1 - Upland source areas: hills, mountains, plateaux.
- EHU 2 - Upland source areas: dissected slopes and plains.
- EHU 3 - Upland transitional areas: drainage floors within EHUs 1 and 2 that accumulate surface flows from up-gradient.
- EHU 4 - Upland channel zones: channel systems of higher-order streams that are typically flanked by EHU 3 and dissect EHUs 1 and 2.
- EHU 5 - Lowland sand plains: level to gently-undulating surfaces with occasional linear dunes. Erratic drainage patterns but some tracts receive surface water flow from upland units.
- EHU 6 - Lowland alluvial plains: typically of low relief and featuring low-energy, dissipative drainage.
- EHU 7 - Lowland calcrete plains: generally bordering major drainage tracts and termini, typically with shallow soils and frequent calcrete exposures.
- EHU 8 - Lowland major channel systems and associated floodplains.
- EHU 9 - Lowland receiving areas: drainage termini in the form of ephemeral lakes, claypans and flats.

Upland source areas associated with EHUs 1 and 2 have similar ecohydrological regimes based on topographic position and drainage patterns. EHUs 3 and 4 receive surface water contribution from EHUs 1 and 2 before transmitting down-gradient into lowland areas. Three types of lowland plains have been recognised (EHUs 5, 6 and 7), which are distinguished on the basis of different geomorphology, vegetation and soil types. EHU 8 includes major drainage systems that receive, store and transmit large volumes of surface water. EHU 9 is associated with terminal areas in the drainage network, where water is accumulated, lost to evapotranspiration and/or contributes recharge into groundwater systems.

Information contributing to the development of the EHUs included Pilbara land-systems mapping (van Vreeswyk et al., 2004), a high-resolution, digital-elevation model (DEM), interpretation of connectivity between surface and groundwater systems, major vegetation types based on consolidated vegetation mapping within BHP Billiton Iron Ore’s tenements (Onshore Environmental, 2014), and inferred water use behaviour of major vegetation types based on Landsat Normalised Difference Vegetation Index (NDVI) data.

Ecological assets and ecohydrological receptors

Thirteen regionally significant ecological assets with recognised conservation values were identified in the study area, which were classified as Tier 1 (directly protected under Federal or State legislation) or Tier 2 (formal level of protection for conservation purposes or foreseeable level of future protection) based on the legislative framework in place for their protection.

The only Tier 1 asset proximal to the study area is Karijini National Park. Most of the national park is situated outside the study area and will be largely unaffected by potential ecohydrological change associated with the Strategic Proposal. A small portion of the national park located in the Ashburton River Catchment has the potential to be influenced by dewatering activities in the Mudlark mining area. This drawdown is unlikely to influence the upland landscape and associated receptors owing to geological structural complexity, hydrogeological discontinuity, topographic differences and separation distance.

Five (Tier 2) ecological assets within in the study area are identified to have strong ecohydrological connectivity with the regional hydrological regime and high ecohydrological sensitivity. These assets constitute ecohydrological receptors. Ecohydrological conceptualisations have been developed for each receptor to inform receptor level change assessment, summarised as follows:

Ecohydrological receptor	Ecohydrological description
Coondewanna Flats	The Coondewanna Flats (EHU 6) is a receiving area for surface water runoff from surrounding catchments. Floodwaters accumulate on the flats, replenishing soil moisture in the deep unsaturated profile and contributing to groundwater recharge. The watertable lies at 20 to 30 m bgl within an unconfined calcrete aquifer that is overlain by unsaturated Tertiary detritals. Coondewanna Flats support regionally unusual *Eucalyptus victrix* woodland communities with two being classified as PECs. The ecological water requirements of these woodlands are considered to be met by surface water; however, a precautionary approach has been adopted as further studies are required to fully demonstrate and confirm any groundwater dependency
Ethel Gorge environs, including the Ethel Gorge Aquifer Stygobiont Community TEC	Ethel Gorge is a zone of confluence of surface water and groundwater flows from the headwaters of the Upper Fortescue River catchment. The Ethel Gorge groundwater system occurs in detrital sediments bound by low-permeability basement rocks. The shallow unconfined aquifer is variably disconnected from a deeper aquifer by an extensive low-permeability clay aquitard. The shallow alluvial and calcrete aquifers of Ethel Gorge support a unique and diverse stygofauna assemblage, classified as the Ethel Gorge Aquifer Stygobiont Community TEC. The area also supports riparian woodland communities with potential groundwater dependence. Ophthalmia Dam has a strong influence on the hydraulic response of the shallow unconfined aquifer. Since the early 1980s, the dam and associated managed aquifer recharge (MAR) has resulted in increased groundwater recharge and hydraulic loading to this aquifer. There has been mine dewatering associated with the nearby Eastern Ridge operations since 2006, but drawdown has been localised and offset by recharge from the Opthalmia Dam and the recharge ponds...
Fortescue Marsh	Fortescue Marsh is an extensive drainage terminus feature (EHU 9) occupying approximately 1,000 km^2, which receives surface water inflows from the Upper Fortescue River catchment. The water regime and water balance is dominated by episodic surface water inflows, with the majority of inflows contributed by the Fortescue River and to a lesser extent Weeli Wolli Creek. Numerous smaller drainages from surrounding catchments also flow directly into the Marsh. Groundwater discharge is minimal and likely to be spatially restricted.

Ecohydrological receptor	Ecohydrological description
	Over the past 20 years, increased inflow rates, associated unprecedented wet climate phase, has resulted in an increased frequency and areal extent of inundation, which affected the structure and functioning of the Marsh. The Marsh is an important regional conservation asset with multiple ecological values.
Weeli Wolli Spring	Weeli Wolli Spring occurs in a zone of confluence of surface water and groundwater flows from the headwaters of the Upper Weeli Wolli Creek catchment. The groundwater system comprises an unconfined aquifer sequence including calcrete and detritals. Groundwater is shallow at less than 10 m bgl and becomes shallower towards the spring. As the aquifer thins and narrows towards Weeli Wolli Spring, groundwater flow is concentrated and discharged over near-surface basement as baseflow. Weeli Wolli Spring supports permanent and persistent pools and riparian woodland communities with a groundwater dependency. The groundwater system supports a diverse stygofauna assemblage. These values collectively contribute to the Weeli Wolli Spring's PEC conservation status. Weeli Wolli Spring is currently impacted by the Hope Downs mining area (third-party operated). The operators of the Hope Downs mine have implemented measures to artificially maintain the water regime in accordance with Ministerial Conditions. Elements of the Weeli Wolli Spring PEC also occur at Ben's Oasis, located about 20 km further upstream and south of Weeli Wolli Spring. At this location, the vegetation is concentrated along a relatively narrow creek channel adjacent to some surface water pools. There is very little documented information about the geology, hydrology and ecology of this area.
Freshwater Claypans of the Fortescue Valley	Five claypans in the Lower Fortescue River Valley (EHU 9) are classified as the Freshwater Claypans of the Fortescue Valley PEC. The three easternmost claypans are proximal to BHP Billiton Iron Ore's Roy Hill mining area included in the Strategic Proposal. There is very little documented information about the geology, hydrology and ecology of this area. Claypan water regimes are dominated by episodic surface water inflows from surrounding catchments. Interaction with the groundwater regime is poorly understood, but is likely to be minimal or negligible. Ecological values include unusual vegetation types and diverse aquatic invertebrate assemblages.

Four additional (Tier 2) ecological assets associated with Priority Ecological Communities are considered to have low ecohydrological sensitivity and rely on direct or locally redistributed rainfall to support their unique vegetation communities. These include:

- Wona Land System communities (also located outside the study area);
- Brockman Iron clay communities (also located outside the study area);
- West Angelas cracking clay communities; and
- Fortescue Valley sand dune communities.

These assets are considered to have low potential to experience ecohydrological change associated with the Strategic Proposal.

Ecohydrological change assessment

The change assessment outlines the potential for the Strategic Proposal to influence the hydrological regime of landscapes and ecohydrological receptors for three scenarios:

- **Baseline:** Current disturbance scenario based on actual production rates (as at September 2014)
- **30% Development Scenario:** Development scenario based on the production rate associated with approximately 30% of BHP Billiton Iron Ores future identified projects being in concurrent operation; and
- **Full Development Scenario:** Development scenario based on the production rate associated with full development of BHP Billiton Iron Ores future identified projects and these projects being in concurrent operation.

The influence of third-party mining operations was also considered, providing an indication of baseline and cumulative change potential. It was assumed that third-parties would comply with existing Ministerial Conditions.

Ecohydrological change potential has been evaluated as a function of hydrological change and the sensitivity of EHUs to hydrological change, using a combination of conceptual, analytical and GIS-based spatial analysis approaches. Separate assessments were undertaken for the following threatening processes that have potential to influence surface water and groundwater regimes:

- Groundwater drawdown - the groundwater drawdown footprint was defined to include areas where groundwater levels are predicted to decline by greater than 1 m relative to the ‘no disturbance’ baseline. The significance of potential change was evaluated as a function of EHU type sensitivity, depth to groundwater and groundwater salinity being classified as either none, low, moderate or high;
- Reduction in surface water availability - evaluated in terms of catchment area reduction determined through a GIS-spatial analysis and EHU type sensitivity being classified as either none, insignificant, low, moderate or high;
- The ability to manage surplus water above operational needs - indicative water balances were developed for each of the BHP Billiton Iron Ore mining areas within the Strategic Proposal to determine areas with a water deficit (water negative) or surplus water (water positive) over the development timeframe;
- Acidic and metalliferous drainage (AMD) - a risk-based assessment methodology was used to characterise potential AMD sources, based on the magnitude of disturbance, release potential of disturbed rock types, and leachability of constituents;
- Saline intrusion impact on groundwater quality - the potential for interaction between mine dewatering operations and the position of the saltwater interface within the Fortescue River Valley; and
- The ability to manage pit lakes - evaluated in terms of overburden availability related to the need for backfilling and an appreciation of their regional distribution.

More detailed evaluation of ecohydrological change potential was also undertaken for each of the ecohydrological receptors in the study area, taking into consideration the resolved ecohydrological conceptualisations.

The major findings of the change assessment are summarised in Table ES1. Note that the change assessment reflects an unmitigated scenario assuming the implementation of existing normal business water management practices.

Management considerations

Under BHP Billiton Iron Ore’s adaptive management framework, the overall management approach for key ecohydrological receptors includes the following components:

- Knowledge improvement actions:
    - Validate and refine receptor ecohydrological conceptualisations, Note that that the baseline scenario used in the change assessment represent a wet phase, therefore regional declines in groundwater levels and reduced surface water flows are possible if the climate trajectory returns to a dry phase,

  - Inform the selection and design of management approaches addressing relevant threatening processes,
  - Reduce management uncertainty, and
  - Contribute to the development and implementation of outcome-based management thresholds;
- Preventative control options – designed to separate receptors from potentially threatening processes as per outcomes-based objectives for the receptor; and
- Mitigating control options – designed to mitigate or counteract potentially threatening processes as per outcomes-based objectives for the receptor.

Based on the receptor level ecohydrological conceptualisations and aggregate findings of the change assessment[2], a set of key management considerations have been identified with respect to each threatening process. These are described in Table ES1.

[2] i.e. aggregate findings for the 30% and full development scenarios taking into account BHP Billiton Iron Ore and third party influences.

Table ES1 Summary of change assessment findings and management for ecohydrological receptors in the study area

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential			Management considerations		
			Drawdown	Surface water availability	Other	Normal business practices	Targeted management (RMS')	Knowledge improvement
Coondewanna Flats	2014	Cumulative	None	Negligible	Excess dewatering from MAC mining area.	**Environmental monitoring:** • Groundwater levels beneath Coondewanna Flats, between the stressor and receptor (i.e. the pathway) and the down-gradient groundwater system, with a focus on its responsiveness to flooding events (i.e. the recharge regime); • Surface water inflows into Coondewanna Flats; and • Vegetation health of the Coondewanna Flats PECs. **Surface water:** • Diversion and flow dynamics in major drainages that contribute inflows to Lake Robinson and the broader Coondewanna Flats. **AMD:** • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	**Water RMS:** • Outcome-based objectives for Coondewanna Flats. • Management triggers and thresholds for Coondewanna Flats. • Groundwater levels and surplus water - surplus water from the MAC mining area may be returned to the groundwater system where practicable and appropriate. The use of MAR may minimise the spatial extent of groundwater drawdown. **Closure RMS:** • Outcome-based closure objectives for Coondewanna Flats. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms.	**Targeted ecohydrological studies:** • Validation and refinement of the current ecohydrological conceptualisation for Coondewanna Flats; including the contribution of groundwater to vegetation water use. • Quantitative analysis of flooding, soil moisture replenishment and recharge. • Ecosystem responses to modified hydrological regimes (i.e. flood duration, flood timing and inter-flood periods). • Validation of potential land surface modifications/catchment reduction on the hydrological regime at Coondewanna Flats. **Targeted surplus studies:** • Improved accuracy of mining area level water balance forecasts. • Trials of surplus water management options including MAR. **Targeted closure studies:** • Optimal surface water management designs in closure landforms.
	30% development	BHP Billiton Iron Ore Only	**Moderate** Small area of drawdown from MAC mining area reaches northern extent of receptor.	**Moderate** Aggregate catchment reduction from MAC, Parallel Ridge, South Flank and Mudlark mining areas.	n/a			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
	Full development	BHP Billiton Iron Ore Only	**Moderate** Drawdown from MAC, South Flank and Mudlark mining areas.	**High** Aggregate catchment reduction from MAC, Parallel Ridge, South Flank, Mudlark and Tandanya mining areas.	n/a The Tandanya mining area has a moderate AMD potential.			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
Ethel Gorge	2014	**Cumulative**	**Moderate**, but change potential offset by infiltration from Ophthalmia Dam. Consequently the residual change is **Low.**	None Minor (<5%) catchment reduction from Eastern Ridge mining area.	Slight increase in salt loads due to excess dewatering discharged in Ophthalmia Dam, but salinity likely to remain within historical ranges – refer to Ethel Gorge Case Study. Whaleback mine has high AMD source potential with AMD from OSAs being currently managed via collection and treatment.	**Environmental monitoring:** • Groundwater levels at Ethel Gorge; • Groundwater quality at Ethel Gorge and in Ophthalmia Dam; and • The stygofauna assemblage at Ethel Gorge. **Groundwater and surface water:** • Maintenance of natural surface water flow into Ethel Gorge and further downstream within the Upper Fortescue River. Flows in Fortescue River are captured by Ophthalmia Dam during low flow events and provide recharge into the Ethel Gorge groundwater system. • Ophthalmia Dam and other existing MAR facilities provide for bulk and targeted replenishment of groundwater to minimise impacts in and near Ethel Gorge. **AMD:** • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	**Water RMS:** • Surplus water - Under the current Ophthalmia Dam Scheme, water availability is matched to operational needs where possible, and opportunities actively sought for optimising water balances within mining areas and preferentially between mining areas. • Surplus water may be returned to the groundwater system where practicable and appropriate. The most likely surplus water management approach will be MAR via discharge into Ophthalmia Dam. The use of MAR minimises the spatial extent of groundwater drawdown, thereby contributing to the preservation of stygofauna habitat. • Borefield abstraction - Abstraction from the Ophthalmia borefield may potentially be used to control the groundwater level and groundwater quality. Abstraction serves to balance the aquifer where necessary. • Targeted creek discharge - Discharge into creek lines may be used to supplement natural surface water flow within a threshold range. **Closure RMS:** • Outcome-based closure objectives for Ethel Gorge. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects.	**Targeted ecohydrological studies:** • Validation and refinement of the current ecohydrological conceptualisation for Ethel Gorge; including the contribution of groundwater to vegetation water use and level of dependence of the vegetation of groundwater. • Quantitative analysis of recharge processes at Ethel Gorge, including consideration of the influence of Ophthalmia Dam and MAR on water levels and water quality (in terms of salt loads). • Ecosystem responses to modified hydrological regimes (i.e. groundwater salinity changes). • Validation of potential land surface modifications/catchment reduction on the hydrological regime at Ethel Gorge. **Targeted surplus studies:** • Improved accuracy of mining area level water balance forecasts. • Trials of surplus water management options including MAR and surface discharge to riparian areas. Ensure multiple options are available proportional to capacity uncertainty. • Assessment of the receiving capacity of the hydrogeological system. **Targeted closure studies:** • Optimal groundwater and surface water management designs in closure landforms.
	30% development	BHP Billiton Iron Ore Only	**High** at OB37, but change potential is offset by infiltration from Ophthalmia Dam. Consequently the residual change is **Low** – refer to Ethel Gorge Case Study	**Moderate** Catchment reduction associated with Eastern Ridge and Shovelanna mining areas.	Increase in salt loads due to discharge of excess dewatering in Ophthalmia Dam from various operations – refer to Ethel Gorge Case Study. Whaleback mine has high AMD source potential with AMD from OSAs being currently managed via collection and treatment.			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
	Full development	BHP Billiton Iron Ore Only	**High** at OB37, but change potential is offset by infiltration from Ophthalmia Dam. Modelling indicate residual change is **Low** – refer to Ethel Gorge Case Study	**High** Catchment reduction from Eastern Ridge, Shovelanna, Homestead, and East Ophthalmia mining areas.	Increase in salt loads due to discharge of excess dewatering in Ophthalmia Dam from various operations. Whaleback has high AMD source potential will likely form a groundwater sink after closure with no connection to Ethel Gorge.			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential			Management considerations		
			Drawdown	Surface water availability	Other	Normal business practices	Targeted management (RMS')	Knowledge improvement
Fortescue Marsh	2014	Cumulative	None Drawdown change potential from FMG's Christmas Creek and Cloudbreak operations managed by MAR.	None Low change potential restricted to local drainages north of the Marsh due to reduced catchment from FMG mining areas.	Excess dewatering from FMG's Christmas Creek and Cloudbreak mining areas is managed by MAR. The excess dewatering volumes include both fresh and hypersaline water.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	**Targeted ecohydrological studies:** • Validating, amending and improving the current ecohydrological conceptualisation of Fortescue Marsh. • Review the findings of ecohydrological studies undertaken by third parties (where available). • Implement studies targeting any knowledge gaps (as required). Seek to collaborate with third parties where opportunities for mutual benefit are identified.
	30% development	BHP Billiton Iron Ore Only	None Only AWT mining at Marillana.	None Moderate to high change potential in local drainages only, owing to reduced catchment from Marillana mining area.	None			
		Third party only	None Drawdown change potential from FMG's Christmas Creek and Cloudbreak operations managed by MAR.	None Low to moderate change potential in local drainages in the Marsh area owing to reduced catchment from third-party mining areas.	Excess dewatering (saline and fresh) from FMG's Christmas Creek and Cloudbreak mining areas managed by MAR. Other third-party operations (Brockman Resources' Marillana, FMG's Nyidinghu and Mindy Mindy, and HPPL's Roy Hill) are assumed to be conditioned to have no change potential on Fortescue Marsh from disposal of excess dewatering water.			
		Cumulative	None	None	Assumed to be conditioned to have no change potential on Fortescue Marsh from disposal of excess dewatering water.			
	Full development	BHP Billiton Iron Ore Only	**High** - within a small portion of southern fringe of Marsh related to Marillana mining area. **None** – remainder of Marsh	None. Moderate to high change potential in local drainages and a portion of Weeli Wolli Creek due to reduced catchment at Marillana mining area.	Excess dewatering water from Marillana, Mindy and Coondiner mining areas will require management to have no change potential on Fortescue Marsh. AMD potential (pit lakes and OSAs) is generally low but could be **high** if BHP Billiton Iron Ore targets deeper ore reserves at the Mindy mining area.	**Environmental monitoring:** • Prior to mine development in the vicinity of Fortescue Marsh, review and consider the groundwater and surface water monitoring data collected by the existing mine operators (where and if available). Based on this review, target multi-level monitoring networks and data will be developed to address any knowledge gaps. **Surface water:** • Diversion and flow dynamics in major drainages that contribute inflows to Fortescue Marsh. **AMD:** • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	**Water RMS:** • Surplus water management - Water availability to be matched with operational needs where possible, and opportunities actively sought for optimising water balances within mining areas and potentially between mining areas. • Management and mitigation of potential saline water ingress associated with orebody dewatering using options such as MAR. **Closure RMS:** • Outcome-based closure objectives for Fortescue Marsh. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects. Mitigating controls will be developed as required to address threatening processes.	**Targeted ecohydrological studies:** • Validating, amending and improving the current ecohydrological conceptualisation of Fortescue Marsh. • Review the findings of ecohydrological studies undertaken by third parties (where available). • Implement studies targeting any knowledge gaps (as required). Seek to collaborate with third parties where opportunities for mutual benefit are identified. **Targeted surplus studies:** • Improved accuracy of water balance forecasting. • Local to sub-regional trialling of surplus water management approaches to help understand hydrological controls and determine practicable mitigation options. **Targeted closure studies:** • Optimal groundwater and surface water management designs in closure landforms.
		Third party only	None	None Moderate to high change potential in local drainages and a portion of Weeli Wolli Creek due to reduced catchment at Brockman Resource's Marillana mining area.	Third-party operations (Brockman Resources' Marillana, FMG's Nyidinghu and Mindy Mindy, and HPPL's Roy Hill) are assumed to be conditioned to have no change potential on Fortescue Marsh from disposal of excess dewatering water.			
		Cumulative	**High** - within a small portion of southern fringe of Marsh related to Marillana mining area.None – remainder of Marsh	**Moderate** Cumulative reduction in catchment area >5% from multiple mining areas.	Excess dewatering water from BHP Billiton Iron Ore and third-party operations will require management to have no change potential on Fortescue Marsh. AMD potential is generally low but may increase if deeper ore reserves are targeted.			
Freshwater claypans of the Fortescue Valley	2014	Cumulative	None	None	None	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	**Targeted ecohydrological studies:** • Validating, amending and improving the current ecohydrological conceptualisation of the Freshwater Claypans of the Fortescue Valley. • Implement studies targeting any knowledge gaps (as required).
	30% development	BHP Billiton Iron Ore Only	None	None	None			
		Third party only	None	None	None			
		Cumulative	None	None	None			
	Full development	BHP Billiton Iron Ore Only	None	None Low to moderate change potentially confined to localised drainages in the vicinity of the Roy Hill mining area.	Potential for surplus water from BHP Billiton Iron Ore's Roy Hill mining area. It is possible that a proportion of excess dewatering water may be saline.	**Environmental monitoring:** • Groundwater levels at the Roy Hill mining area. • The need for other monitoring parameters to be determined. **Surface water:** • Diversion and flow dynamics in major drainages that contribute inflows to Fortescue Marsh.	**Water RMS:** • Surplus water management - Water availability to be matched with operational needs where possible • Management and mitigation of potential saline water ingress associated with orebody dewatering using options such as MAR.	**Targeted ecohydrological studies:** • Validating, amending and improving the current ecohydrological conceptualisation of the Freshwater Claypans of the Fortescue Valley. • Implement studies targeting any knowledge gaps (as required).

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential			Management considerations		
			Drawdown	Surface water availability	Other	Normal business practices	Targeted management (RMS')	Knowledge improvement
Freshwater claypans of the Fortescue Valley	Full development	Third party only	None	None	None	**AMD:** • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard	**Closure RMS:** • Outcome-based closure objectives for Freshwater Claypans of the Fortescue Valley and the Fortescue Marsh. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects. Mitigating controls will be developed as required to address threatening processes.	**Targeted surplus studies:** • Improved accuracy of water balance forecasting. • Local to sub-regional trialling of surplus water management approaches to help understand hydrological controls and determine practicable mitigation options. **Targeted closure studies:** • Optimal surface water management designs in closure landforms.
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
Weeli Wolli Spring	2014	Cumulative	None Substantial drawdown in area of Spring due to RTIO's Hope Downs operation, but ecohydrological change at Spring is managed through irrigation.	None Flow at Weeli Wolli Spring is being maintained through irrigation by Hope Down's operator.	Substantial discharge of excess dewatering water in Weeli Wolli Creek from Hope Downs, but water quality is fresh.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under the baseline scenario.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under the baseline scenario.	**Targeted ecohydrological studies** • Validating, amending and improving the current ecohydrological conceptualisation of Weeli Wolli Spring. • Review the findings of ecohydrological studies undertaken by Rio Tinto's Iron Ore business at Hope Downs (where available).
	30% development	BHP Billiton Iron Ore Only	**Low** - small drawdown from MAC mining area towards spring; however, to be managed as **High** in recognition of spring sensitivity and analysis uncertainty	**Moderate** Reduction in catchment due to combined effect of deposit MAC (A and C Deposits) and Jinidi mining areas.	If both MAC and Jinidi are considered may be water negative requiring water supply (e.g. borefield); otherwise, slightly surplus.	**Environmental monitoring:** • Groundwater levels at Weeli Wolli Spring and surrounding groundwater systems; • Surface water flow regime at Weeli Wolli Spring and relationship with recharge dynamics; • Recharge dynamics in the upper catchment, and throughflow effects relevant to Weeli Wolli Spring. • Ecological health condition • Stygofauna assemblage at Weeli Wolli Spring. • Riparian vegetation community health at Weeli Wolli Spring. • Aquatic biota of the river pools associated with Weeli Wolli Spring. **Surface water:** • Diversion and flow dynamics in major drainages that contribute inflows to Weeli Wolli Spring. • Surplus water management - Water availability to be matched with operational needs where possible, and opportunities actively sought for optimising water balances within mining areas and potentially between mining areas. There are a range of options available with some trials current underway at the MAC mining area. **AMD:** • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	**Water RMS:** • Appropriate interfacing with management program being implemented by RTIO, in consultation with RTIO • Surplus water - Surplus water may be returned to the groundwater system where practicable and appropriate. The use of MAR may minimise the spatial extent of groundwater drawdown. • Surface water diversion - Augmentation of natural surface water flow into Weeli Wolli Spring via targeted drainages, if required. • Vegetation health - Augmentation of soil moisture via irrigation, if required. **Closure RMS:** • Outcome-based closure objectives for Weeli Wolli Spring. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects.	**Targeted ecohydrological studies** • Validating, amending and improving the current ecohydrological conceptualisation of Weeli Wolli Spring. • Quantitative analysis of surface water and groundwater interactions at Weeli Wolli Spring. • Ecosystem responses to modified groundwater levels and groundwater throughflow regime. • Contribution of groundwater to vegetation water use at Weeli Wolli Spring. • Characterisation of the effect of land surface modifications within the catchment on the hydrological regime at Weeli Wolli Spring. **Targeted surplus studies:** • Improved accuracy of water balance forecasting. • Local-scale trialling of additional surplus water management options considering the proposed activities and influence of third parties. **Targeted closure studies:** • Ongoing mineral waste characterisation during pre-development phases. • Source – pathway – receptor analysis for deposits with AMD source risk. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning.
		Third party only	**Moderate** Hope Downs closed by 2024, and residual drawdown dependent on closure strategy.	**Low** OSAs rehabilitated and pit backfilled.	RTIO's Hope Downs operation will be closed. Change potential depends on post-closure water level response.			
		Cumulative	**Moderate** Hope Downs closed by 2024, and residual drawdown dependent on closure strategy.	**Moderate** Combined catchment reduction from Hope Downs, MAC and Jinidi mining areas.	Change potential depends on the closure strategy of RTIO's Hope Downs operation.			
	Full development	BHP Billiton Iron Ore Only	**Low to moderate** - encroaching drawdown from MAC and Jinidi mining areas towards spring; however, proposed to be managed as **High** in accordance with a precautionary approach.	**High** Reduction in catchment due to combined effect of MAC (A and C Deposits) and Jinidi mining areas.	For most of the period, operations are water negative, which require water supply (e.g. borefield) with potential change potential on groundwater resource. There will be periods of dewatering surplus. OB 13 and 16 in Jinidi mining area has moderate potential for AMD.			
		Third party only	**High** Depends on closure outcomes from Hope Downs.	**Low** Assuming Hope Downs OSAs rehabilitated and pit backfilled.	Change potential at Weeli Wolli Spring will be dependent on the closure outcomes from Hope Downs.			
		Cumulative	**High** Depends on closure outcomes from BHP Billiton Iron Ore operations and Hope Downs.	**High** Cumulative reduction in catchment from BHP Billiton and third-party operations.	Aggregate change potential from BHP Billiton Iron Ore Operations and depends on closure outcomes from Hope Downs.			

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential			Management considerations		
			Drawdown	Surface water availability	Other	Normal business practices	Targeted management (RMS')	Knowledge improvement
Karijini National Park	2014	Cumulative	None	None Minor (<5%) catchment reduction due to West Angelas mining area	RTIOs West Angelas mining area is licenced to discharge surplus water into local creek system. Existing borefield provides groundwater supply with potential change on groundwater resource.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	Validation of postulated hydrological linkages and discontinuities between the Mudlark mining area and Karijini National Park (refer to Section 7.1).
	30% development	BHP Billiton Iron Ore Only	None	None	Water negative operations at Mudlark mining area that may require groundwater supply resulting in potential change on groundwater resource.			
		Third party only	None	**Low** (Turee Creek East) - Catchment reduction due to RTIO West Angelas mining area.	RTIOs West Angelas mining area is licenced to discharge surplus water into local creek system. Borefield provides groundwater supply with potential change on groundwater resource.			
		Cumulative	None	**Low** – as above	Combined effect of groundwater supply bores on groundwater resource.			
	Full development	BHP Billiton Iron Ore Only	**Low to moderate** Drawdown associated with Alligator South mine may extend to the national park; however the likelihood is low owing to hydrogeological complexity, geological structure, topographic differences and separation distance (Section 7.1.3). Further validation is necessary to confirm ecohydrological change potential.	**Low** Catchment reduction due to Alligator South mining area.	Mainly water negative operations which require potential groundwater supply with potential change on groundwater resource. Occasional water surplus which require management.	**Environmental monitoring:** • The need for groundwater, surface water and other monitoring parameters to be determined. **AMD:** • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	**Water RMS:** • Surplus water management - Water availability to be matched with operational needs where possible. • Surplus water to be managed in order to maintain the hydrological regime of Karijini National Park within a threshold range. **Closure RMS:** • Outcome-based closure objectives for Karijini National Park. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning.	**Targeted ecohydrological studies** • Validating, amending and improving the current ecohydrological conceptualisation of Karijini National Park.
		Third party only	None	**Low** (Turee Creek East)- Catchment reduction due to RTIO West Angelas mining area	West Angelas mining area is closed.			
		Cumulative	**Low to moderate** As above	**Low** Catchment reduction due to Alligator South and West Angelas mining area	Aggregate change potential depends on BHP Billiton Iron Ore groundwater supply option and closure strategy.			

[1] Change potential due to BHP Billiton activities is before mitigation is considered. Change potential due to third-party operations is after mitigating measures are applied (consistent with publicly-available information)

Part I - Introduction

BHP Billiton Iron Ore is undertaking a regional strategic environmental assessment (SEA) for the Strategic Proposal, which comprises construction and operation of a number of new operational iron ore hubs, expansion of existing operational iron ore hubs, and capacity upgrades to the main Newman to Port Hedland rail line and associated spur lines to existing and proposed hubs. This report describes the potential hydrological change (both surface water and groundwater) associated with the cumulative mining operations and discusses the implications of this change on environmental assets at a regional scale, focussing in particular on the key environmental factors of Hydrological Processes and Inland Waters Environmental Quality.

The basis of the change assessment is an ecohydrological conceptualisation of Pilbara landscapes, which characterises the landscape hydrological regime with a focus on understanding the connectivity between water resources and major ecosystem components. This has provided a framework for evaluating the potential effects of hydrological change at a regional scale and for selected environmental receptors, through consideration of key threatening processes associated with current and proposed mining operations for BHP Billiton Iron Ore and third parties. The change assessment has been undertaken within the context of the Water Regional Management Strategy that BHP Billiton Iron Ore will use to minimise its ecohydrological footprint.

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1. Background

BHP Billiton Iron Ore is undertaking a regional strategic environmental assessment (SEA) for the Strategic Proposal, which addresses selected future mining activities and associated infrastructure developments. The SEA provides a regional-scale assessment of the potential change associated with mining proposals within the Strategic Proposal, individually or in combination, on the environment.

The Strategic Proposal comprises construction and operation of a number of new operational iron ore hubs, expansion of existing operational iron ore hubs, and capacity upgrades to the main Newman to Port Hedland rail line and associated spur lines to existing and proposed hubs. The extent of the Strategic Proposal is limited, with specific exclusions including the existing BHP Billiton Iron Ore operations and infrastructure, future development of BHP Billiton Iron Ore northern Pilbara operations at Yarrie and Goldsworthy and associated infrastructure; and development and operations at Port Hedland, including rail to the 26 kilometre chainage mark.

The SEA ecohydrological change assessment provides a regional scale appreciation of the potential impacts of the Strategic Proposal on regional water regimes and ecological assets, thereby enabling the significance of potential impacts to be evaluated. In addition to developing a present day baseline (2014), change assessment scenarios have been developed for the following development scenarios:

- **30% Development Scenario:** Development scenario based on the production rate associated with approximately 30% of BHP Billiton Iron Ores future identified projects being in concurrent operation; and

- **Full Development Scenario:** Development scenario based on the production rate associated with the full development of BHP Billiton Iron Ores future identified projects and these projects being in concurrent operation.

Hydrological Processes and Inland Waters Environmental Quality were recognised as key environmental factors during the scoping of the SEA (BHP Billiton Iron Ore, 2013). The scoping process identified a requirement for assessment methodologies to consider the influence of hydrological (groundwater and surface water) change on these factors; which collectively encompass aspects of water resources, ecosystems and ecological assets. Where hydrological change has the potential to cause environmental impacts, change will be managed in accordance with BHP Billiton Iron Ore's Water Regional Management Strategy (Water RMS) in addition to other normal business management controls currently implemented by the company.

2. Objectives

More than 40 years of water resource exploration, assessment and monitoring by BHP Billiton Iron Ore has contributed to a strong hydrological understanding of Pilbara landscapes. This has included an ongoing program of studies and investigations, and the collection of water resource data. In aggregate, this knowledge has provided important insights into surface and groundwater systems of the Pilbara, and supported the formulation of water management approaches in BHP Billiton Iron Ore's mining areas.

The hydrological component of this document provides an up-to-date understanding of surface water and groundwater resources across the catchments in which BHP Billiton Iron Ore currently operates and proposes to operate in the future. Key aspects include the identification of major hydrological processes within the different catchments; evaluation of hydraulic connectivity between key ecological assets and mining areas (existing and proposed); and an assessment of likely hydrological change within an outcome-based management framework that can be modified as new knowledge is acquired.

The ecohydrological conceptualisation (Part II) describes landscape-scale relationships between surface water, groundwater and ecosystems (referred to as ecohydrology). Key to this approach is the delineation of landscape elements with similar ecological characteristics and water-related processes. The conceptualisation provides a baseline understanding of ecohydrological conditions, under the prevailing landscape water regime, taking into account existing and approved mining projects and the hydroclimatic variability in the region. It extends across the entire area of hydrological influence, referred to as the ecohydrological study area (the study area; refer to Map 1), that may be influenced by the proposed mine and overburden storage areas (OSAs) footprints within the Strategic Proposal. This study excludes the Rocklea mining area, as it is located outside the study area in a different hydrological setting.

The ecohydrological change assessment (Part III) considers mechanisms by which regional-scale ecohydrological processes could be altered (referred to as threatening processes) by hydrological change, and potential impacts on key ecological assets associated with the Strategic Proposal.

For the purpose of the assessment, hydrological change refers to modifications to surface water and groundwater regimes caused by the activities of BHP Billiton Iron Ore and third parties. Ecohydrological change refers to material change[3] in ecosystem structure, function and/or biodiversity resulting from hydrological change. 'Ecohydrological change potential' has been adopted as a precautionary measure of the potential for hydrological change to cause material environmental change in the absence of targeted management.

The change assessment constitutes a regional appraisal for:

- identifying ecological assets and water resources that may be sensitive to hydrological change,
- identifying key threatening processes contributing to ecohydrological change potential, and
- considering management approaches addressing ecohydrological change potential within the context of BHP Billiton Iron Ore's adaptive management framework.

The assessment focusses on ecohydrological change potential with respect to the landscapes of the study area, specific ecohydrological receptors (refer to Section 6) and hydrological resources (quality and quantity).

The ways in which ecosystems may respond to hydrological change depends on connectivity between water movement pathways and ecosystem components; variability in water regimes; and ecosystem resistance and resilience[4]. The significance of ecohydrological change can be considered within the context of levels of acceptable change on overall ecosystem condition. The change assessment provides a basis for distinguishing between landscape elements with no, low, moderate and high ecohydrological change potential as a result of the Strategic Proposal. This approach also considers the potential for cumulative interaction with third-party projects.

[3] Material change is considered to include persistent, measurable change over annual or longer timescales.
[4] Resistance is the property of communities or populations to remain "essentially unchanged" when subject to disturbance (Levin, 2009). Resilience is the capacity of a system to absorb shocks and disturbances and retain the same level of fundamental functions (Mori *et al*., 2012)

Potentially threatening processes that may be associated with the Strategic Proposal, such as groundwater drawdown and reduced surface water availability, are characterised and used in the analysis of ecohydrological change.

Consistent with the preceding discussion, this report has been structured to address the following objectives:

- Provide an understanding of the prevailing hydrological regime (surface and groundwater, and considering hydrological variability), including relationships with ecosystem components and processes (Sections 5);
- Identify and classify ecological assets with consideration of their ecohydrological functioning and connectivity with surface water and groundwater systems. Ecological assets with a high level of hydrological dependency and connectivity are considered to be 'ecohydrological receptors'; (Sections 6 to 8)
- Understand the influence of current and proposed mining projects on hydrological conditions, including hydraulic connectivity with the regional groundwater system and the potential for reductions in surface water flow. (Sections 9 to 11)
- Evaluate the potential for ecohydrological change associated with proposed mining development in the study area. This includes consideration of BHP Billiton Iron Ore and third-party mining projects, where information is available, in order to gain an appreciation of potential cumulative impacts; (Sections 12 and 13)
- Describe the management approach for addressing potential change at ecohydrological receptors within the context of the BHP Billiton Iron Ore's Water RMS; (Sections 14 to 16) and
- Present the Ethel Gorge ecohydrological case study as an example of a quantitative evaluation of changes in groundwater conditions under proposed mining scenarios in the vicinity of the Ethel Gorge Threatened Ecological Community (TEC).(Section 17 and Appendix G)

3. Regional Management Strategies

3.1. Water Regional Management Strategy

The Water Regional Management Strategy (Water RMS) outlines an adaptive management approach for water-related aspects of BHP Billiton Iron Ore activities, and is applicable to all BHP Billiton Iron Ore operations (Figure 1). It provides a standard overarching framework for considering and addressing water resource challenges across BHP Billiton Iron Ore's wider business. It is adaptable to a wide range of strategic and operational water management scenarios.

The objective of water management within BHP Billiton Iron Ore is to proactively avoid and/or minimise environmental impact through implementing preventative controls on a regional scale, as part of 'business as usual' activities. The Water RMS supports sustainable water resource management by framing options for mitigating and/or minimising operational impacts on surface water and groundwater; and setting outcome-based conditions for managing water assets within catchment scale water management plans. This approach is consistent with the Department of Water's (DoW) guidance in the Western Australian Water in Mining Guideline (DoW, 2013), and reflects the water management hierarchy advocated in the guideline. In the context of the strategy, water assets are considered to include ecohydrological receptors.

Adaptive management within the Water RMS is staged, iterative and responsive to the specific water requirements of environmental receptors. Decision making is based on the development of baselines, assessment of hydrological changes (predicted and actual), prediction of impacts on receptors, monitoring of change, and evaluation of the outcomes of management actions where applied. Management approaches are progressively developed and refined, as informed by accumulated scientific knowledge and measured outcomes. The key elements of the approach are further articulated in Figure 2.

The Water RMS is underpinned by a risk-based approach that considers scientific uncertainty and outcome-based objectives. Early warning triggers and thresholds are selected to ensure that monitoring is targeted to relevant hydrological change processes and ecosystem responses, in order to mitigate and manage potential impacts on receptors. In the early stages of the process, these triggers and thresholds are typically conservative and precautionary reflecting incomplete scientific knowledge. As scientific understanding becomes more complete, often involving a transition from regional- or catchment-scale to site-specific interpretative investigations, the level of uncertainty reduces with management triggers and thresholds being iteratively refined.

The Water RMS provides the basis for a range of water management options that address hydrological changes and potential impacts to receptors during mining operations (Figure 3). These are grouped within six broad categories defined by water end-use including the return of operational water surpluses to the environment. A selection of practicable and feasible options provides flexibility in meeting multiple water management objectives across the business.

3.2. Other Regional Management Strategies

The Water RMS will be one of a number of BHP Billiton Iron Ore regional management strategies (RMS) that interface and collectively address the company's overall environmental management portfolio. Each RMS is regularly reviewed and updated in accordance with evolving business needs and objectives. Environmental factors addressed in other proposed RMS documents, such as biodiversity and closure, interface with specific aspects of the Water RMS.

The Closure and Rehabilitation RMS (Closure RMS) describes BHP Billiton Iron Ore's regional approach to environmental management of closure and rehabilitation activities at its Pilbara operations. The Closure RMS interfaces with aspects of the Water RMS through the consideration of hydrological change and potential impacts on receptors at the post mining stage of the production cycle. It outlines closure management tools (planning and physical measures) that recognise water management aspects including surface water drainage, acidic and metalliferous drainage (AMD) and mine void management (Figure 4). Each RMS guides aspects of operational environmental management at the project level. Within the SEA framework, as mining operations are considered for development and approval at the Derived Proposal stage the RMS' will be used to inform the development of Asset Management Plans (AMPs) where necessary. These plans will address local-scale management considerations and establish thresholds, triggers and outcome-based objectives for relevant environmental assets.

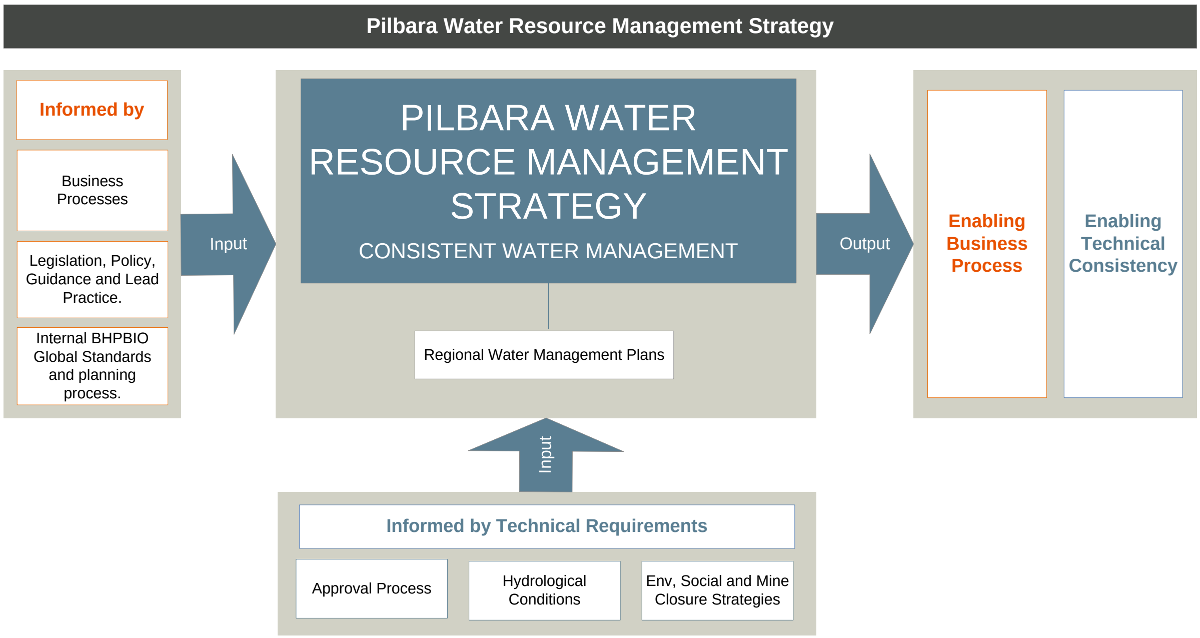

Figure 1 Water Resource Management Strategy

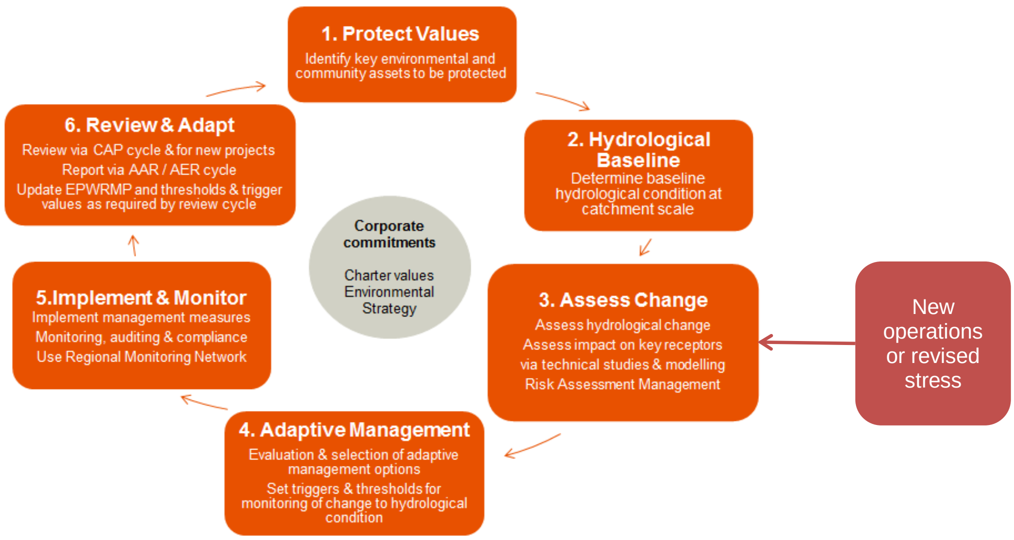

Figure 2 Adaptive management within the Water RMS

WATER RESOURCE	TRANSFER	STORAGE	TREATMENT	DISCHARGE	OTHER
Proactive Dewatering (all mines)	**Short term pipeline** (MAC, Yandi, JB)	**In-pit Storage** (MAC)	**Desalination** (nil)	**Managed Aquifer Recharge (MAR)** (MAC, JB)	**Agriculture** (nil)
Aquifer Abstraction (all mines)	**Long pipeline** (ER/WB & Yarrie)	**Tanks, Turkey Nests, Ponds** (all mines)	**Sediment Basins** (all sites)	**Infiltration Ponds** (ER, MAC)	**Community project** (Newman)
Surface Water Capture (nil)		**Managed Aquifer Recharge (MAR)** (MAC, JB)		**Evaporation Ponds** (WB)	**3rd Party Supply** (Newman)
Desalination (nil)		**Infiltration Dam and Ponds** (Ophthalmia area)		**Creek Discharge** (Yandi, JB)	
		Storage Dam (nil)		**In-pit Storage Short term** (MAC)	
				Irrigation of Trees (ER)	

Figure 3 Water management options in the Water RMS

Baseline Assessment	Impact Assessment	Controls	Monitoring	Consultation and Engagement
Groundwater and surface water studies	Surface water and groundwater modelling	Mine Closure Plan	Rehabilitation establishment assessment	Stakeholder engagement process
Resource block model	Landscape and visual impact assessment	Progressive rehabilitation	Rehabilitation development monitoring	Community consultative groups
Baseline soil survey	Cumulative impact assessment	Mine void management	Rehabilitation landform appraisal	
Geochemical waste characterisation	Social impact and opportunity assessment	OSA location and design	AMD monitoring	
Research and development	Climate change sensitivity assessment	Financial evaluation and provisioning	Surface water and groundwater monitoring	
	Resource sterilisation assessment	Growth media and seed management		
	AMD risk assessment	PAF and unstable material avoidance and management		
	Erosion potential modelling	Weed control		
	Ecohydrological conceptual model	Surface water drainage control		
		Infrastructure transfer or decommissioning		

Figure 4 Closure management options in the Closure and Rehabilitation RMS

4. Assessment Methodology

A multidisciplinary methodology was developed to assess the potential effects of hydrological change on Pilbara landscapes and individual ecological assets. The methodology included the conceptualisation of landscape ecohydrological elements and processes, and more detailed ecohydrological characterisation of ecological assets. Sensitivities to various change processes associated with the Strategic Proposal were evaluated and used to determine ecohydrological change potential, before and after the application of management.

This assessment aligns with the adaptive management iterative process, as outlined in Figure 2, with stages 1 (Protect Values) through to 4 (Adaptive Management) being considered at a landscape level. An overview of the adopted stepwise approach from conceptualisation through to the assessment of potential impacts including consideration of BHP Billiton Iron Ore's regional management strategies is provided in Figure 5.

The large scale and complexity of the study area, which includes an irregular distribution of existing and proposed BHP Billiton Iron Ore operations, was addressed by partitioning the area into four regions based on major catchment boundaries (Map 1). Proposed operations are described in more detail in Part III (Section 10). Key features of each region are outlined as follows:

- Eastern Pilbara - current operations around Newman and towards Jimblebar. The proposed mining areas include Homestead, Eastern Ridge, Whaleback, Shovelanna, Wheelarra (and Jimblebar), Caramulla, Ophthalmia, and Prairie Downs and the proposed third party operations include Davidson Creek to be operated by Atlas Iron;
- Central Pilbara - current operations at Mining Area C and mines at Hope Downs 1, Hope Downs 4 and West Angelas operated by Rio Tinto's Iron Ore business (RTIO). The proposed mining areas include Jinidi, South Flank, Mudlark, Mudlark Well and Tandanya;
- Marillana Creek - current operations at Yandi and as well as the RTIO operation at Yandicoogina. The proposed operations include Munjina, Upper Marillana and Tandanya as well as the proposed RTIO Yandicoogina expansion and additional third-party operations;
- Fortescue Marsh - current mines at Cloudbreak and Christmas Creek operated by Fortescue Metals Group (FMG). The proposed operations include Marillana, Mindy, Coondiner and Roy Hill and additional proposed third-party operations at Roy Hill to be operated by Hancock Prospecting (HPPL), Koodaideri (RTIO), Nyidingu and Mindy Mindy (FMG), and Marillana (Brockman Resources).

The study area also comprise a portion of the Fortescue Marsh catchment which does not form part of any region as there are no proposed mining operations in that area, but was included as part of the surface water change assessment (Section III).

Detailed reports providing an in-depth analysis of the hydrological and ecohydrological features of each region are provided in Appendices C, D, E and F. These reports provided an important knowledge base for the subsequent change assessment.

4.1. Knowledge status

BHP Billiton Iron Ore has been operating in the Pilbara for more than 40 years and has developed a strong hydrological understanding in the region. BHP Billiton has accumulated a wealth of hydrological data through water resource exploration, assessment and monitoring, and ongoing programs of studies and investigations associated with its mining projects.

In parallel, third party operations have also been operating in the Pilbara for several decades and accumulated substantial hydrological data used in technical studies in support of environmental approvals. These environmental referral documents are publically available and have contributed to the understanding of hydrological processes outside BHP Billiton Iron Ore's operations.

In addition, a considerable number of scientific studies have been carried out in the Pilbara by government agencies and research institutions including: geological surveys, biological surveys, land resource condition assessments, water resource assessments, climate change studies, and detailed ecophysiological behaviour of particular vegetation species. Collectively, these studies have strongly contributed to the current understanding of ecohydrological processes in the Pilbara.

Map 2 depicts the level of ecohydrological information available to inform the Strategic Proposal. Despite the significant collective knowledge base, there is a distinct lack of published regional scale hydrological studies in the Pilbara. Consequently, the resolution of ecohydrological knowledge over a substantial portion of the study area is relatively low as depicted in Map 2. Areas of relatively high knowledge status are generally associated with current and approved BHP Billiton Iron Ore and third party mining operations and specific studies carried out at some ecohydrological receptors (namely Ethel Gorge, Coondewanna Flats and Weeli Wolli Spring) discussed in more detail in Section II. Areas of moderate knowledge status generally include areas within the BHP Iron Ore leases which are currently being assessed for future development, and areas proximal to ecological assets such as the Fortescue Marsh.

As a component of the Ecohydrological Change Assessment, BHP Billiton Iron Ore developed a landscape scale ecohydrological conceptualisation of the study area, which is described in more detail below. This constitutes a synthesis of key elements of the aforementioned knowledge sources.

4.2. Conceptualisation

Ecohydrological conceptualisation provides a simplified representation of integrated hydrological and ecological systems, with consideration of the abiotic and biotic processes that control or influence the movement and/or storage of water and its fate within ecosystems. The intent is to understand and communicate ecohydrological functioning as simply as possible; whilst retaining sufficient detail and resolution to adequately represent key system elements and their interactions at a landscape scale.

The conceptualisation process involved literature reviews, data collation and interpretation by a multidisciplinary team with expertise in mine planning, geology, hydrology/hydrogeology, geomorphology, ecology, and Geographic Information Systems (GIS). Conceptual models of major landscape elements and processes were formulated based on the available data, augmented by consensus of professional experience and judgment.

Using land-system mapping by Van Vreeswyk et al. (2004) as a base layer, landscapes were differentiated in terms of topographic position, surface drainage patterns and processes, connectivity between surface and groundwater systems, major vegetation types and their (inferred) water use behaviour, and occurrence and type of wetlands. The conceptualisation provided a basis for formulating and testing hypotheses to determine the level, extent and/or sensitivity of landscapes and ecological assets to changes in the water regime. This analysis also provided a basis for considering change management options and approaches.

A summary description of the ecohydrological conceptualisation approach is provided in Part II of this document.

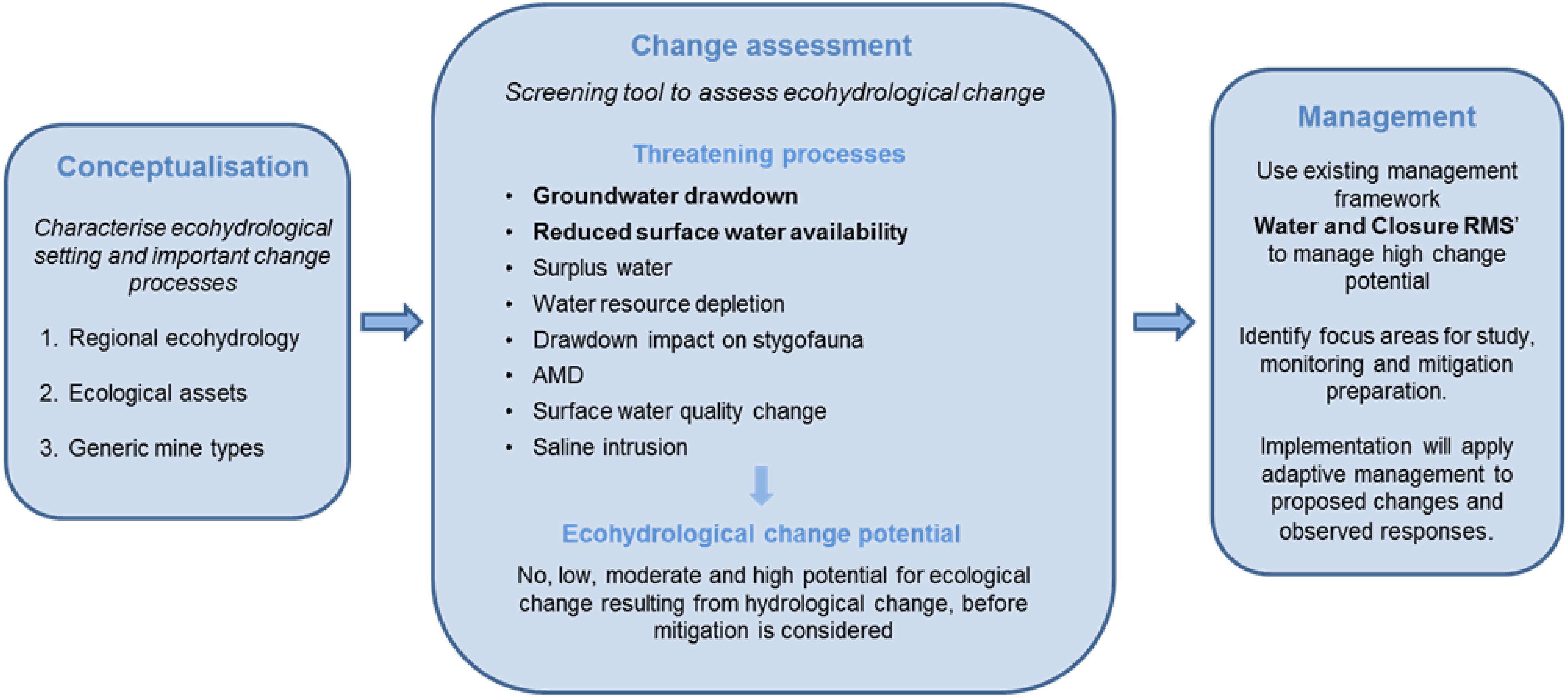

Figure 5 Stepwise methodology used in the ecohydrological change assessment

4.3. Change Assessment

The purpose of the ecohydrological change assessment was to provide a regional-scale understanding of potential modifications to surface water and groundwater regimes arising from mining developments across the study area, and the influence of these changes on landscape elements and ecological assets. The assessment included a baseline scenario (reflecting current conditions as at 2014), 30% development scenario and full development scenario including:

- Current and proposed BHP Billiton Iron Ore mining areas, and
- Current and proposed third-party mining areas. Where relevant information was publicly available, interpretations of groundwater drawdown have been considered and integrated into the cumulative assessment.

The change assessment considered existing BHP Billiton Iron Ore's operations subject to the following normal business management practices:

- Proactive strategic water management that aims to avoid and/or minimise environmental impact through implementing preventative controls, such as on-site use of dewatering water and returning a portion of surplus dewatering water to the aquifer to minimise drawdown effects, if required to meet management objectives, in accordance with BHP Billiton Iron Ore's water stewardship policy (BHP Billiton Iron Ore, 2014a);
- Surface water derived from up-gradient areas is diverted around mine pits and infrastructure;
- Proposed infrastructure corridors, such as railway and conveyor lines, are designed as to permit surface water flow and prevent inundation / accumulation on the upgradient side. For the purposes of the change assessment, linear infrastructure is considered to be designed and constructed to avoid significant impact on surface water regimes;
- Measures for the prevention and containment of sediment, hydrocarbons and other contaminants are implemented (i.e. water interception, detention and treatment structures/facilities);
- Mined potentially acid forming (PAF) materials stored within pits and ex-pit are managed to prevent release to the environment; and
- Placement of infill is considered as part of mine overburden schedule optimisation. Additional backfilling specifically to address post-closure management of impacts to ecological assets is assessed on a case by case basis (as outlined in the Closure and Rehabilitation RMS).

Under the future change assessment scenarios (30% development scenario and full development scenario) for the Strategic Proposal, it is assumed that all BHP Billiton Iron Ore operations are subject to these normal business management practices.

Additional approaches and assumptions inherent to the change assessment included:

- No consideration of groundwater recharge in estimating groundwater drawdown extents, contributing to a conservative estimate of drawdown;
- No consideration of post-dewatering recovery of groundwater levels, contributing to a conservative estimate of drawdown ;
- Where normal business overburden schedule optimisation does *not* lead to pits being infilled as, pits were assumed to remain open after closure
- Surface water incident on pits and infrastructure is permanently "lost" from the catchment water balance (including post-closure), contributing to a conservative estimate of surface water change;
- Third-party operations considered in the assessment include those that were approved or referred under the EP Act as at 30 September 2014;
- Existing third-party mine operators will meet their environmental commitments specified in the conditions of Ministerial Statements issued under the EP Act.
- Acidic and metalliferous drainage has been evaluated principally with respect to AMD source potential.

The following key threatening processes with potential for cause ecohydrological change, during operational and post-closure project stages respectively, have been considered:

Operations

- Groundwater drawdown
- Surface water availability - reduction
- Surplus water disposal
- AMD source potential
- Groundwater quality - saltwater intrusion
- Surface water quality - reduction

Post-mining / closure

- Groundwater drawdown
- Surface water availability - reduction
- AMD source potential
- Pit lake formation

These threatening processes are discussed in further detail in Part III. Note that the relevance and importance of each threatening process may vary throughout the life of any mining operation. Furthermore, the assessment also considered the depletion of the groundwater resource as a potential threat to existing and potential future groundwater users.

The potential for ecohydrological change resulting from each threatening processes has been considered at a regional-scale, either by spatial dataset analysis or a qualitative, expert assessment of the most likely scenario and/or outcomes. Spatial data analysis was undertaken for the key processes of groundwater drawdown and reduction in surface water availability. A summary of the methodology is provided as follows with further detail provided in Part III and more-comprehensive analysis for selected threatening processes in Appendix B.

4.3.1. Groundwater drawdown

The relevant processes considered in the groundwater drawdown change assessment included:

- Water level decline associated with mine dewatering and propagation of drawdown; and
- Reduction of stygofauna habitat caused by groundwater drawdown.

The potential for post-dewatering water level recovery was not determined in the change assessment. Water storage replenishment, short and long-term water level recovery, and footprint reduction is subject to considerable site level complexity and is therefore difficult to predict using regional scale datasets. For the purpose of the change assessment, this level of detail was not considered to be necessary where a suitably conservative methodology was adopted. It was also recognised that any drawdown estimation without comprehensive data has significant uncertainty. By assuming no water level recovery in aquifers associated with dewatering the magnitude and extent of groundwater drawdown for the 30% development scenario and full development scenario were overestimated; consistent with a precautionary approach.

4.3.2. Surface water availability

The reduction in surface water availability associated with the excavation of open-cut pits and development of overburden storage areas (OSAs) was evaluated with respect to the direct loss of catchment area at different points in the landscape. The potential for surface water change was evaluated based on existing and proposed mining project footprints.

Surface water management approaches used by BHP Billiton Iron Ore typically involve the use of water diversion and conveyance structures, which tend to result in the partial reinstatement of flow regimes. However, the potential for partial reinstatement of flow regimes in disturbance areas is subject to considerable site level complexity and is therefore difficult to predict using regional-scale datasets. For the purpose of the change assessment, this level of detail was not considered to be necessary where a suitably conservative methodology was adopted. By making conservative assumptions about the effect of catchment area reduction on runoff volumes, the magnitude and extent of reduced surface water availability for the 30% development scenario and full development scenario were overestimated; consistent with a precautionary approach.

4.4. Management Response

Over and above the application of normal business management practices, hydrological change associated with the Strategic Proposal will be managed in accordance with the BHP Billiton Iron Ore's Water and Closure RMS'. The RMS' provide an adaptive management framework for water management (refer to Section 3). The Water RMS also outlines a range of feasible and practicable water management options for addressing hydrological change at the local mine operation and catchment scale.

With respect to each identified threatening process, the change assessment provides a regional scale evaluation for the potential for altered surface water and groundwater regimes to cause ecohydrological change and at key ecohydrological receptors during the implementation of the Strategic Proposal. The following ecohydrological change potential categories have been adopted for the assessment:

- **Low change potential** – where the effect of hydrological change caused by mining activities on landscape elements or ecological assets is unlikely to be significant;
- **Moderate change potential** - where the effect of hydrological change caused by mining activities on landscape elements or ecological assets may be significant in the absence of BHP Billiton Iron Ore's normal business management practices, but is unlikely to be when those practices are employed; and
- **High change potential** - where the effect of hydrological change caused by mining activities on landscape elements or ecological receptors may require a more targeted management approach. Management options developed under the Water RMS may be required to avoid or minimise environmental impacts.

The change assessment is necessarily precautionary and takes into account knowledge limitations and uncertainties. It complements BHP Billiton Iron Ore's adaptive management approach, by helping to inform studies and investigations that will improve knowledge and refine the assessment findings prior to the Derived Proposal stage. This includes the validation of thresholds and trigger values for the management of ecohydrological receptors.

4.5. Case Study - Ethel Gorge

The Ethel Gorge ecohydrological case study provides a credible and practical example of BHP Billiton Iron Ore's adaptive management process, as outlined in the Water RMS. The case study includes:

- A quantitative evaluation of changes in groundwater conditions under proposed mining scenarios in the Ethel Gorge area,
- An assessment of the implications of these changes for ecohydrological receptors at Ethel Gorge, which include the Ethel Gorge aquifer stygobiont community[5] and riparian vegetation communities, and
- Appraisal of options under the Water RMS for managing potential environmental impacts associated with hydrological change. .

Numerical modelling was undertaken to provide a predictive assessment of changes in groundwater level and salinity for the Ethel Gorge aquifer relating to the key threatening processes of groundwater drawdown and discharging surplus dewatering water into Ophthalmia Dam. The model integrates the Strategic Proposal mining schedule to represent predicted change at the 30% development scenario and for post-mining conditions. The case study is summarised in Section 15 and fully described in Appendix G.

[5] Listed as a Threatened Ecological Community by the WA Minister for Environment.

Part II - Existing Environment

The study area experiences a semi-arid climate with infrequent but intense rainfall events associated with tropical cyclones and rain depressions. This rainfall produces short-duration, high-energy streamflow within networks of ephemeral creeks, which is rapidly concentrated into major drainages and drainage termini such as the Fortescue Marsh. Floodwaters replenish storage in the vadose zone underlying the drainage network, as well as bank storage on the fringes of drainages. The majority of this water is ultimately lost to evapotranspiration; however, some contributes to groundwater recharge in focus areas.

A regional groundwater flow system comprising Tertiary detritals and Wittenoom Formation dolomite is bound within low-permeability basement rocks. Localised aquifers also occur in zones of higher permeability associated with orebody mineralisation, geological structure, and preferential weathering. Hydraulic connectivity between orebodies and the regional groundwater system varies on a case by case basis, which strongly influences mine dewatering requirements and the magnitude of drawdown at ecohydrological receptors.

The climate and surface water regime greatly influences the nature and distribution of ecosystems across the landscape. Terrestrial ecosystems with a dependency on groundwater are uncommon and typically restricted to riparian habitats where groundwater is relatively shallow. Aquifers support subterranean ecosystems, which frequently include stygobiotic species with restricted distributions.

An ecohydrological conceptualisation has been developed that provides a regional-scale appreciation of landscape elements with similar ecological characteristics and water-related processes. This conceptualisation supports the assessment of landscape ecohydrological connectivity and the identification of landscape elements with higher susceptibility to change in the hydrological regime. It also provides an appreciation of key ecohydrological processes relevant to ecohydrological receptors.

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5. Setting

This section provides an overview of the ecohydrological setting for the study area. It summarises the ecohydrological conceptualisation studies completed for the four BHP Billiton Iron Ore mining regions within the Strategic Proposal (Appendices C to F respectively).

5.1. Climate

The climate is semi-arid characterised by high temperatures and low, irregular rainfall. It is influenced by atmospheric instability caused via the interaction of tropical maritime and continental air masses, which generates tropical cyclones and rain-bearing depressions in the summer months of December to March.

Mean maximum daily temperatures exceed 30°C with daytime temperatures often exceeding 42°C in summer months. Mean minimum daily temperatures may exceed 25°C during the summer months (December to February) and decline to less than 10°C in the winter months (June to August).

Rainfall is highly variable inter- and intra-annually as influenced by the frequency of tropical cyclones. Mean annual rainfall varies from 250 to 400 mm/year across the study area (Map 3); however, rainfall can be less than 100 mm to more than 1000 mm in any given year. Rainfall events tend to be of high-intensity and short-duration, resulting in surface water runoff and transient flooding of drainages that are interspersed with long dry periods.

A relatively wet climate phase has been experienced since the mid-1990s. Mean annual rainfall at Newman recorded between 1995 and 2013 was 466 mm, with a maximum rainfall of 803 mm in 1999 coinciding with Cyclone John, in contrast with the long-term mean annual rainfall of about 290 mm. This sustained period of higher rainfall has influenced the water regime, contributing to higher groundwater levels and more-frequent flooding of ephemeral drainages and wetlands.

There is some uncertainty in resolving regional climate owing to a limited number of climate stations, in particular along and within the Hamersley Range. It is possible that elevated catchment areas in the Central Pilbara region receive more rainfall, when compared with the more flat-lying Fortescue Marsh region.

Mean annual potential evaporation is greater than 3500 mm/year (BOM, 2014), which is an order of magnitude greater than annual rainfall resulting in a large moisture deficit in the environment. This has profound implications for surface water regimes, groundwater regimes and ecosystems. A large proportion of rainfall is lost to evaporation and soil moisture replenishment before reaching drainages. The majority of stored soil water is ultimately lost to evapotranspiration. Recharge to groundwater systems comprises only a small proportion of rainfall and occurs mainly as creek recharge during periods of streamflow following large rainfall events. Recharge tends to be focussed in stream zones with favourable hydrogeological / geomorphological attributes.

Future climate projections for the Pilbara developed by CSIRO (Charles et al, 2013) suggest that average rainfall will not vary by more than 5% under a median global greenhouse emissions scenario. The frequency of cyclones will either decrease or remain the same; however, cyclone intensity is likely to increase. Potential evaporation is expected to progressively increase from current levels, in the order of 3% by 2030 and 5% by 2050 in association with increasing temperature. In summary, the future climate is anticipated to feature an increased moisture deficit with higher evaporation rates and more irregular, higher intensity rainfall.

5.2. Topography

The topography is strongly influenced by the underlying geology. Outcropping and less weathered lithologies of the Hamersley Group form the Hamersley and Chichester Ranges, which are separated by the extensive sediment receiving areas of the Fortescue River Valley. Nominal elevations range between 400 and 700 m AHD with some peaks in excess of 1000 m AHD. The Hamersley Range forms an extensive mountainous area featuring ridgelines and peaks incised by steep-sided drainages. The Chichester Range is a more subdued feature with lower hills that are less incised. At the base of the ranges, the topography transitions into gently-undulating to flat valleys.

The Fortescue River Valley is bound by the Chichester Range to the north and Hamersley Range to the south. It includes broad areas of low relief and an extensive saline, endorheic wetland within the centre of the valley referred to as the Fortescue Marsh. The Fortescue River and Weeli Wolli Creek are regional drainage systems that emanate from the Hamersley Range, receive substantial sediment from elevated areas, and contribute substantial surface water into the Fortescue Marsh during flooding events.

5.3. Hydrology

5.3.1. Regional drainage

The study area is 32 000 km^2 and is almost entirely situated within the Upper Fortescue River Basin, which drains west towards the Indian Ocean and has a total catchment area of about 50 000 km^2. Goodiadarrie Hills, west of the Fortescue Marsh, effectively separates the Fortescue River into the Lower Fortescue River and Upper Fortescue River. The Fortescue Marsh is a closed system that forms the surface flow terminus of the Upper Fortescue River.

Most regional drainage is towards the Fortescue Marsh. There is a small portion of drainage (less than 2% of the study area) in the southwest associated with Turee Creek East Branch, which is an upper tributary of the Ashburton River. Goodiadarrie Swamp is a small, internally-draining sub-catchment of the Lower Fortescue that is immediately west of and hydraulically separated from the Fortescue Marsh.

The main catchment areas in the study area are shown in Map 4. The major catchment areas were based on the DoW hydrographic catchments and the boundaries modified based on high resolution Digital Elevation Model (DEM) data (5m DEM LIDAR captured by Fugro, August 2013). Sub-catchment boundaries were delineated based on the high resolution DEM data.

The Upper Fortescue River, Weeli Wolli Creek and Marillana Creek are major surface water drainages (Table 1). Marillana Creek drains into Weeli Wolli Creek and eventually towards the south-western portion of the Fortescue Marsh; whereas the Upper Fortescue River drains directly into eastern parts of the Fortescue Marsh. The combined catchment area for these drainages is 21 100 km^2, which is about 65% of the study area.

Table 1 Main surface water catchments in the study area

Catchment	Regional River System	Area (km^2)
	Eastern Pilbara	
Upper Fortescue River	Upper Fortescue River	9 688
Warrawanda Creek	Upper Fortescue River	1 265
Whaleback Creek	Upper Fortescue River	204
Shovelanna Creek	Upper Fortescue River	244
Homestead Creek	Upper Fortescue River	305
Fortescue	Upper Fortescue River	2 884
Jimblebar Creek	Upper Fortescue River	349
Caramulla Creek	Upper Fortescue River	727
Davidson Creek	Upper Fortescue River	649
Subtotal		*16 316*
	Central Pilbara	
Pebble Mouse Creek	Weeli Wolli Creek	1450
Coondewanna	Internal draining	856
Wannamunna	Internal draining	501
Turee Creek East Branch	Ashburton River	599
Sub total		*3 406*
	Marillana Creek	
Marillana Creek	Weeli Wolli Creek	2 228
Weeli Wolli Creek	Weeli Wolli Creek	313
Sub total		*2 541*
	Fortescue Marsh	
Fortescue Marsh (East and West)	Fortescue Marsh	980
Goodiaddarie Swamp	Lower Fortescue River	3 419
Coondiner Creek	Fortescue Marsh	2 720
Mindy Mindy	Fortescue Marsh	486
Chuckalong	Fortescue Marsh	433
Weeli Wolli Alluvium Fan	Weeli Wolli Creek	827
Koodaideri Creek	Fortescue Marsh	623
Kulkinbah Creek	Fortescue Marsh	674
Kulbee Creek	Fortescue Marsh	469
Goman/Sandy Creek	Fortescue Marsh	1 172
Christmas Creek	Fortescue Marsh	242
Roy Hill East	Fortescue Marsh	377
Roy Hill West	Lower Fortescue River	725
Subtotal		*13 148*
Total		***35 411***

Mindy Mindy and Coondiner Creeks are smaller drainages emanating in the Hamersley Range to the east of Weeli Wolli Creek that discharge into the Fortescue Marsh. The Chichester Range includes numerous smaller drainages that discharge into the northern margins of the Fortescue Marsh.

There are two internally-draining catchments associated with Coondewanna and Wannamunna Flats. Surface water in the Coondewanna Flats catchment is captured in an endorheic basin including the ephemeral Lake Robinson. This area is considered to be an important zone of groundwater recharge. Little is known about the hydrological functioning of Wannamunna Flats.

In the Upper Marillana Creek catchment, the Munjina Claypan is an important feature that attenuates flows in Marillana Creek. Little is known about the hydrological functioning of the Munjina Claypan.

5.3.2. Streamflow

Surface runoff is generated when the rate of rainfall exceeds the water holding and/or infiltration capacity of the creek bed. Runoff generation is strongly influenced by antecedent moisture derived from previous rainfall, runoff and infiltration events. In the majority of landscapes, runoff is concentrated into drainage networks connecting with regional creek systems.

Drainage lines are well-defined in the upper slopes where creeks are incised in the landscape. These lower-order tributaries converge into a small number of well-defined, higher-order drainages and associated floodplains. Riparian woodlands commonly fringe the main drainages and utilise water that replenishes the vadose zone following streamflow.

Drainages in flat-lying areas tend to be braided and indistinct. In some landscapes certain combinations of topography, hydrological conditions and soil types give rise to sheet flow, which can be associated with banded-vegetation communities. During significant rainfall events, floodwater can overflow creek channels and extend across wider floodplains. This is an important mechanism in these areas for replenishing soil moisture and recharging groundwater resources.

All river and creek drainages are ephemeral. Streamflow typically occurs during the summer months of December to March associated with large and intense rainfall events from tropical cyclones and thunderstorms. Streamflow in smaller and upper catchments is invariably short in duration. In the higher order drainages with larger catchments, there may be more persistent flows in the order of several weeks or possibly months associated with very infrequent flood events. Silberstein (2014) suggests that daily rainfall events of between 15 and 25 mm are required to generate streamflow in drainages.

Drainages tend to be 'losing systems' with surface water infiltrating the creek bed that replenish the soil moisture zones, including areas of bank storage with lateral dissipation over months following significant rainfall events. In larger events, groundwater recharge may occur preferentially in zones of surface flow concentration and permeable (leaky) creek beds.

In rare situations, there can be groundwater discharge to the surface that contributes to surface water flow, such as at Weeli Wolli Spring. The occurrences of springs and groundwater-fed pools across the study area are spatially restricted and often geologically controlled. Where present, these areas often support distinct biota and ecosystems.

5.3.3. Key Surface Water Features

The most prominent hydrological features in the study area are listed below and further described in Table 2:

- Fortescue Marsh;
- Ethel Gorge (and Ophthalmia Dam);
- Weeli Wolli Spring; and
- Coondewanna Flats (and Lake Robinson).

Table 2 Prominent hydrological features

Hydrological feature	Description
Fortescue Marsh	The Fortescue Marsh is an extensive intermittent wetland being 100 km long and up to 10 km wide. The Marsh is a surface water dominated system that receives substantial runoff from the Upper Fortescue River and Weeli Wolli Creek with a combined catchment area of about 34 800 km^2. Annual runoff into the Marsh is highly variable and more than 30% of its surface is inundated once in every nine years (MWH, 2014). This impounded surface water becomes increasingly saline owing to evapoconcentration before infiltrating into the groundwater system. A number of fringing, persistent pools occur along the northern edge of the Marsh, locally known as yintas. They are maintained by drainages emanating from the Chichester Range and marsh flooding events. Periodic flooding is important for replenishing soil moisture that supports fringing samphire vegetation communities, sustaining the fringing pools, and providing groundwater recharge into shallow aquifers.
Ethel Gorge (and Ophthalmia Dam)	Ethel Gorge is located in the Upper Fortescue River where it cuts through the Ophthalmia Range, 15 km northeast of Newman and about 100 km upstream of the Fortescue Marsh. Homestead, Whaleback, Shovelanna and Warrawanda Creeks drain into Fortescue River upstream of Ethel Gorge with a combined catchment area (upstream of Ethel Gorge) of 4 872 km^2. The aquifers in the vicinity of Ethel Gorge provide habitat for the Ethel Gorge stygobiont community. In this area, the hydrological regime is important for the TEC as it maintains groundwater levels and provides nutrients through the infiltration of surface water. Prior to passing through Ethel Gorge, Whaleback and Warrawanda Creeks discharge into Ophthalmia Dam. The dam was constructed in the 1980s to artificially recharge groundwater aquifers utilised as the water supply for Eastern Pilbara region operations and town of Newman. Surface water is captured by the dam and only overflows when full resulting in periodic flows through Ethel Gorge. Shovelanna Creek is also important as it captures slightly more saline surface water from the Ophthalmia Range and transports into the Ethel Gorge area. Ophthalmia Dam has a maximum storage water depth of 4.5 m and storage capacity of about 31 GL. When it is full, runoff overtops the service spillway and discharges via the former Warramanda Creek into Ethel Gorge and the Upper Fortescue River. In addition to overflow, water loss is primarily associated with seepage and evaporation.
Weeli Wolli Spring	Weeli Wolli Spring is a natural expression of groundwater discharge in Weeli Wolli Creek. The spring is located about 60 km upstream of the Fortescue Marsh and has a catchment area of about 1 450 km^2. It is perennial with shallow groundwater levels around the spring being maintained by a series of permanent pools (interconnected in places) within the creek. The hydrological regime supports a unique riparian ecological community that is listed as a Priority 1 Ecological Community. In recent years, the hydrological regime at Weeli Wolli Spring has been influence by dewatering and discharge activities at RTIO's Hope Downs operation. The current water management strategy comprises a series of water discharge points upstream of the spring that maintain spring flows.
Coondewanna Flats and Lake Robinson	Coondewanna Flats is an internal drainage feature receiving runoff from surrounding hills. Numerous incised alluvial creeks splay out onto the flats becoming broad and poorly defined. Lake Robinson is an ephemeral claypan on the northern fringe being lowest elevation across the flats. The southern flats are characterised by poorly-defined drainage channels. Large rainfall events (with a nominal return period of one in every four years) inundate Lake Robinson with impounded surface water replenishing soil moisture in the vadose zone and recharging underlying aquifers. A large portion of standing water that may persistent for a number of months following inundation tends to evaporate over time. Coondewanna Flats contain Priority Ecological Communities (PECs) that require frequent surface water inflows to maintain vegetation health.

5.4. Geology

The regional geology is dominated by the Archean to Lower Proterozoic Hamersley Basin that unconformably overlies the Archean granite - greenstone terrane of the Pilbara Craton (Map 5). The Hamersley Basin comprises the Fortescue, Hamersley and Turee Creek Groups that are exposed throughout the Hamersley and Chichester Ranges comprising metasedimentary rocks and minor felsic volcanics. The Hamersley Group and (to a lesser extent) the uppermost Fortescue Group that underlies the Hamersley Group occurs more extensively in the northern and central parts of the study area; whereas, the Hamersley Group is absent in the south exposing members of the Jeerinah Formation of the Fortescue Group and Archean granite. In places, iron enrichment of banded-iron formations (BIF) has formed orebodies within the Brockman and Marra Mamba Formations.

The basement lithologies have been structurally influenced by a complex tectonic history producing the predominantly SW-NE striking regional synclines and anticlines, as well as a series of more intense tighter folds that control outcrop geology and topography. Several regional-scale geological faults have offset the basement geology. These include transverse faults in the Eastern Pilbara region associated with Whaleback, Fortescue River and Wheelara Faults, and parallel faults associated with Homestead and Ophthalmia Faults. Local thrust faulting in the Marra Mamba Iron Formation, particularly where in contact with the Wittenoom Formation, has influenced mineralisation. Dolerite dykes that trend NW-SE to NE-SW have also intruded basement lithologies.

The geological structure has controlled erosional and depositional processes. Large-scale faults have offset and cross-cut across multiple geological units, as observed in the Upper Fortescue River and Cathedral Gorge. Tertiary detritals are often aligned with topographic lows but along regional strike associated with preferentially weathering of the underlying dolomites and shales. Marra Mamba and Brockman orebodies are also structurally influenced with a strong relationship between mineralisation and structural control.

Basement geology has a strong influence on topography. The more-resistant banded iron formations outcrop in mountainous areas and local peaks; whereas, the less-resistant formations associated with the Paraburdoo Member of the Wittenoom Formation have been extensively weathered to underlie the broad valley floors. The Marra Mamba Formation also occurs in topographic lows associated with the dolomites and overlain by alluvial sediments in many areas.

Since the Tertiary, eroded channels and valleys (known as palaeochannels and palaeovalleys) have been infilled with a variety of chemical and erosional sediments during multiple phases and modes of deposition. In places, deeper and more incised palaeochannels contain sequences of channel iron deposits (CID) comprising iron-rich detritus that have been iron-enriched to form major orebodies at BHP Billiton Iron Ore's Yandi operation and the proposed Munjina and Upper Marillana mining areas in the Marillana Creek region.

In the larger valleys, there are variable deposits of alluvial, colluvial and floodplain sediments (referred to as Tertiary detritals or valley-fill) that increase in thickness towards the centre of the valleys, and may be more than 100 m thick in parts of the Fortescue River Valley. There are minor detrital orebodies associated with colluvial / scree deposits at the base of mineralised basement lithologies, as well as interspersed layers of calcrete, silcrete and lacustrine clays.

More recent surficial sediments are thin, and associated with active creek channels and floodplains (Map 5). Alluvial and colluvial deposits comprise unconsolidated silt and clay through to coarse gravel. There may be ongoing calcrete and silcrete formation in these sediments, particularly in the Fortescue River Valley, associated with low rates of groundwater movement resulting in calcium carbonate precipitation and secondary silicification. A thin cover of lacustrine clay forms the surface of the Fortescue Marsh.

The regional stratigraphy is summarised in Table 3, including a brief commentary on groundwater potential.

Table 3 Regional stratigraphy

Age	Group	Formation	Member	Lithological Description	Hydrogeological Description
Cainozoic	Quaternary	Eolian deposits		Sands in sheets and longitudinal dunes	Generally unsaturated
		Alluvium		Unconsolidated silt, sand and gravel in drainage channels and floodplains	Often unsaturated, occasional aquifer
		Colluvium		Unconsolidated quartz and rock fragments	Unsaturated, but may form localised perched aquifers
	Tertiary Detritals (TD)	TD3		Sand, silt and clay	Generally low permeability
				Calcrete and silcrete	***Aquifer***
		TD2		Channel Iron Deposit (CID) and mottled clay occurring in palaeochannels	***Aquifer***
		TD1		Magnetite and haematite pisolite, red ochre and scree on palaeovalley sides	Low permeability
Archean to Early Proterozoic	Hamersley Group	Boolgeeda Iron		Fine grained, finely laminated iron formation with minor chert, jaspilite and shale	Low permeability
		Woongarra Rhyolite		Lavas and tuffs with minor iron formation	Low permeability
		Weeli Wolli		Banded iron formation (BIF), shale and jaspilite intruded by dolerite sills and dykes	Low permeability
		Brockman Iron	Yandicoogina	Banded iron formation shale and jaspilite intruded by dolerite sills and dykes	Low permeability
			Joffre	BIF with minor shale bands – ***major ore host***	Low permeability, except mineralised zones
			Whaleback Shale	Interbedded shale, chert and BIF	Low permeability
			Dales Gorge	Interbedded BIF with minor shale bands – ***major ore host***	Low permeability, except mineralised zones
		Mount McRae Shale		Graphitic and chloritic shale interbedded with BIF. Carbonaceous and pyritic	Low permeability with localised high permeability bands (Colonial Chert)
		Mount Sylvia		Shale, dolomite and BIF bands	Low permeability with localised high permeability bands (Bruno's Band)
		Wittenoom	Bee Gorge	Calcareous shale and dolomite.	Low permeability
			Paraburdoo	Dolomite – locally with karstic characteristics.	***Regional aquifer in karstic zones***
			West Angela	Shale-BIF-chert-dolomite. Locally manganiferous	Low permeability with localised high permeability
		Marra Mamba Iron	Mount Newman	BIF with interbedded carbonate and shale. ***Major ore-host***	Low permeability, except mineralised zones
			MacLeod	BIF, chert and shale	Low permeability
			Nammuldi	BIF, chert and shale	Low permeability, except mineralised zones
	Fortescue Group	Jeerinah	Roy Hill Shale	Shale with some dolomitic shale	Low permeability
			Warrie	Chert, quartzite, shale and jaspilite	Low permeability
			Woodiana	Silicified mudstone, shale, siltstone, chert, quartzite and tuff	Low permeability
		Granitoid		Granite and gneiss	Low permeability

5.5. Hydrogeology

5.5.1. Overview

The study area includes a regional groundwater system comprising Tertiary detritals and underlying Wittenoom Formation (dominated by Paraburdoo Member dolomite) that is bound within low-permeability lithologies. There are localised areas of higher permeability associated with orebody aquifers, geological structures and preferential weathering profiles that are in variable hydraulic connection with the regional groundwater system. Channel-iron deposits (CIDs) are localised orebody aquifers having variable connectivity with surface water systems such as within Marillana Creek.

The dolomite aquifer of the Wittenoom Formation occurs at depth beneath most of the Fortescue River Valley and the major drainage features such as Weeli Wolli Creek. The dolomite has a low permeability where fresh and relatively unfractured; however, karstification has enhanced its permeability and aquifer potential. Its distribution is associated with regional EWE-WSW striking anticlines and synclines across the study area, which preferentially influences groundwater flow into either an easterly or westerly direction. As the dolomite has been weathered to form valleys and in-filled with Tertiary sediments, there is strong hydraulic connectivity between the dolomite and detrital aquifers that collectively comprise the ‘regional groundwater system’ (Map 6).

As the landscape rises into the ranges away from the valleys, the hydrogeology features a complex assortment of fractured-rock aquifers. Mineralised zones in the Brockman and Marra Mamba Formations can have enhanced permeability and aquifer potential is limited below and along strike by low permeability unmineralised BIF. The extent of orebody aquifers and hydraulic connectivity with the regional groundwater system may be enhanced by site-specific faulting and/or preferential weathering.

Structural features have an important influence on groundwater flow and connectivity. Whaleback, Fortescue River and Wheelarra Faults in the Eastern Pilbara region are transverse faults that form low-permeability barriers restricting the movement of groundwater. Dolerite dykes can also impede groundwater flow. In contrast, local thrust faults have improved permeability through brecciation of the dolomite aquifer and resulted in direct hydraulic connection between orebodies and the regional groundwater system.

CIDs form both orebodies and important aquifers that can act as regional groundwater drains, most notably along Marillana Creek. In places, CID aquifers are in hydraulic connection with the alluvium in present day creeks.

Alluvial and colluvial sediments, comprising the Tertiary detritals, range from localised unconfined aquifers of limited lateral extent in upland areas through to extensive groundwater systems; for example where associated with the main drainages of Weeli Wolli Creek, upgradient of Ethel Gorge and within the Fortescue River Valley. Saturated thickness progressively increases from the margins of the Chichester and Hamersley Ranges into the main valleys and is greatest in the lower parts of the landscape. In places, the Tertiary detritals have been calcretised and karstified to form zones of higher permeability, which often constitute important aquifers and habitat for stygofauna.

Groundwater recharge is mainly associated with surface water flow along creeks and in areas of water impoundment. Diffuse recharge is less significant for the regional water balance. Large soil moisture deficits generally prevent recharge where groundwater levels are greater than 30 m bgl. In contrast where surface water accumulates and depth to water is shallow (less than about 15 m bgl), recharge occurs on an annual basis associated with streamflow. Elsewhere, recharge through infiltration is infrequent and inconsistent.

Groundwater discharge is primarily associated with spring baseflow, throughflow within aquifers, and evapotranspiration losses. Within the study area, the discharge of groundwater discharge into surface water features are rare and dependant on site-specific geology. A noticeable occurrence is at Weeli Wolli Spring, where regional groundwater flow is concentrated into a shallow aquifer that is further constrained by a gorge in Wildflower Range.

Across the study area, groundwater is fresh to marginally brackish being less than 1 500 mg/L TDS (total dissolved solids) with localised areas of slightly elevated groundwater salinity associated with evapotranspiration by phreatophytic vegetation (e.g. at Ethel Gorge and Weeli Wolli Spring). The main exception is the Fortescue River Valley where a mound of saline to hypersaline groundwater has formed beneath the Fortescue Marsh. This saline groundwater system is the product of internal drainage and high evaporation rates over a long period

(Skrzypek et al., 2013). Towards the valley flanks, there is a freshwater – saltwater interface within the Tertiary detrital aquifer.

5.5.2. Hydraulic connectivity of orebody aquifers

Hydraulic connectivity between orebody aquifers and the regional groundwater system is an important consideration in resolving the scale of mine dewatering and its influence on ecohydrological receptors, which is considered in the change assessment (Part III).

To assist with the interpretation of hydraulic connectivity, current and proposed orebodies were categorised into generic mine types based on ore type, extent of the orebody aquifer below the watertable, and the likely degree of hydraulic connection with the regional aquifer.

The key hydrogeological relationships and connectivities for each generic mine type are summarised in Table 4. The typical landscape setting and potential connectivity pathways for each generic mine type are schematically presented in Figure 6 and Figure 7.

Table 4 Generic mine types considered in the ecohydrological change assessment

Generic mine type	Hydrogeological connectivity	Potential implications
Above the watertable (AWT)	Orebodies in upland areas with deep groundwater levels and no connectivity with groundwater. No mine dewatering is required.	No potential for drawdown impacts on sensitive receptors owing to lack of connection. Operations often have a water deficiency and may require additional water supply from other surplus areas or dedicated borefields.
Isolated or disconnected	Orebodies in upland areas surrounded by low-permeability lithologies. Inflows are minimal (<2 ML/day) with groundwater drawdown being restricted and localised.	There is limited potential for drawdown impacts on sensitive receptors owing to limited hydraulic connection. Operations often have a water deficiency and may require additional water supply from other surplus areas or dedicated borefields.
Partially connected	Orebodies along valley margins with the valley side pit wall intersecting thinly-saturated Tertiary detritals or geological structures providing limited hydraulic connection. Dewatering rates will typically be between 2 and 10 ML/day with minor groundwater drawdown extending into the regional aquifer.	There is limited potential for drawdown impacts on sensitive receptors owing to limited connection. Operations may be either water deficit or surplus. In most cases, water supply will be locally used within operations. Excess dewatering water may require management.
Connected	Orebodies within valleys with pit walls intersecting saturated Tertiary detritals providing significant hydraulic connection. Dewatering rates between 10 and 20 ML/day with groundwater drawdown extending several kilometres into the regional aquifer.	Mitigation measures may also be necessary to minimise potential impacts at sensitive receptors. Operations often have a significant water surplus requiring management.
Fully connected	Orebodies within valley with most pit walls intersecting saturated Tertiary detritals and Paraburdoo dolomite resulting in in a high degree of hydraulic connection. Dewatering rates may be substantial, typically exceeding 20 ML/day, with groundwater drawdown extending more than 5 km into the regional aquifer.	Mitigation measures may also be necessary to minimise potential impacts at sensitive receptors. Operations often have a large water surplus requiring management.

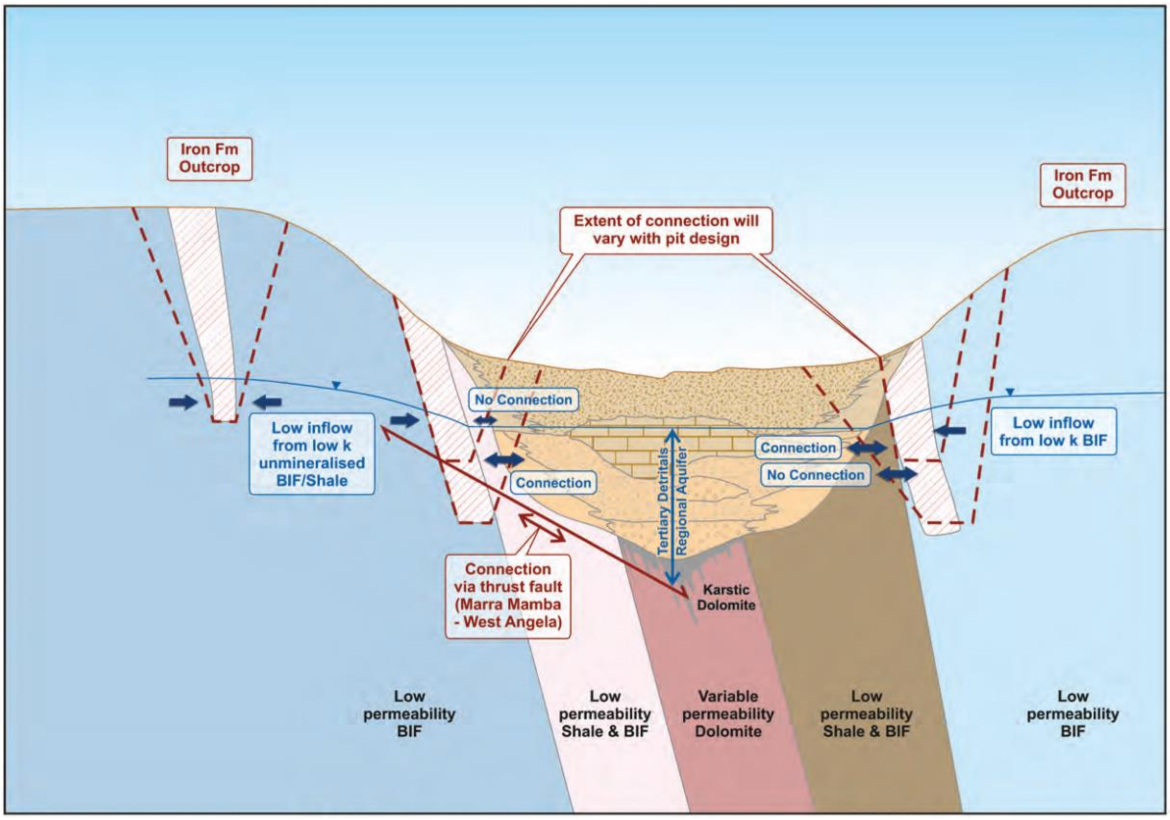

Figure 6 Schematic figure showing regional aquifer / groundwater system and likely connectivities

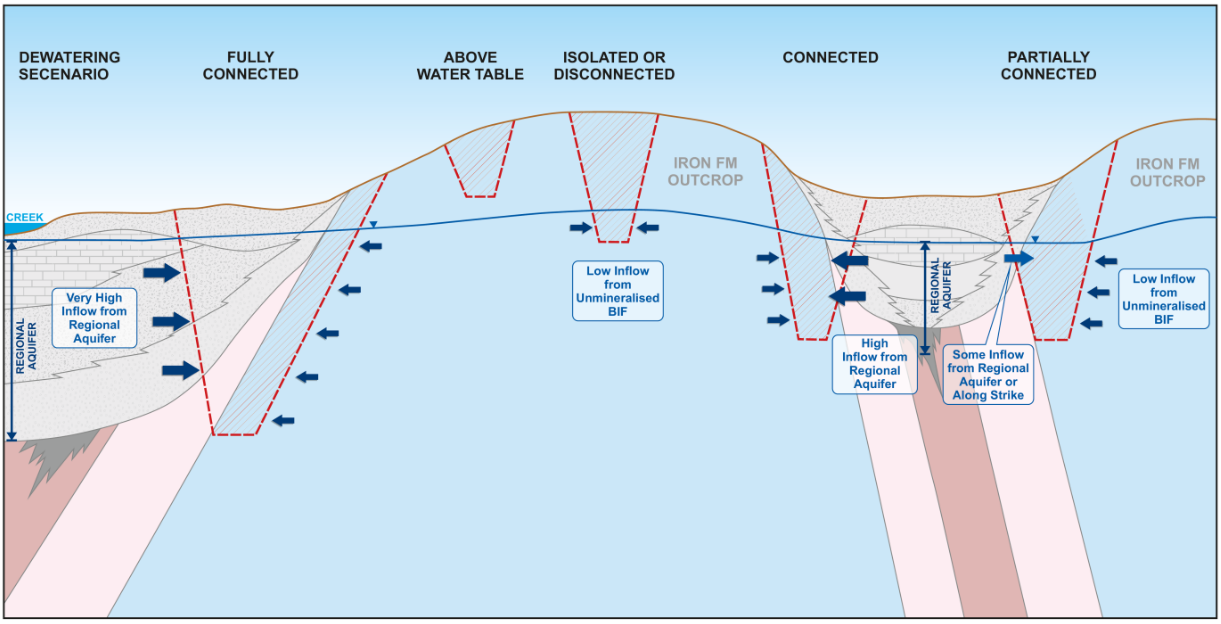

Figure 7 Generic mine types for Marra Mamba and Brockman deposits

5.6. Hydroclimatic variability

The hydrological regime in the study area is highly variable and dynamic, reflecting the similarly variable and dynamic climate. Rainfall is influenced by the frequency of tropical cyclones that cross the northwest Australian coast, some of which deliver substantial rainfall across the Pilbara. This episodic rainfall can lead to widespread flooding and inundation, and ultimately accumulates in the Fortescue Marsh and other smaller ephemeral lakes, such as Lake Robinson. Groundwater levels are also responsive to the variability in climate. In addition to seasonal patterns of response, there are also long-term groundwater trends, overprinting the seasonal groundwater fluctuations, associated with longer-term wet or dry phases.

The Pilbara region has experienced a pronounced “wet phase” over the last 20 years, described in more detail below. The “wet phase” is characterised by substantially increased mean annual rainfall in comparison with the previous 200 years or more (O’Donnel *et al*, in press), more frequent and larger-scale flooding, and a regional scale increase in groundwater levels. The “wet phase” constitutes a hydrological “state change” and is associated with greater ecological water availability.

Ecosystems have almost certainly responded to the wetter conditions over the past 20 years by taking advantage of the greater water availability; however, no systematic regional-scale and long-term assessment is available to quantify or verify this adaptation. The ecohydrological assessment considers that the “baseline” conditions are representative of a “wet phase”. Projecting into the future, it is possible that the climate could revert back to conditions more reflective of long term rainfall patterns (i.e. reinstatement of the “dry phase”). Alternatively, the wetter period over the past 20 years may represent a climatic “step change” resulting in a persistently altered hydrological system state. In either case the future climate will be subject to anthropogenic influences and is likely to be characterised by higher temperatures (Charles et al, 2013).

5.6.1. Climate variability

The annual variability in rainfall has been assessed using the long-term rainfall record from the SILO enhanced climate database hosted by the Science Delivery Division of the Queensland Government’s Department of Science, Information, Technology, Innovation and the Arts (DSITIA) (https://www.longpaddock.qld.gov.au/silo/). SILO contains Australian climate data from 1889 and is suitable for research and climate applications. A detailed description of the SILO analysis is provided in Appendix B

An example of the transient rainfall conditions in the study area are depicted in Figure 8, which is a long-term SILO annual rainfall record at Ethel Gorge (23°30'S, 119°30'E). Annual rainfall varies considerably ranging between 36 mm and 837 mm (average is 250 mm)[6]. The standard deviation is about 62% of the mean yearly rainfall.

The five-year moving average rainfall was consistently between 150 and 320 mm in the period between 1890 and 1995; however, the onset of the “wet phase” is evident from the mid-1990s with substantial rainfall occurring in 1999 coinciding with cyclone John. Over the full period of records, the frequency of substantially higher rainfall years defined as rainfall greater than 300 mm/yr is approximately one in four years. For the period prior to 1995, the frequency is lower at one in five years, whilst since 1995 the frequency of high rainfall years increased to two out of three years. This sustained period of higher rainfall has been associated with higher groundwater levels and more-frequent flooding of ephemeral drainages, as described in sections 5.6.2 and 5.6.7.

[6] The values are expressed in terms of rainfall years; 1 July to 30 June.

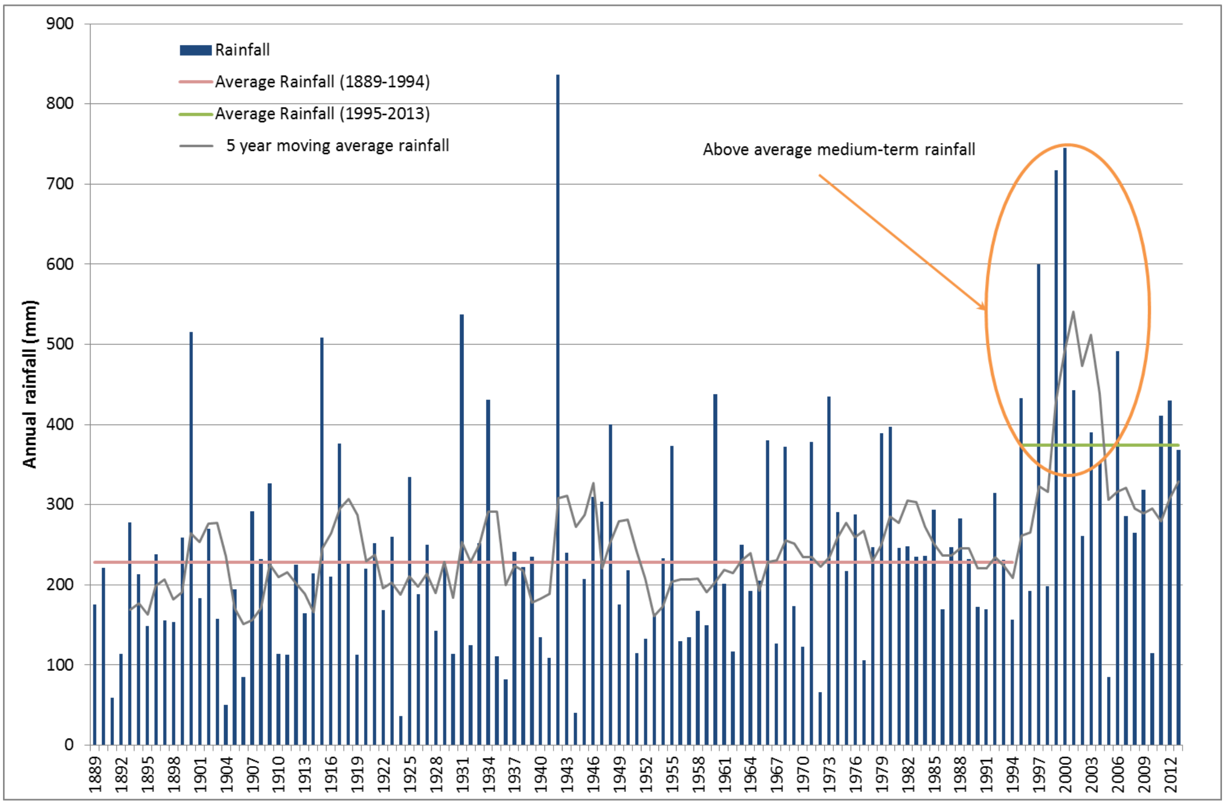

Figure 8 SILO database yearly rainfall at Ethel Gorge

The disparity and significance of the recent "wet phase" is further supported by longer term hydroclimate reconstruction for the Pilbara using a 210 year tree ring chronology from *Callitris columellaris* (O'Donnel *et al*, in press). The hydroclimatic reconstruction revealed long periods of below average rainfall extending between one to three decades interspersed with periods of above average rainfall. The reconstruction revealed that the past two decades have been unusually wet compared to at least the previous two centuries.

5.6.2. Streamflow variability

The variability in streamflow rates for larger drainage channels is depicted in Figure 9, which illustrates the estimated long-term annual streamflow rates for the Fortescue River directly up-gradient of Ethel Gorge. Using a regression relationship between rainfall and streamflow developed from actual streamflow records (DoW station 708011) for the period 1981 to 2014 (described in more detail in Appendix B), the streamflow record for the period 1889-1980 has been derived from interpolated (SILO) long term rainfall records from the region.

Annual streamflow rates vary significantly, with generally low streamflow rates periodically interspersed by years with substantial streamflow rates. Based on the actual 1981 to 2013 record, annual streamflow rates for Fortescue River varies between 0 and 390 GL. The average streamflow rate is about 49 GL/yr but the average value is significantly skewed by a small number of higher streamflow years. The median streamflow is 19 GL and the standard deviation is 400%. About once every ten years, there is no significant streamflow for the entire year.

The actual streamflow record shows two distinct phases namely a period of below-average streamflow rates from 1980 to 1994 followed by a period of substantially higher streamflow rates. The five year moving average of streamflow rates are consistently below 50 GL and noticeably lower than the wet phase in the late 1990s and early 2000s where five-year averaged streamflow rates reached 150 GL/yr.

As with rainfall, the frequency of years with substantially high streamflow rates (>50 GL/yr) was one in five for the period to before 1995. Since then, the frequency of years with high streamflow increased to two in every three years.

The higher streamflow rates over the past 20 years have contributed to an increased frequency and areal extent of inundation at the Fortescue Marsh (Rouillard *et al*, 2015). In their study, Rouillard *et al*. (2015) noted that extreme wet years (occurring in 7 out of 100 years) resulted in the Marsh being inundated for more than 12 months. The prolonged and extensive inundation between 1999 and 2006 is considered unprecedented compared to the preceding century. In the event that the wet phase persists, the structure and functioning of the Marsh as a wetland is likely to differ from the preceding “dry phase”; although potential trajectories of change are difficult to predict. Similar concepts may apply to other ecohydrological receptors in the study area.

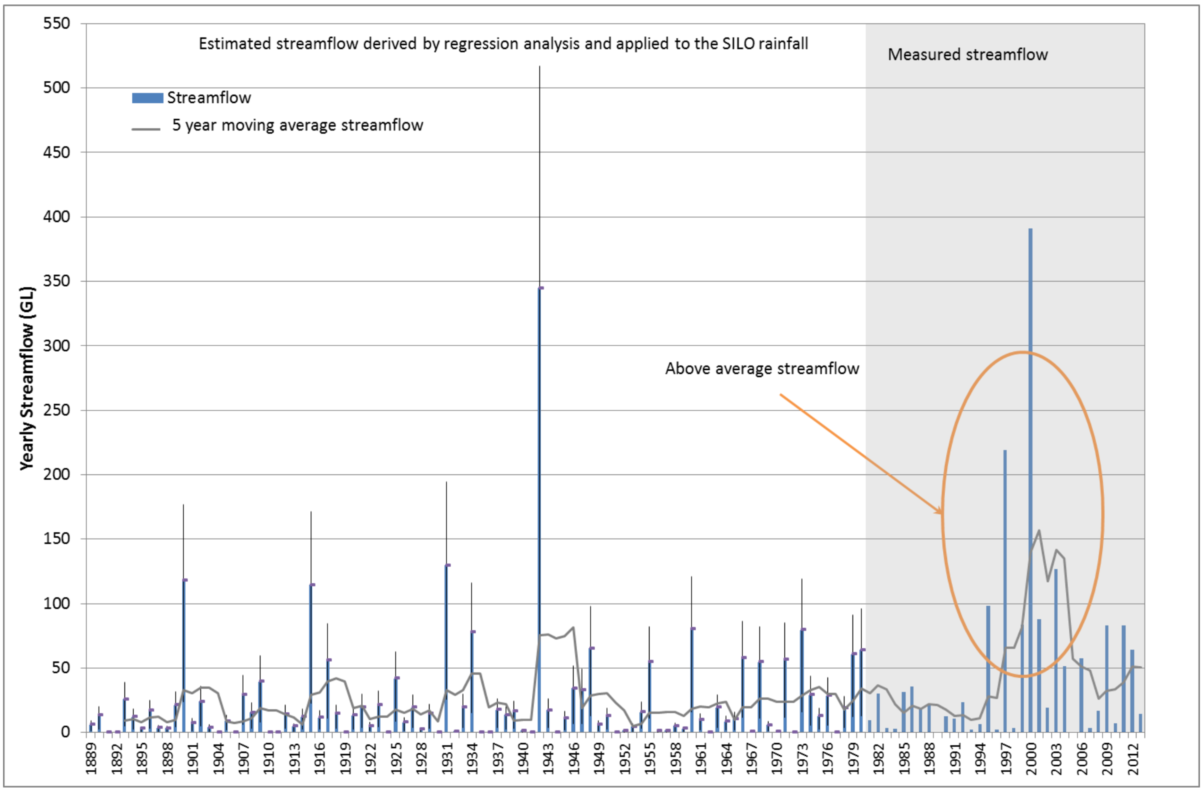

Figure 9 Derived long-term streamflow at Fortescue River (DOW 708011)

5.6.3. Groundwater level variability

Groundwater fluctuations and variability in the study area were assessed based on normalised groundwater hydrographs at the Ophthalmia borefield and Yandi operations. These monitoring bores represent up-gradient baseline conditions and are unaffected by dewatering, groundwater abstraction or groundwater injection/infiltration activities. Monitoring bores at the other existing BHP Billiton Iron Ore operations were excluded owing to insufficient monitoring data. The hydrographs were normalised with groundwater levels set at 520 m AHD for the 18 January 1994, which provides a suitable comparison of relative groundwater level changes. The normalisation date occurs in a period of relatively low groundwater fluctuations and where actual groundwater levels were available for all four monitoring bores. The development of the hydrographs is described in more detail in Appendix B.

Groundwater levels respond seasonally mainly to streamflow recharge events characterised by a sharp water level increase and rapid groundwater recession curve (Figure 10). Long-term groundwater level changes overprint these seasonal fluctuations owing to medium and long-term variability in streamflow rates and rainfall. Groundwater levels can vary by several metres depending on longer-term streamflow variability. The distinct wet phase from 1995 is evident, resulting in a pronounced regional scale increase in groundwater levels and slow groundwater recession. Note that the magnitude of groundwater level increase and subsequent recession is affected by site-specific conditions. The regional increase in groundwater levels over the past 20 years may have increased the level of interaction between groundwater and terrestrial ecosystems; for example by facilitating opportunistic groundwater use by deep rooted vegetation such as riparian Eucalypt species. In some areas this may have contributed to increases in riparian vegetation densities. The increase in saturated thickness has also potentially expanded subterranean habitat supporting stygofauna assemblages.

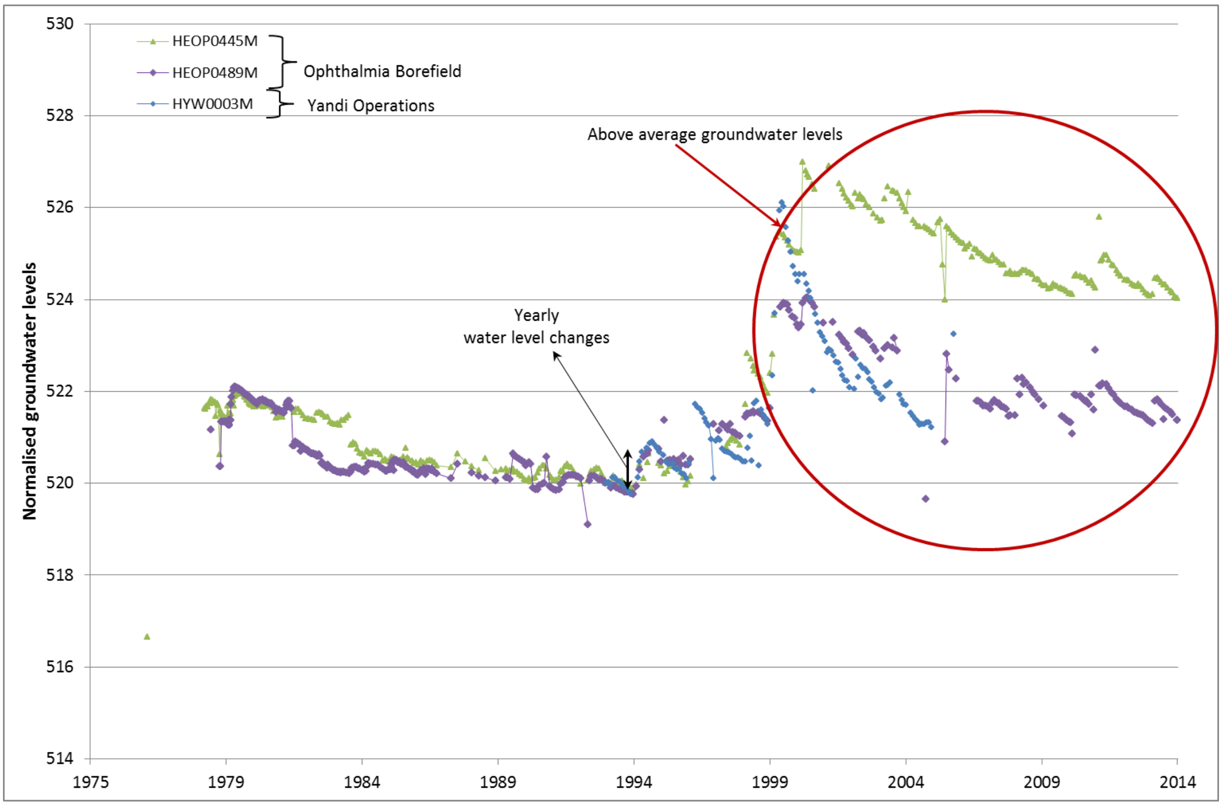

Figure 10 **Long term groundwater level changes at the Ophthalmia borefield and Yandi operations**

5.7. Ecology

5.7.1. Bioregion

The study area is situated within the Pilbara bioregion as defined under the Interim Biogeographic Regionalisation for Australia (IBRA). It includes three geographically distinct biogeographic subregions described as follows (Pepper et al., 2013):

- Chichester subregion: encompasses the granite/greenstone terranes of the northern Pilbara Craton but also includes the Chichester Plateau of the Hamersley Basin. While the broader Chichester subregion 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 subregion: delineated by the Fortescue River Valley consists of salt marshes, mulga-bunch and short grass communities, with eucalypt (*Eucalyptus* spp.) woodlands along floodplains and associated with permanent springs.
- Hamersley subregion: is a mountainous area of ranges, ridges and hills 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 supporting spinifex grassland with Mulga and Snappy Gum tree steppe.

5.7.2. Flora and Vegetation

The study area is within the Fortescue Botanical District of the Eremaean Botanical Province described by Beard (1975 and 1990) (Map 7). The vegetation 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). McKenzie et al. (2009) provides a more recent synthesis of the broad vegetation patterns in the IBRA subregions of the Pilbara bioregion that provides additional details on vegetation distribution (refer to Appendices C to F).

BHP Billiton Iron Ore has recently consolidated historical baseline flora and vegetation surveys completed across its Pilbara tenements, including some areas outside the study area. The consolidated database contains raw data for more than 8 000 study sites with more than 176 000 flora records (Onshore Environmental, 2014). More than 220 vegetation associations were classified under 53 broad floristic formations being described and mapped across BHP Billiton Iron Ore tenure, and distributed across 15 broad landform types.

The study area includes two species listed under State and Commonwealth legislation, *Lepidium catapycnon* (EPBC - Vulnerable, WC Act - DRF) and *Thryptomene wittweri* (EPBC - Vulnerable, WC Act - DRF), both of which occur in uplands of the Hamersley Range. A number of additional Priority taxa recognised by the DPaW occur across a wide variety of landscape types. Across BHP Billiton Iron Ore's tenure, 57 conservation significant plant taxa have been recorded including multiple populations of *Lepidium catapycnon*, 14 Priority 1 flora taxa, 11 Priority 2 flora taxa, 26 Priority 3 flora taxa, and four Priority 4 flora taxa (Onshore Environmental, 2014). The flora of the study area includes a number of introduced species, some of which are recognised environmental weeds. Across BHP Billiton Iron Ore's tenure, 56 introduced weed taxa have been recorded (Onshore Environmental, 2014).

5.7.3. Terrestrial Fauna

Pilbara fauna is typified by arid-adapted vertebrates with generally extensive regional distributions. Many species have affinities with land surface substrates and structural vegetation types. Climatic variables tend to have a lessor influence on species distributions (McKenzie et al., 2009). Informed by land system mapping and previously completed fauna surveys, the major habitat types are characterised as:

- mountainous rugged terrain associated with the Hamersley Range comprising ridges, plateaus, steep hills with free faces and stream channels;
- rolling hills and foothills associated with the Hamersley Range;
- rolling hills and foothills associated with the Chichester Range;
- gently sloping to flat-lying alluvial plains within the broader Fortescue Valley;
- calcrete platforms and plains, generally adjacent to the Fortescue Marsh;
- major drainage systems and floodplains with riparian Eucalypt woodlands being principally associated with Weeli Wolli Creek, Mindy Mindy Creek, Coondiner Creek (south of the Fortescue Marsh); Christmas Creek (north of the Marsh), and the Fortescue River and its Eastern Pilbara tributaries; and
- Fortescue Marsh including clay flats and fringing samphire communities.

BHP Billiton Iron Ore has recently consolidated fauna habitat mapping completed across its Pilbara tenements, including some areas outside of the study area. Seventeen habitat types were described and mapped across BHP Billiton Iron Ore's tenure, representing a refinement of the major habitat types (Biologic, 2014). These include stony plain, sandy/stony plain, sand plain, sand dune, mulga, minor drainage line, major drainage line, hardpan plain, granite domes and boulders (tors), gorge/gully, gilgai (cracking clay), Fortescue Marsh samphire, drainage line, drainage area, crest/slope, calcrete areas and artificial habitats. Of these, the most specious habitats include crest and slope, sand plains, drainage areas, stony plain, major drainage lines and mulga.

The existing conservation reserve system in the Pilbara aims to characterise and represent a wide variety of the sandy, clayey and rocky substrates and geomorphic units (McKenzie et al., 2003), and is considered sufficient to provide adequate habitat for species persistence with appropriate management (Gibson and McKenzie, 2009, Burbidge et al., 2010, Doughty et al., 2011). Riparian vegetation has been noted to support distinctive bird assemblages and may require special conservation attention (Burbidge et al., 2010). In addition, two microbat species (*Nyctophilus bifax* and *Chalinolobus morio*) are restricted to productive riparian environments (McKenzie and Bullen, 2009).

A number of fauna with conservation significance, including those listed under State and Commonwealth legislation, are known to occur in the study area. Key species which have an association with drainages and wetland habitats include (Biologic, 2014):

- Bush Stone-curlew (*Burhinus grallarius*) (DPaW - Priority 4, IUCN - Near Threatened);
- Cattle Egret (*Bubulcus ibis*) (EPBC Act - Migratory, WC Act - Schedule 3);
- Eastern Great Egret (*Ardea modesta*) (EPBC Act - Migratory, WC Act - Schedule 3);
- Grey Falcon (*Falco hypoleucos*) (DPaW - Priority 4);
- Northern Quoll (*Dasyurus hallucatus*) (EPBC Act - Endangered, WC Act - Schedule 1);
- Peregrine Falcon (*Falco peregrines*) (WC Act - Schedule 4);
- Pilbara Olive Python (*Liasis olivaceus barroni*) (EPBC - Vulnerable, WC Act - Schedule 1);
- Pilbara Leaf-nosed Bat (*Rhinonicteris aurantius*) (EPBC - Vulnerable, WC Act - Schedule 1); and
- Rainbow Bee-eater (*Merops ornatus*) (EPBC Act - Migratory, WC Act - Schedule 3).

Migratory wetland birds utilise significant waterbodies associated with major drainage systems and lakes, including the Fortescue Marsh. The Marsh is known to support a variety of migratory waterbird species, including Clamorous Reed-warbler (*Acrocephalus stentoreus*), Great Egret (*Ardea alba*), Swamp harrier (*Circus approximans*) and Whiskered Tern (*Chlidonias hybridus*), as well as Sacred Kingfisher (*Todiramphus sanctus*). It is a major breeding area for the Australian Pelican (*Pelecanus conspicillatus*) and Black Swan (*Cygnus atratus*) (DEC, 2009).

5.7.4. Subterranean fauna

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 promoted speciation.

Owing to their requirement for permanent groundwater and their ancient origins, the presence of stygofauna may indicate the long-term presence of groundwater (Humphreys, 2006). Stygobitic species are obligate groundwater inhabitants with potential for restricted geographical distributions, depending on the extent and connectivity of the inhabited groundwater system. They may be classified as Short Range Endemic species (SREs), where confined to a particular aquifer system that effectively functions as a subterranean ‘habitat’ island. Ostracods are the dominant stygofaunal group in the Pilbara, in terms of both species richness and animal abundance. Other major groups include copepods, amphipods and oligochaetes.

A variety of factors influencing the diversity and distribution of stygofauna in the Pilbara have been identified (Hancock et al., 2005; Boulton, 2000). Capture rates are significantly lower where the depth to groundwater is greater than 30 m (Halse et al., 2014). Alluvial and calcrete aquifers can have greater species diversity and abundance (Maurice and Bloomfield, 2012). Heterogeneity of habitat and water chemistry within groundwater systems may give rise to distinct stygofauna assemblages (Hahn and Fuchs, 2009; Maurice and Bloomfield, 2012).

The Pilbara Biodiversity Study (PBS) identified nine areas of high stygofauna richness in the Pilbara, where some protection of stygofauna values may be warranted if not already in place (Halse et al., 2014). One of these occurs in the study area at Ethel Gorge. Applying the same methodology to an expanded dataset, including BHP Billiton Iron Ore’s monitoring data and additional records from Western Australian Museum, the Regional Subterranean Fauna Survey (Bennelongia, 2014) identified a further seven areas of high stygofauna richness in four localities within the study area including: Upper Weeli Wolli and Coondewanna Creek, Weelumurra Creek, northern and eastern Fortescue Marsh, and Mulga Downs. In the study area, the Ethel Gorge Stygobiont Community is recognised as a TEC and the stygofauna assemblage at Weeli Wolli Spring is a factor contributing to the classification of the Weeli Wolli Spring environs as a PEC.

5.8. Regional Ecohydrology

Ecohydrology provides an understanding of relationships between hydrological regimes and ecosystems. In contrast with traditional descriptive ecological methodologies, ecohydrology provides a process level understanding of water regimes and ecosystem structure and function.

A landscape-scale ecohydrological conceptualisation of the study area was developed to:

- enable the identification of environmental assets with a high level of ecohydrological connectivity (considered to be ecohydrological receptors); and
- provide a basis for assessing the potential of current and proposed mining operations to affect ecohydrological receptors via the alteration of hydrological regimes.

Under the conceptualisation, nine ecohydrological units (EHUs) were defined as landscape elements with broadly consistent and distinctive ecohydrological attributes. Relationships between different landscape elements are described in Figure 11and their distribution across the study area is shown on Map 8.

Upland source areas associated with EHUs 1 and 2 have similar ecohydrological regimes based on topographic position and drainage patterns. EHUs 3 and 4 receive surface water contribution from EHUs 1 and 2 before transmitting down-gradient into lowland areas. Three types of lowland plains have been recognised (EHUs 5, 6 and 7), which are distinguished on the basis of different geomorphology, vegetation and soil types. EHU 8 includes major drainage systems that receive, store and transmit large volumes of surface water. EHU 9 is associated with terminal areas in the drainage network, where water is accumulated, lost to evapotranspiration and/or contributes recharge into groundwater systems. The key attributes of each EHU are further described in Table 5.

Information contributing to the development of the EHUs included Pilbara land-systems mapping (van Vreeswyk et al., 2004), a high-resolution, digital-elevation model (DEM), interpretation of connectivity between surface and groundwater systems, major vegetation types based on consolidated vegetation mapping within BHP Billiton Iron Ore's tenements (Onshore Environmental, 2014), and inferred water use behaviour of major vegetation types based on Landsat Normalised Difference Vegetation Index (NDVI) data. Appendix A provides a detailed description of the methodology used to spatially define and validate the EHUs.

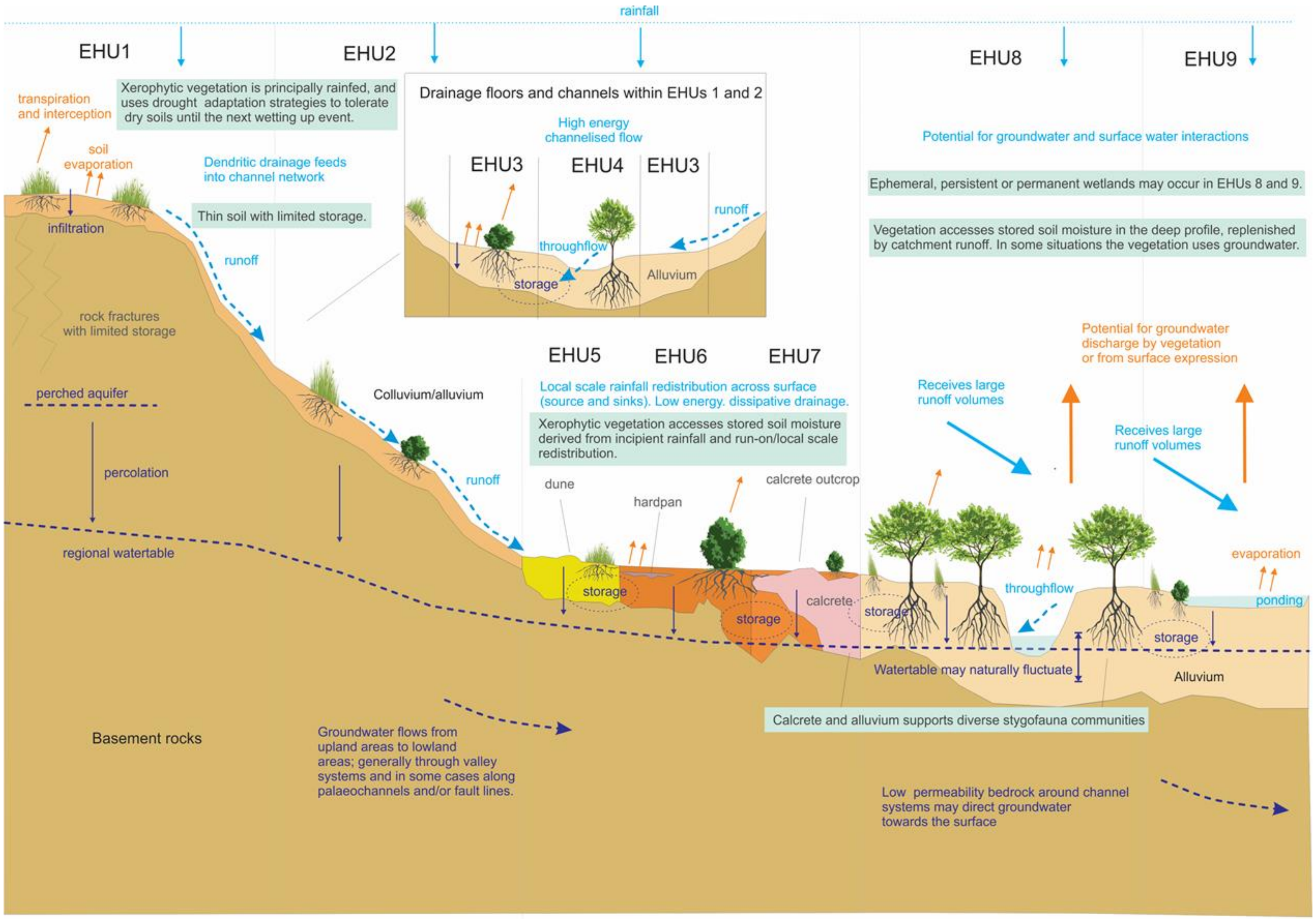

Figure 11 Landscape arrangement of ecohydrological units (EHUs)

Table 5 General attributes of landscape ecohydrological units (EHUs)

EHU	Landscape description	Surface water processes	Connectivity with groundwater regime	Major vegetation types
1	Upland source areas - hills, mountains and plateaux. Land surface is steep and rocky. Shallow or skeletal soils with frequent bedrock exposures.	Generally short distance overland flow into dendritic drainage networks (first to third-order streams).	Groundwater systems are deep and not accessible to vegetation.	Hummock grasslands. Vegetation water demand met by direct rainfall and localised surface runoff.
2	Upland source areas - dissected slopes and plains, down-gradient from EHU 1. Land surface is sloping with shallow to moderately deep colluvial soils.	Overland flow short distance into channel drainage systems (mainly first to fourth-order streams).	Groundwater systems are deep and not accessible to vegetation.	Hummock grasslands. Vegetation water demand met by direct rainfall and localised surface runoff.
3	Upland transitional areas - drainages within EHUs 1 and 2 that accumulate surface water flow from up-gradient. Alluvial soils of variable depth with greater storage capacity relative to soils in EHU 1 and 2.	Accumulation and infiltration of streamflow with some overland flows and channel breakouts. Excess volumes transferred to adjacent channels (EHU 4).	Groundwater systems are deep and not accessible to vegetation. Preferential recharge may occur as dictated by local-scale geology.	Smaller creek beds support hummock grasslands; larger creek beds 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 (greater than fifth order) within EHUs 1 and 2. Channels are high-energy flow environments, subject to bed load movement and reworking.	Channel beds and banks accept and store water during flow events. Moderate flows are transmitted down-gradient. Channels may support intermittent pools replenished by flood flows.	Regional groundwater systems are deep and not accessible to vegetation. Transient or less persistent shallow groundwater systems may develop beneath channels in places.	Channels are often 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 - flat to gently undulating plains with deep sandy soils of eolian origin and linear dunes up to about 15 m in height.	Poorly organised drainage. High rainfall infiltration in sandy areas. Runoff is minimal with localised accumulation in swales and depressions. Sandplains may receive and infiltrate inflows from up-gradient areas.	Groundwater systems are generally moderately deep (>10 m) to deep (>30 m) and rarely accessed by vegetation. Possible localised perching of groundwater.	Hummock grasslands with *Acacia* sp. and other shrubs. Distinctive grassland communities relative to other EHUs.
6	Lowland alluvial plains - broad depositional alluvial plains of low relief. Subsurface calcareous hardpans may be encountered.	Complex surface water drainage network with low energy channels; areas of sheetflow associated with banded-vegetation types. Some areas subjected to infrequent flooding. Infiltration may be significant at local scales in association with drainage foci.	Groundwater systems are generally moderately deep (>10 m) to deep (>30 m) and rarely accessed by vegetation.	*Acacia* shrublands; less commonly Hummock grasslands, Tussock grasslands or low shrublands of Bluebush and Saltbush.
7	Lowland calcrete plains - areas of low relief bordering major drainage tracts and termini.	Complex surface water drainage networks. Calcrete areas have increased potential for	Depth to groundwater can vary from shallow (<5 m) to deep (>20 m).	Hummock grasslands and *Acacia* scrublands with occasional Eucalypts.

EHU	Landscape description	Surface water processes	Connectivity with groundwater regime	Major vegetation types
	Shallow soils associated with calcrete mounds that occasionally outcrop.	infiltration. Land surfaces are generally dissected by low-energy drainages and there are often numerous drainage termini.	Localised pathways may facilitate rapid recharge. Groundwater systems are rarely accessed by vegetation but may support stygofauna assemblages.	Distinctive vegetation communities relative to other EHUs.
8	Lowland major channel systems and associated floodplains - channels are high-energy flow environments subjected to bed load movement, reworking and supporting large flow volumes in flood events. Their distribution may be modified during cyclonic floods.	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. The channels support transient, persistent and permanent riverine pools.	Depth to groundwater can vary from shallow (<5 m) to deep (>20 m). Shallow groundwater is often present beneath channels that may be connected with pools on occasions. The watertable is opportunistically accessed by vegetation. 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 recognised groundwater dependant vegetation communities in the Pilbara, including the key indicator species of *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 with calcrete and silcrete hardpans. Variable surface water salinity that may result in evaporites.	Drainage termini receive inflows from up-gradient drainages. Transient to persistent ponding may occur as dictated by flooding regimes with spillover possible in large flooding events. Sediment accumulation and evaporative concentration of salts.	Depth to groundwater can vary from shallow (<5 m) to deep (>20 m). Groundwater may be fresh, brackish or saline. The watertable may be opportunistically accessed 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, depending on the level of surface and groundwater connectivity; however, this is unlikely to be common.

5.9. Ecohydrological Sensitivity

The ecohydrological conceptualisation provides a basis for identifying and characterising the susceptibility of landscape elements to regional-scale change in surface and groundwater regimes. This includes the potential for a landscape element to be affected by mining-related disturbance activities in other landscape elements, as conferred by landscape-level connectivity. More sensitive landscape elements tend to have the following characteristics:

- They are located lower in the landscape and receive water inflows from up-gradient source areas. These source areas are generally spatially extensive relative to the receiving landscape element. In the case of surface catchments, the source areas often include a combination of upland and lowland landscape units. In the case of groundwater, inflows may be derived from spatially distant recharge zones.
- The magnitude of inflows is substantially greater than incident rainfall.
- There is considerable water storage capacity in the vadose zone and/or connected groundwater systems.
- Groundwater systems consist of well-developed aquifers. In places, the groundwater may interact with the surface (i.e. discharge via surface expression or use by phreatophytic vegetation).
- Ecosystems have evolved to exploit the relative abundance of water resources (and associated carbon/nutrients) available in these areas.

Landscape elements may have different ecohydrological sensitivities to modified surface and groundwater regimes respectively, owing to inherent differences between these water resources. The EHUs are more readily relatable to surface water regimes; however, it is also possible to determine broad relationships between EHUs and depth to watertable to help understand the implications of modified groundwater regimes.

5.9.1. Groundwater

The EHUs are primarily defined based on surface water features and processes, and therefore are not necessarily representative of the sub-surface groundwater environment. Despite this limitation, broad relationships between EHUs and groundwater systems can be discerned based on depth to watertable information. Depth to watertable is widely referenced as a reliable indicator of potential connectivity between groundwater-dependent ecosystems (GDEs) and groundwater resources, with vegetation dependency generally identified only in situations where groundwater is less than 10 m bgl (Loomes, 2010; Braimbridge et al., 2010; Rutherford et al., 2005; Sommer and Froend, 2014; Thomas 2014).

Depth to watertable is also indicator of stygofauna occurrence with high stygofauna abundancies prevailing where groundwater is less than 10 mbgl and low stygofauna abundancies where groundwater is deeper than 30 mbgl (Halse, 2014).

The depth to watertable across the study area was interpreted using aggregated bore records and surface topography. Depth ranges were compared with the spatial distribution of EHUs, demonstrating a strong alignment between areas of shallow watertable (less than 10 m bgl) and the distribution of EHUs 7, 8 and 9. EHUs 5 and 6 are largely associated with groundwater depths of between 10 and 30 m bgl, whilst upland EHUs tend to have groundwater depths of more than 30 m bgl. The methodology for estimating the depth to water table across the study area, and their alignment with EHUs is provided in Appendix B.

Sensitivity to changes in groundwater regimes was rated as low in areas interpreted to have a deep watertable (typically greater than 30 m bgl). In these areas, groundwater is disconnected from surface ecosystems, which instead rely on surface water inputs to satisfy their ecological water requirements. Deep groundwater is also correlated with low stygofauna abundance. Sensitivity is rated as moderate in areas interpreted to have a groundwater depth between 10 and 30 m bgl. In these areas there is limited potential for groundwater use by vegetation; however, there is an increased likelihood of the occurrence of stygofauna populations in groundwater systems. Sensitivity is rated as high in areas interpreted to have shallow groundwater of less than 10 m bgl. These areas have an increased likelihood of surface water and groundwater interaction, and have the greatest potential to support groundwater dependent vegetation, wetlands and stygofauna communities. The groundwater sensitivity ratings for each EHU are presented in Table 6 and a spatial depiction of landscape sensitivity to modified groundwater regimes is shown in Map 9.

Table 6 Landscape-scale ecohydrological sensitivity to change in groundwater regimes

Ecohydrological unit	Depth to watertable	Sensitivity rating
1	>30 mbgl	**Low**
2	>30 mbgl	**Low**
3	>30 mbgl	**Low**
4	>30 mbgl	**Low**
5	10 to 30 mbgl	**Moderate**
6	10 to 30 mbgl	**Moderate**
7	<10 mbgl	**High**
8	<10 mbgl	**High**
9	<10 mbgl	**High**

5.9.2. Surface water

In determining landscape ecohydrological sensitivity to change in the surface water regime, the following factors were considered:

- Landscape position with respect to patterns of drainage and the likelihood of receiving significant water inputs from up-gradient source areas. Landscape elements with a low rating receive no or minimal inflows from small catchment areas; while higher-rated areas tend to receive significant inflows from large, multifaceted catchment areas and multiple drainages.
- Contribution ratio of inflows (from other landscape elements) to incidental rainfall. Rainfall is the principal input to landscape elements with a low rating, whereas water inputs to high-rated areas are dominated by surface and in some cases groundwater inflows.
- Residence time of water within the landscape element, providing an indication of the duration that water is available for ecosystem use. Landscape elements with a low rating tend to have transiently available water that is rapidly lost (e.g. by run-off or rapid evapotranspiration). High-rated areas have longer residence times associated with water capture, storage and release. This may contribute to habitat complexity enabling a greater diversity of water uses strategies within the ecosystem.
- The overall quantity of water available to ecosystems. Landscape elements with a low rating tend to include less-productive ecosystems that are highly constrained by water supply. High-rated areas have relatively abundant water (either persistently or episodically) and tend to host more diverse and productive ecosystems.

Qualitative sensitivity ratings for each EHU were developed from holistic consideration of these factors (Table 7). EHUs 1 and 2 have a low rating given their negligible dependence on water contribution from other landscape elements. EHUs 3 and 4 have a moderate rating, given their functionality as upland receiving areas. Although a significant proportion of water received by these landscape elements is derived from runoff, the overall magnitudes of water received are relatively small as dictated by catchment area. The storage capacity of EHUs 3 and 4 is generally limited and a significant proportion of inflows are transmitted to EHUs further down-gradient. Direct rainfall is the major water input into EHUs 5, 6 and 7, which may be locally redistributed but is largely retained within these land elements prior to loss to evapotranspiration. As a result, these lowland EHUs have a low level of hydrological connectivity with the wider landscape. EHUs 8 and 9 have a high rating as they receive and store large volumes of water sourced from convergent inflows. They are characterised by more complex water regimes and typically support ecosystems with more diverse and demanding ecological water requirements.

A spatial depiction of landscape sensitivity to modified surface water regimes is shown in Map 10. Much of the study area has a low sensitivity rating. Areas of moderate sensitivity are associated with drainage tracts in upland settings. Areas of high sensitivity include the major drainage basins (e.g. Fortescue Marsh, Coondewanna Flats), the Fortescue River and major creek systems (e.g. Weeli Wolli Creek, Marillana Creek and the various creeks that converge at Ethel Gorge).

Table 7 Landscape-scale ecohydrological sensitivity to change in surface water regimes

Ecohydrological unit	Source area for inflows	Residence time within landscape	Quantity of water for ecosystems	Contribution ratio of streamflow to incidental rainfall	Overall sensitivity rating
1	Low	Low	Low	Low	**Low**
2	Low	Low	Low	Low	**Low**
3	Low-Mod	Low-Mod	Low-Mod	Mod-High	**Moderate**
4	Low-Mod	Low-Mod	Low-Mod	Mod-High	**Moderate**
5	Low	Moderate	Low-Mod	Low	**Low**
6	Low	Moderate	Low-Mod	Low	**Low**
7	Low	Moderate	Low-Mod	Low	**Low**
8	High	Mod-High	High	High	**High**
9	Mod-High	High	High	High	**High**

6. Ecological Assets and Ecohydrological Receptors

The study area includes a number of recognised ecological assets (Table 8; Map 11). These can be classified based on the legislative framework, in place for their protection, as follows:

- Tier 1 ecological assets are directly protected under Federal or State legislation, or otherwise recognised as having specific conservation significance under a formal international ranking system. They contain species that are known to be under threat being listed under IUCN Red-list categories and/ or the 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* (e.g. Declared Rare Flora).
- Tier 2 ecological assets have a formal level of protection for conservation purposes or foreseeable level of future protection. They include Environmental Sensitive Areas (ESAs), State-listed Threatened and Priority Ecological Communities, wetlands listed in the Directory of Important Wetlands in Australia, and the Department of Parks and Wildlife (DPaW) proposed 2015 pastoral lease excision areas. This tier may contain species that are listed under international conventions (e.g. JAMBA, CAMBA), as Marine or Migratory under the EPBC Act, in Schedule 3 of the WC Act or as a priority species, and IUCN Category V and VI depending on the values and objectives of the specific reserve.
- Tier 3 ecological assets have no formal level of protection for conservation purposes or foreseeable level of future protection. The tier may contain native species subject to the WC Act, but without any special protections (e.g. as schedule listed species) or other traits that may confer elevated conservation significance (e.g. range outliers, novel and/or undescribed species).

BHP Billiton Iron Ore considers that Tier 1 ecological assets require the most comprehensive level of management consistent with their legislative status. Tier 2 ecological assets are recognised to have conservation importance, but with management priorities determinable on a case-by-case basis. Tier 3 assets are considered to require less comprehensive management than Tier 1 and Tier 2 assets; as such, they have not been considered in the regional scale ecohydrological change assessment.

Tier 1 ecological assets proximal to the study area include Kariijini National Park and the Mungaroona Range Nature Reserve. Most of the Kariijini National Park is situated outside the study area (Map 11) and will not be subject to ecohydrological change associated with the Strategic Proposal. Hydrological connectivity exists between the south east portion of the national park and land to the east associated with the Turee Creek East drainage system. This area includes the West Angelas mine operated by Rio Tinto's iron ore business and BHP Billiton Iron Ore's proposed Mudlark mining area (refer to Section 7). Mungaroona Range Nature Reserve (Tier 1) is hydrologically disconnected from the study area and will not be subject to ecohydrological change associated with the Strategic Proposal.

There are seven Tier 2 ecological assets in the study area, five of which occur in the receiving landscape units. These five have strong ecohydrological connectivity with the regional hydrological regime and high ecohydrological sensitivity and therefore may experience ecohydrological change associated with the Strategic Proposal. These include

- Coondewanna Flats – Coolibah and Lignum Flats (PEC)
- Ethel Gorge Stygobiont Community (TEC)
- Fortescue Marsh - Marsh Land System (PEC)
- Freshwater Claypans of the Fortescue Valley (PEC)
- Weeli Wolli Spring community (PEC)

These assets are classified as ecohydrological receptors. Summary descriptions of each receptor including ecohydrological conceptualisations are provided in Sections 6.1 to 6.5, with additional detail also provided in Appendices C, D, E and F.

Two Tier 2 ecological assets occurring in the study area are located in the upland and transitional landscapes. These ecological assets are situated in areas with a low ecohydrological sensitivity and considered to rely on direct or locally redistributed rainfall to support their unique vegetation communities. Therefore they have no regional hydrological dependency and have low potential to experience ecohydrological change associated with the Strategic Proposal:

- West Angelas cracking clay communities; and
- Fortescue Valley sand dune communities.

Three additional Tier 2 ecological assets are situated outside the study area, are hydraulically disconnected from any proposed mining areas, and will not be subject to ecohydrological change associated with the Strategic Proposal. These include:

- Brockman Iron cracking clay communities PEC (located in Karijini National Park);
- The Mt Bruce Coolibah-Lignum Flats PEC (located in Karijini National Park); and
- Wona Land System (located in the Chichester Range to the north of the study area).

Table 8 Tier 1 and Tier 2 ecological assets considered in the ecohydrological change assessment

Tier	Ecological Assets	Recognised Species
1	Karijini National Park Mungaroona Range Nature Reserve	*Lepidium catapycnon* (Hamersley lepidium) *Thryptomene wittweri* (Mountain thyryptomene) *Liasis olivaceus barroni* (Pilbara Olive Python) *Pezoporus occidentalis* (Night Parrot) *Rhinonicteris aurantia* (Pilbara leaf-nosed bat) *Dasyurus hallucatus* (Northern Quoll) *Dasycercus cristicauda* (Crest tailed Mulgara) *Falco peregrinus* (Peregrine Falcon) *Falco hypoleucos* (Grey Falcon) *Macrotis lagotis* (Greater Bilby)
2	Brockman Iron Clay Communities Coondewanna Flats Ethel Gorge Stygobiont Community Fortescue Marsh Fortescue Valley Sand Dunes Freshwater Claypans of the Fortescue Valley West Angelas cracking clay Weeli Wolli Spring Community Wona Land System	*Acacia bromilowiana* *Acacia effuse* *Acacia kenneallyi* *Acacia subtiliformis* *Aristida jerichoensis* var. *subspinulifera* *Aristida lazaridis* *Brachyscome* sp. Wanna Munna Flats *Brunonia* sp. Long hairs *Bulbostylis burbidgeae* *Calotis latiuscula* *Crotaliaria smithiana* and others (75 in total)

6.1. Coondewanna Flats – Coolibah and Lignum Flats

6.1.1. Landscape context

Coondewanna Flats is an internally-draining surface water feature located 110 km northwest of Newman. It has a catchment area of approximately 866 km^2. The flats occur within an intermontane area bound by hills of Mt Robinson and The Governor to the east and south, and Packsaddle and Mt Meharry to the north and west.

Surface water flows towards the flats from the north, west and south. Surface water runoff accumulates on the flats before being lost to evaporation or infiltrating into the Tertiary detritals, where it replenishes soil water in the unsaturated zone and potentially contributes to groundwater recharge. Lake Robinson (EHU 9) occurs within a topographic low at the northeastern extent of the flats and is ultimate terminus for catchment runoff. It supports distinct Coolibah *(Eucalyptus victrix*) woodland vegetation communities. The surrounding flats (EHU 6) are characterised by poorly-defined drainages with Coolibah and mulga (*Acacia aptaneura*) woodland vegetation.

The depth to groundwater beneath the Coondewanna Flats is about 20 m bgl suggesting that interaction between the groundwater system and terrestrial ecosystems is unlikely. Ongoing studies on the hydrology and vegetation water use have found that vegetation communities of the flats are likely to be dependent on the surface water regime of the flats.

6.1.2. Environmental values

Coondewanna Flats includes several vegetation communities with two being classified as priority ecological communities (DPaW, 2014):

- Coolibah woodlands over lignum over swamp wandiree (Priority 1). Lake Robinson has the only known occurrence of this community.
- Coolibah and Mulga woodland over lignum and tussock grass on clay plains (Priority 3). This community has only been identified at Coondewanna Flats and Wannamunna, which is about 40 km to the southeast. It is extensive on the flats to the south of Lake Robinson.

Waterbodies formed on the Coondewanna Flats from flood waters are ephemeral, but may persist for several months following periods of heavy rainfall depending on the volume of surface water contribution. Little is known about the water quality or aquatic invertebrate assemblages of the flooded waterbody (Pinder *et al*. 2009).

6.1.3. Ecohydrological conceptualisation

An ecohydrological conceptualisation of Coondewanna Flats is provided in Figure 12 with the key aspects being:

Surface and groundwater systems

- Surface water runoff from surrounding catchments is attenuated in the internally-draining, low-relief landscape of the flats. It principally accumulates in Lake Robinson and other depressions to the south but extends more widely across the flats during large flooding events.
- Surface water flow into Coondewanna Flats is likely to occur every three in four years and is an important process for replenishing soil moisture in the unsaturated profile.
- Beneath the flats, an unconfined calcrete aquifer is present at a depth of 20 to 30 m bgl. It is overlain by largely unsaturated Tertiary detritals and underlain by low to high permeability dolomite of the Wittenoom Formation. This dolomite forms part of a regional groundwater flow system that ultimately reaches Weeli Wolli Spring.
- Groundwater recharge is associated with the infiltration of ponded surface water runoff. Recharge events are estimated to occur once in every four years. RPS (2014a) estimated that annual average recharge rates are about 2.4 GL at Lake Robinson and 4 GL over the broader Coondewanna Flats area. The Coondewanna Flats is considered an important groundwater recharge area for Weeli Wolli Spring.
- Groundwater discharge occurs as outflow to the South Flank and Mining Area C (MAC) Valleys, which hydraulically connect the Coondewanna and Weeli Wolli Spring catchments from a groundwater perspective.

- A southwest-northeast trending dyke may act as a partial groundwater flow barrier to regional throughflow at the eastern end of Coondewanna Flats.

Ecosystem components

- *E. victrix* trees on Coondewanna Flats rely on stored soil moisture to meet their water requirements, which is replenished by surface water inflow. Studies completed by BHP Billiton Iron Ore indicate these trees are able to obtain soil moisture for prolonged periods from horizons within the unsaturated zone above the watertable (Astron, 2014). The *E. victrix* woodlands at Coondewanna Flats are considered unlikely to rely on groundwater; however, a precautionary approach has been adopted as further studies are required to fully demonstrate and confirm any groundwater dependency.
- The surface water dynamics of Coondewanna Flats are likely to influence bud-set, flowering, seed production and seedling recruitment of the *E. victrix*. However, further investigations are necessary to understand the relationship between flooding regimes and the reproductive cycle of the woodland trees.
- Mulga is a shallow-rooted species with xerophytic adaptations to drought stress. Water use requirements of the Mulga communities on the flats are most likely met by soil water in surface layers (up to 5 m bgl), which is replenished by rainfall and runoff.
- The Lake Robinson waterbody is ephemeral but may persist for several months.

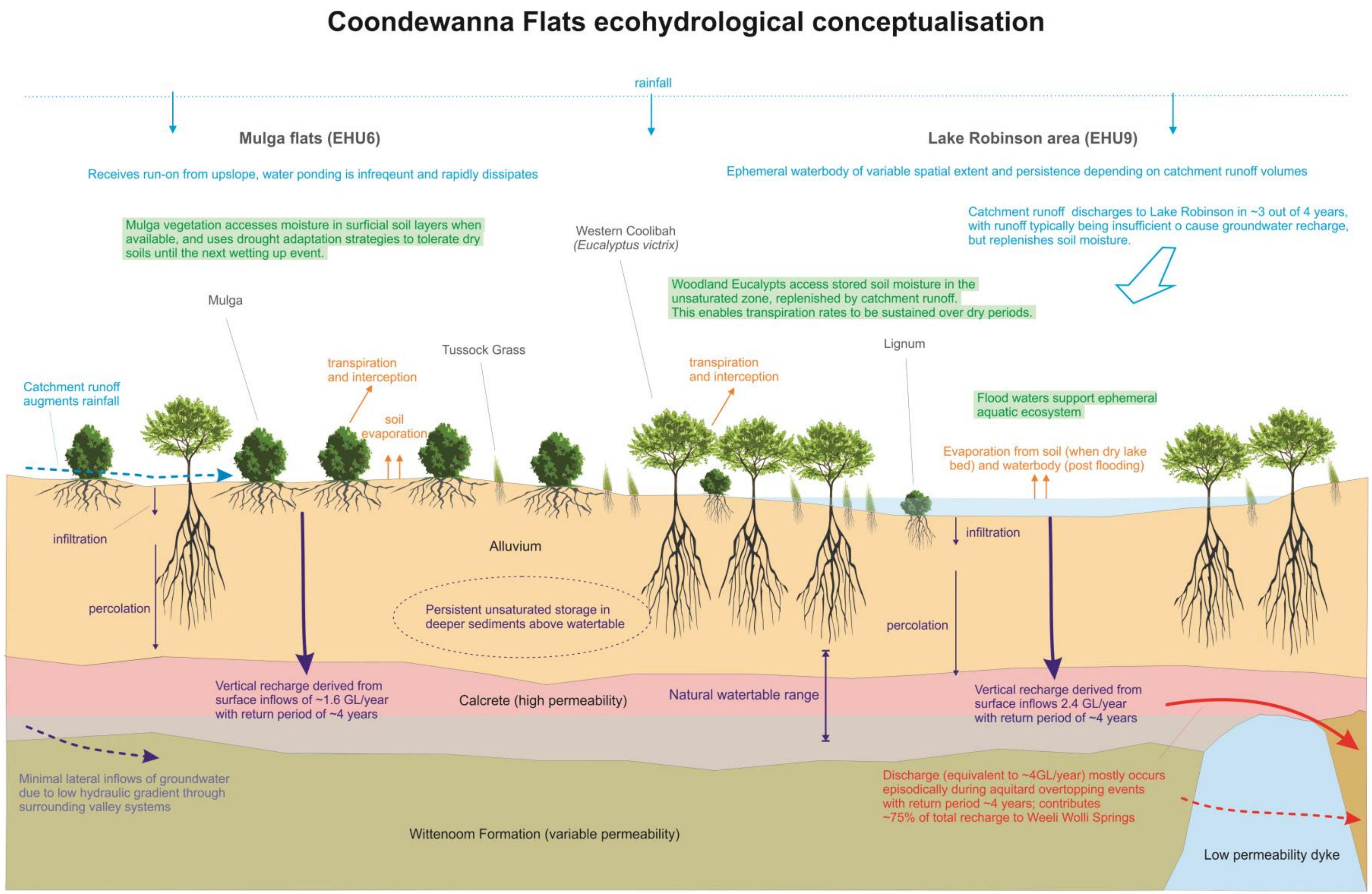

Figure 12 Coondewanna Flats ecohydrological conceptualisation

6.2. Ethel Gorge Stygobiont Community

6.2.1. Landscape context

Ethel Gorge is situated on the Fortescue River 15 km northeast of Newman and downstream of the confluence of Homestead, Shovelanna and Warrawanda Creeks. It is formed where the Fortescue River flows through the Ophthalmia Range in a northerly direction. Downstream of Ethel Gorge, the river flows via a narrow channel to the north, then onto a broad floodplain and ultimately into the Fortescue Marsh. It is effectively a subsurface gorge with the watertable becoming shallower as bedrock shallows, and it is also a confluence for regional streamflow.

The Fortescue River and its surrounding floodplain in the vicinity of Ethel Gorge is a Receiving Landscape Unit (EHU 8) within the ecohydrological conceptualisation. Surface and groundwater contribution from the entire upstream catchment area are focused into Ethel Gorge resulting in relatively shallow groundwater levels typically less than 10 m below ground level (m bgl). This provides the basis for interactions between the groundwater regime and terrestrial ecosystems.

The shallow groundwater levels at Ethel Gorge have been artificially sustained by the Ophthalmia Dam since the early 1980s. The dam has and continues to influence the hydrology of the Ethel Gorge area.

6.2.2. Environmental values

The shallow alluvial and calcrete aquifers of Ethel Gorge support a unique and diverse stygofauna assemblage, constituting the Ethel Gorge Aquifer Stygobiont Community Threatened Ecological Community (TEC). It exists in the shallow alluvial aquifer, within an area on the Fortescue River floodplain extending approximately 2 km upstream to 4 km downstream of Ethel Gorge.

The Ethel Gorge area supports riparian woodland vegetation communities (including the facultative phreatophytes *Eucalyptus camaldulensis* and *E. victrix*) that contribute to groundwater discharge. The Ethel Gorge area also hosts a number of persistent pools for which little ecological information is available.

6.2.3. Ecohydrological conceptualisation

An ecohydrological conceptualisation of the Ethel Gorge system is provided in Figure 13 with the key features being:

Surface and groundwater systems

- The Ethel Gorge groundwater system occurs in detrital sediments bound by low permeability basement rocks. It consists of a highly-permeable alluvial aquifer with an upper horizon of sandy-alluvium and calcrete (shallow aquifer) and a lower horizon of gravelly alluvium (deep aquifer). The two horizons are separated by an extensive low permeability clay/silt sequence. Orebody aquifers, hosted in the adjacent Brockman Formation, may have varying levels of hydraulic connection with the detrital aquifers.
- Ophthalmia Dam has a strong influence on the hydraulic response of the groundwater system. Since the early 1980s, the dam and associated managed aquifer recharge (MAR) has resulted in increased groundwater recharge and elevated water levels in the shallow aquifer.
- The shallow aquifer is unconfined and receives recharge from direct infiltration associated with streamflow. In addition to seasonal recharge, this aquifer also receives substantial leakage (estimated at about 50 ML/day in RPS, 2014b) from Ophthalmia Dam.
- The watertable in the shallow aquifer is less than 10 m bgl. This ensures a substantial saturated thickness in the upper alluvium and calcrete, which constitutes the main stygofauna habitat and root-zone of phreatophytic vegetation.
- The wetter climate since 2000 has also contributed to a high watertable resulting in a greater thickness of saturated alluvium and calcrete habitat for stygofauna.
- The deeper aquifer is confined by the overlying clay/silt sequence with groundwater levels influenced by hydraulic connectivity with Ophthalmia Dam. It is unlikely that this deeper aquifer has much influence on the distribution and presence of Ethel Gorge ecosystems.

Ecosystem components

- The area in the vicinity of Ethel Gorge and Ophthalmia Dam supports approximately 3 650 ha of Eucalypt woodland communities, including phreatophytic trees. These access shallow groundwater and are estimated to contribute to groundwater discharge via evapotranspiration of up to 60 ML/day. The proportion of groundwater utilised by the woodlands may be greatest where the depth to watertable is shallow (i.e. where soil moisture storage in the unsaturated profile is limited by depth).
- The Stygobiont Community TEC exists in the saturated alluvium and calcrete of the shallow aquifer. The deep aquifer is less important for the stygobiont community.
- Groundwater levels in the aquifer hosting the TEC have historically fluctuated; mostly in relation to climatic cycles of wetter and drier periods. The commissioning of Ophthalmia Dam has changed the groundwater regime by contributing to elevated groundwater levels. The dam plays an important role in sustaining the present day groundwater system and hence stygofauna habitat.

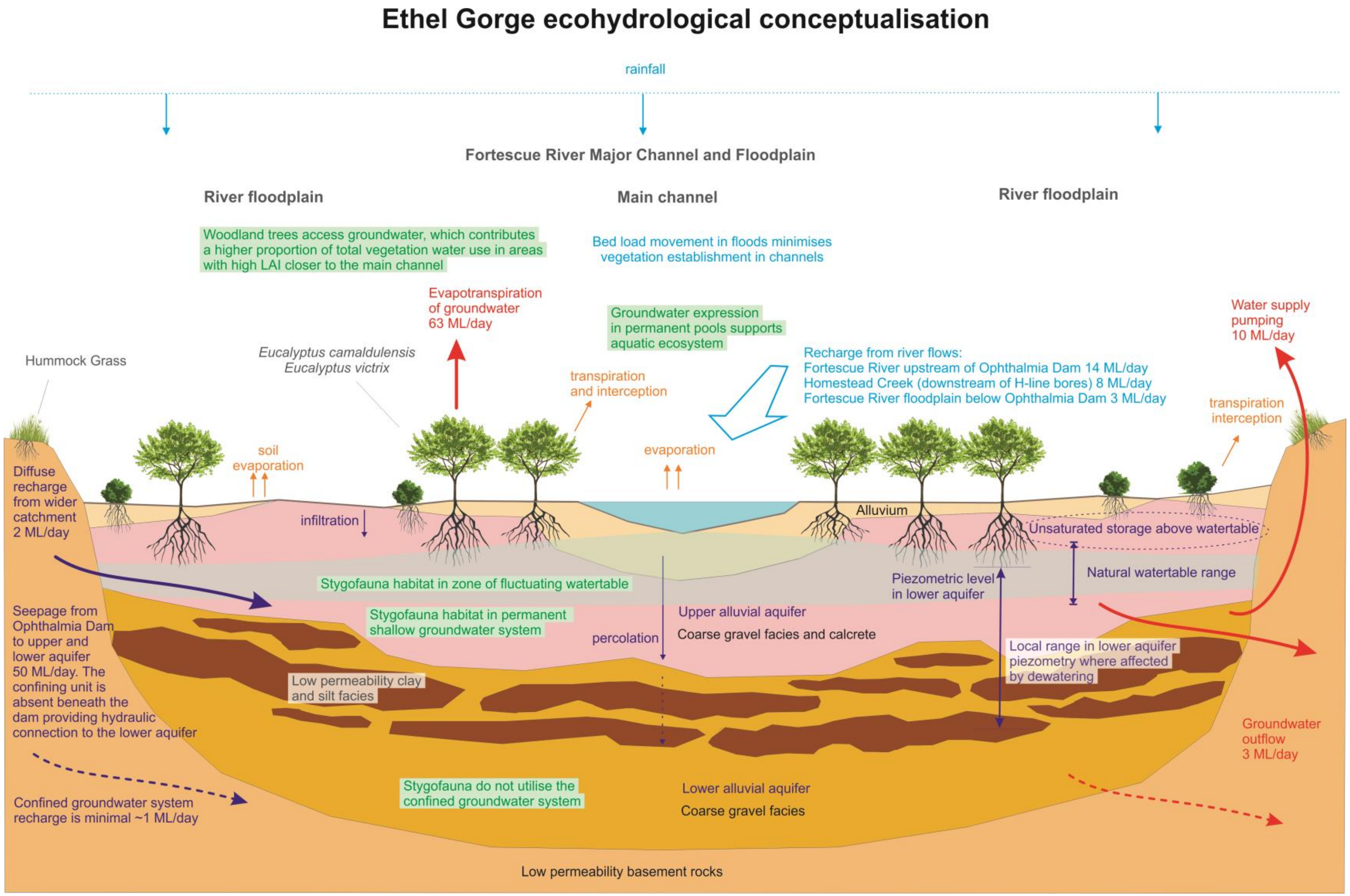

Figure 13 Ethel Gorge ecohydrological conceptualisation

6.3. Fortescue Marsh

6.3.1. Landscape context

The Fortescue Marsh is a brackish to saline, endorheic wetland within the drainage terminus of the Upper Fortescue River. It is a unique regional-scale landscape feature, extending for about 100 km along the Fortescue Valley with a width of between 3 and 10 km. The boundary of the Marsh is broadly defined by the Marsh Land System (van Vreeswyk et al., 2004). Bed levels in the Marsh lie between 400 m and 405 m AHD with fringing samphire vegetation typically extending to about 407 to 408 m AHD.

Based on ecohydrological conceptualisation, the Marsh is classified as EHU 9. It is surrounded by alluvial plains (EHU 6) of the Fortescue River Valley, and some areas of calcrete plain (EHU 7) along its southern margin. A number of major creek systems (EHU 8) contribute surface flow into the Marsh with the most important being the Upper Fortescue River and Weeli Wolli Creek.

The Marsh is episodically inundated following large rainfall, surface water runoff and streamflow events. Analysis of flood levels and high resolution topographical data indicates that the Marsh waterbody segregates into eastern and western basins. Floodwaters may persist for several months providing breeding and foraging habitat for waterbirds and other biota. Surface waterbodies in the Marsh rapidly evaporate leading to salt accumulation. Beneath the Marsh, the groundwater is hypersaline.

The Marsh has a history of pastoral land use since the late 19th century and is still accessed by roaming cattle. Large portions of the Marsh have been identified for transition into conservation tenure and management following the expiry of overlapping pastoral leases in mid-2015.

6.3.2. Environmental values

The Marsh has a wide range of environmental values summarised as follows (EPA, 2013; Department of Parks and Wildlife, 2014).

- classified as a wetland of national importance within the Directory of Important Wetlands in Australia (Ref. WA066);
- recognised as a nationally important bird area (Dutson et al. 2009) and supporting multiple species subject to international treaties (e.g. JAMBA, CAMBA, ROKAMBA);
- the Marsh Land System is classified as a Priority Ecological Community (Priority 1);
- provides habitat for multiple rare plant taxa (endemic *Eremophila*, *Tecticornia* and other Priority species);
- provides habitat for rare vertebrate fauna - possibly including the critically endangered Night Parrot (*Pezoporus occidentalis;* EPBC Act Endangered, WC Act Schedule 1). Additional fauna species of conservation significance are present in areas fringing the Marsh including the Bilby (*Macrotis lagotis*; EPBC Act Vulnerable, WC Act Schedule 1), Northern Quoll (*Dasyurus hallucatus;* EPBC Act Endangered, WC Act Schedule 1), and Mulgara (*Dasycercus cristicauda;* EPBC Act Vulnerable, WC Act Schedule 1); and
- provides habitat for rare invertebrate fauna (locally restricted aquatic invertebrates).

These values collectively contribute to the high conservation status of the Marsh. In 2013, the Environmental Protection Authority (EPA) published information and management guidance for protecting the water regime and environmental values of the Marsh (EPA Report 1484; EPA 2013). Further details on specific environmental values of the Marsh are provided in the EPA guidance document.

6.3.3. Ecohydrological conceptualisation

An ecohydrological conceptualisation of the Marsh is provided in Figure 14 with the key aspects being:

Surface and groundwater systems

- Surface water inflows to the Marsh are largely contributed by the Fortescue River and Weeli Wolli Creek, accounting for about 52% and 19% of mean annual inflows respectively. Catchment areas for these major drainages extend outside the study area. The remaining inflow (29%) derives from smaller catchments that report directly into the Marsh.

- Flooding is generally associated with cyclonic rainfall and runoff in the summer months, with large-scale inundation events estimated to occur every five to seven years on average. Inundation of the eastern and western basins may be different for smaller events; however, large-scale inundation extends across both basins.
- Surface ponding is facilitated by the presence of relatively low permeability clay and silcrete/calcrete hardpans in the surficial sediments. Higher permeability zones within these sediments may provide pathways for the infiltration of floodwater into the shallow groundwater system.
- A shallow, unconfined aquifer is present in the surficial sediments. Groundwater levels range between 2 and 4 m bgl with the shallow watertable being influenced by a combination of flooding events, groundwater inflow and evapotranspiration. Soil moisture in the shallow, often unsaturated alluvium, of the Marsh is replenished by rainfall and surface water inflows. During flooding events, localised groundwater mounds may develop for a short time.
- Beneath the surficial sediments, there are clayey aquitard and calcrete horizons of the Oakover Formation throughout the Tertiary detrital aquifer. These horizons provide vertical barriers and lateral pathways for groundwater flow that may influence groundwater recharge and discharge processes. There is limited lateral groundwater flow towards the Marsh from the margins of the Fortescue River Valley under low hydraulic gradients.
- The Marsh water balance is dominated by surface water contribution. Major flooding events have potential to contribute up to 100 GL that enable the refilling of the unsaturated zone and lead to the creation of large areas of ponded water.
- On average, approximately 200 GL/yr surface water flows into the Fortescue Marsh. Inflow volumes vary widely with the median inflows of 61 GL/yr and the maximum annual inflow of more than 1400 GL/yr.
- Large-scale inundation events, associated with cyclonic rainfall, occur about once in five to seven years, during which more than 20% of the Marsh is inundated. The maximum recorded flooding extent occurred in April 2000 which inundated 985 km^2 (50%) of the Marsh.
- Groundwater contribution is estimated at 40 GL/yr with the main groundwater throughflow occurring from the Chichester Ranges (20 GL/yr) and Upper Fortescue River (8 to 10 GL/yr). Most of this contributing water is considered to be lost via direct evaporation from impounded waterbodies and the Marsh surface, capillary evaporation through the marsh bed, and potentially evapotranspiration from vegetated surfaces during the period between floods (interfloods).

Ecosystem components

- The interior of the Marsh comprises sparsely vegetated clay flats within a series of low elevation flood basins. Vegetation recruitment may occur during dry phases; however, the frequency and depth of inundation events is a constraint to long-term vegetation persistence.
- Fringing the lake bed extent are unique samphire vegetation communities including a number of rare flora taxa. Species zonation is evident and considered to be a function of the combined stresses of seasonal drought, soil salinity, waterlogging and inundation. Structural complexity is provided by patches of lignum shrubland (*Duma florulenta* and *Muellerolimon salicorniaceum*), grassland areas dominated by *Eragrostis* and *Eriachne* species, and *Melaleuca* woodlands (*M. glomerata* and *M. lasiandra*). The *Melaleuca* woodlands in particular may be important for providing roosting and nesting sites for waterbirds.
- Samphire vegetation communities exhibit conservative water use behaviour, and are most likely reliant on pulses of fresh water associated with floods and stored soil moisture. The flooding regime is likely to be a major factor influencing samphire recruitment and mortality.
- The Marsh habitat may contribute to the foraging range of fauna of conservation significance (i.e. Bilby, Northern Quoll, Mulgara and Night Parrot).
- The Marsh supports aquatic invertebrate assemblages of conservation interest including species known only to be present in the Marsh; however, little is known of the ecological requirements of these taxa.

- The Marsh has not been sampled for stygofauna owing to a lack of bores located within the Marsh. However; subterranean fauna communities in areas adjacent to the Marsh are relatively poorly developed when compared with other Pilbara localities.
- A number of persistent pools, known as Yintas, are present on the northern fringe and associated with drainage channels from Chichester Range and the inflow of the upper Fortescue River. These may be sustained by storage in the surrounding alluvium following flood events and provide possible refugia for some aquatic fauna species during inter-floods.

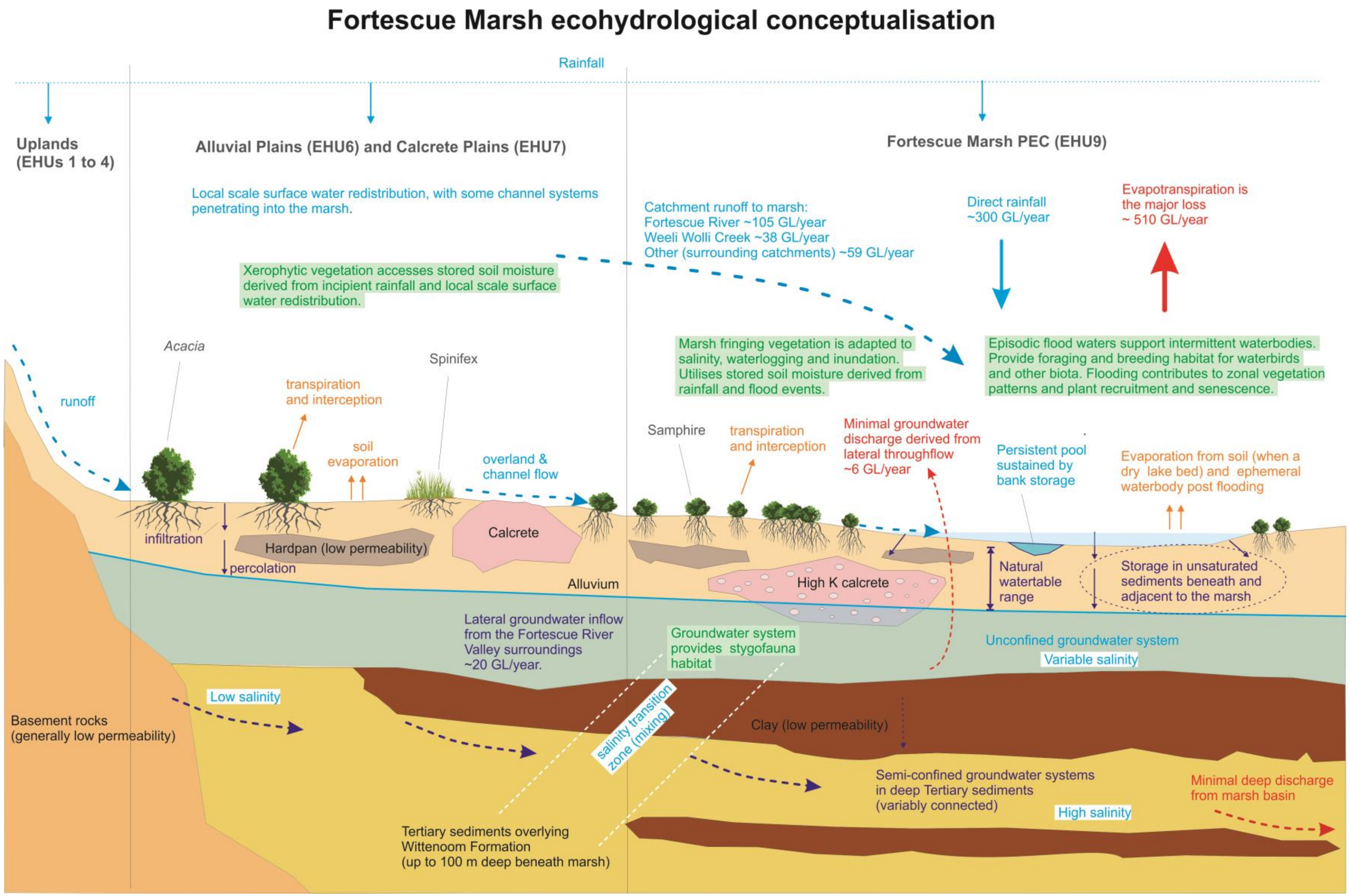

Figure 14 Fortescue Marsh ecohydrological conceptualisation

6.4. Freshwater Claypans of the Fortescue Valley

6.4.1. Landscape context

The Fortescue River Valley, downstream of the Fortescue Marsh, supports a series of claypans adjacent to the main river channel. Three of these claypans occur in the study area. Based on the ecohydrological conceptualisation, these claypans are receiving areas (EHU 9) that support unusual flora and fauna communities. They are characterised as having relatively few trees (*Eucalyptus victrix*) and expansive bare clay flats.

6.4.2. Environmental values

Five claypans within the Fortescue River, west of the Goodaidarrie Hills, have been classified as the Freshwater Claypans of the Fortescue Valley PEC (DPaW, 2014). These claypans are considered to be important for waterbirds, invertebrates and some poorly collected plants (*Eriachne* spp, *Eragrostis* spp. grasslands).

6.4.3. Ecohydrological conceptualisation

Compared to the other ecohydrological receptors, little is known about the Freshwater Claypans of the Fortescue Valley as they are distant from any existing or referred mining project and has therefore not been studied in the context of environmental approvals. An ecohydrological conceptualisation of the Freshwater Claypans of the Fortescue Valley is provided in Figure 15 with the key features being:

Surface and groundwater systems

- Surface water runoff is attenuated in the internally-draining, low-relief landscape of the claypans. The estimated flooding frequency may be similar to the Fortescue Marsh ranging between 1 in 5 years to 1 in 27 years. No information is available on flood levels and regimes that would be required to support the claypan ecosystems.
- Soil moisture in the claypan sediments is replenished by a combination of rainfall and surface inflows.
- Waterbodies in the claypans are rapidly evaporated after flooding.
- Large floods that exceed the storage volume of the claypan will overflow and provide a flushing mechanism that restricts salt accumulation (in contrast with the Fortescue Marsh environment).
- The depth to watertable beneath the claypans is unknown, but likely to be about 2 to 4 m bgl.
- Little is known of the hydrostratigraphy beneath the claypans; however, they are likely underlain by low permeability sediments that may result in localised perching of water above the regional groundwater system. Further investigations are required to determine the underlying stratigraphy.

Ecosystem components

- The expansive bare clay flats are fringed with *Eucalyptus victrix* and tussock grassland vegetation communities. The Eucalypt trees are likely to rely on stored soil moisture accumulated from surface inflows.
- The claypans support diverse aquatic invertebrate assemblages during flood events. Waterbody ephemerality, turbidity and connectivity with the broader Fortescue River floodplain may be important factors that may influence species composition; however, the ecology of the claypans is not well understood.
- The claypans provide foraging habitat for waterbirds, and may also provide breeding habitat for some species.

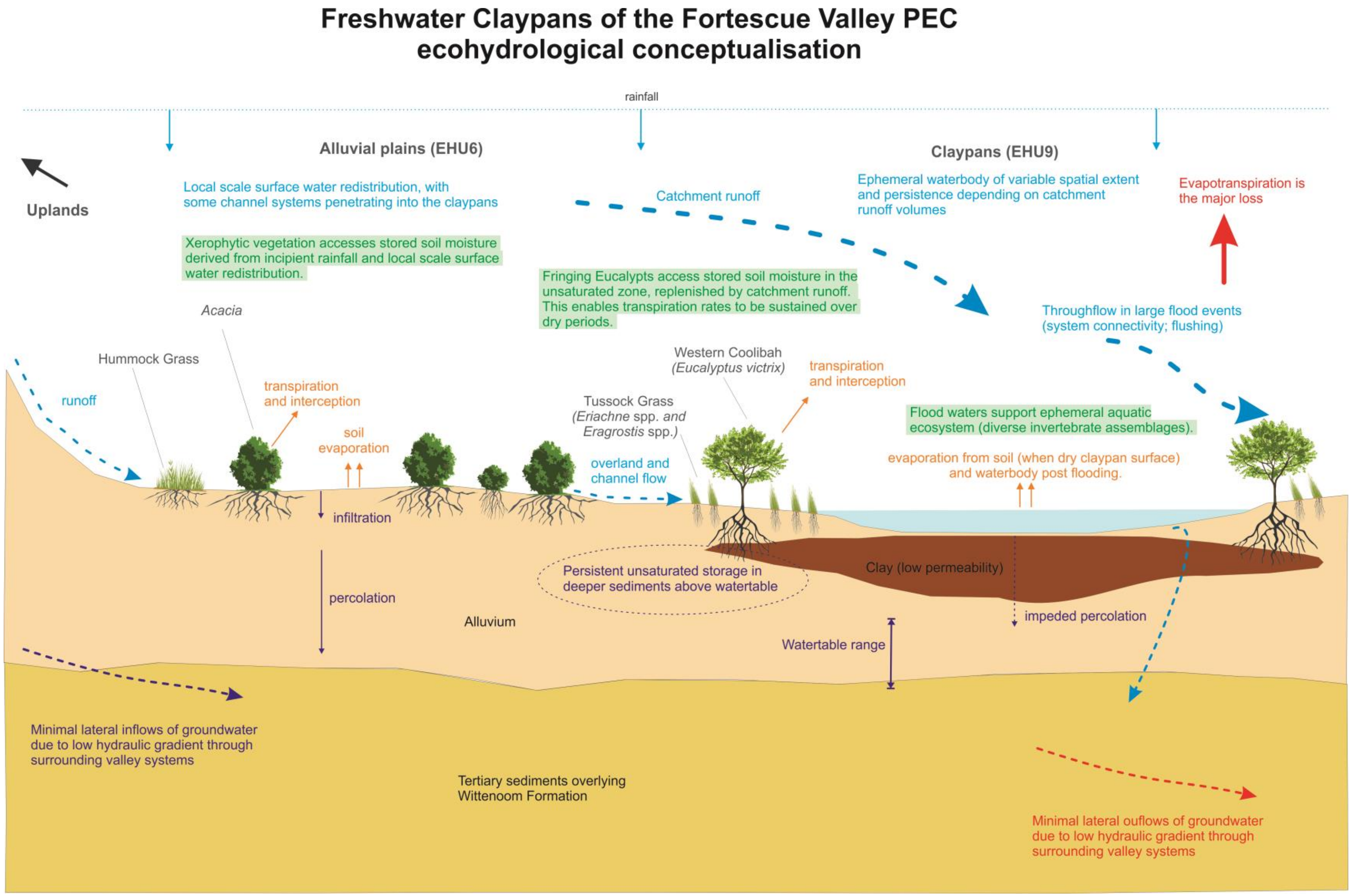

Figure 15 Freshwater claypans ecohydrological conceptualisation

6.5. Weeli Wolli Spring Community

6.5.1. Landscape context

Weeli Wolli Spring is located approximately 75 km northwest of Newman and comprises an area where surface water and groundwater flows discharge from the Upper Weeli Wolli Creek catchment. The spring occurs where groundwater flow is constrained through a gorge in the Wildflower Range. The creek and surrounding floodplain area (EHU 8) support permanent pools and riparian woodlands.

A shallow groundwater system with extensive areas of calcrete is present up-gradient of the spring. Downstream of the gorge, the creek flows via a narrow channel past the confluence with Marillana Creek and ultimately into the Fortescue River Valley.

6.5.2. Environmental values

The Weeli Wolli Spring area is recognised as having multiple ecological values that collectively contribute to its status as a Priority 1 Ecological Community (DEC, 2009; DPaW, 2014). These include:

- Riparian woodland and forest associations with unusual understorey species composition including an assortment of wattles (*Acacia* spp.), and sedges and herbs that fringe many of the pools and associated water bodies along the main channel. There are several species of conservation interest including one named after the spring (*Stylidium weeliwolli*). The woodland trees include the obligate phreatophyte *Melaleuca argentea*, and facultative phreatophytes *Eucalyptus camaldulensis* and *E. victrix*.
- An unusual and diverse aquatic fauna assemblage occurs in a series of permanent pools upgradient of the spring associated with the shallow groundwater system. The permanent discharge from Weeli Wolli Spring is an uncommon habitat for the Pilbara and may function as a refuge for mesic-adapted fauna.
- A relatively high diversity of stygofauna is associated with the calcrete and alluvial aquifer system.
- The creek valley at Weeli Wolli Spring supports a diverse bird assemblage (over 60 species) and very rich microbat assemblage including the Ghost bat (*Macroderma gigas*), a State and Commonwealth listed species. The permanent pools provide a water source and foraging habitat for microbats.

The Weeli Wolli Spring PEC also occurs at Ben's Oasis, located about 20 km further upstream and south of Weeli Wolli Spring. Ben's Oasis is a name that is locally used by BHP Billiton Iron Ore. At this location, the vegetation is concentrated along a relatively narrow creek channel adjacent to some surface water pools. There is very little documented information about the geology, hydrology and ecology of Ben's Oasis.

6.5.3. Ecohydrological conceptualisation

An ecohydrological conceptualisation of Weeli Wolli Spring is provided in Figure 16 with the key features being:

Surface and groundwater systems

- Surface flow at Weeli Wolli Spring is a combination of spring baseflow supported by groundwater discharge, as well as seasonal surface water inflows.
- On average, the area experiences two surface water flow events each year. Local infiltration of the surface water results in recharge to the shallow groundwater system.
- The groundwater system comprises an unconfined aquifer sequence including calcrete and detritals. Groundwater is shallow being less than 10 m bgl and becoming shallower towards the spring. As the aquifer thins and narrows towards Weeli Wolli Spring, groundwater flow is concentrated and discharged over near-surface basement as baseflow.
- The water balance suggests that groundwater throughflow from the upstream catchment is about 11 ML/day. Discharge occurs as spring baseflow (7 ML/day), evapotranspiration (2.6 ML/day) and groundwater throughflow in the shallow aquifer (4 ML/day).
- There is no evidence for outflow associated with a fractured-rock aquifer through the gorge in Wildflower Range. There may be a zone of slightly enhanced permeability; otherwise, the basement at the spring is of low permeability.

Ecosystem components

- The Weeli Wolli Spring area hosts a PEC comprising groundwater-dependent vegetation, permanent pools supporting a range of fauna, and a diverse stygofauna community.
- There is up to 30 m of saturated calcrete that provides the main stygofauna habitat.
- A number of permanent pools upgradient from Weeli Wolli Spring (sustained by the shallow groundwater regime) provide aquatic habitat, and a permanent water source for terrestrial fauna and avifauna.
- The creek valley of Weeli Wolli Spring is known to support a very rich microbat assemblage including the Ghost Bat (*Macroderma gigas*; EPBC Act - Vulnerable, WC Act - Schedule 4), the Chocolate Bat (*Chalinolobus morio)* occurring at the most northern extent of its natural rang, and the White-striped Free-tailed Bat (*Tadarida australis*) (McKenzie and Bullen, 2009; Department of Environment and Conservation, 2009b).

No information is available regarding groundwater levels or seasonal variation at Ben's Oasis. At present, there is insufficient information to formulate a conceptual ecohydrological model for Ben's Oasis.

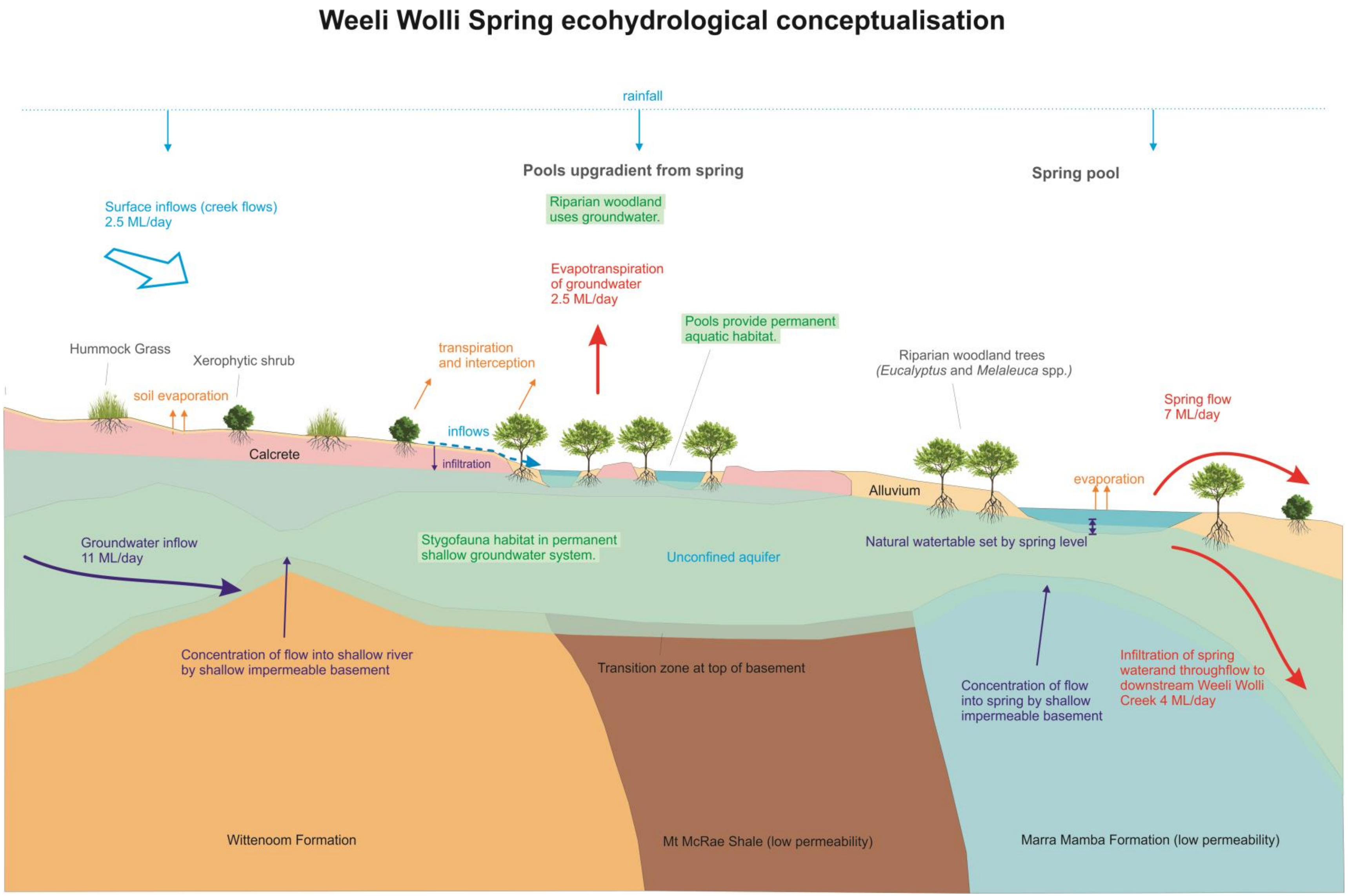

Figure 16 Weeli Wolli Spring ecohydrological conceptualisation

7. Other Ecological Assets

7.1. Tier 1 - Karijini National Park

7.1.1. Landscape context

Karijini National Park covers an area of about 624 000 ha. It contains a representative sample of the regional geology, plant and animal communities, and landscape of the central Hamersley Range.

Based on the ecohydrological conceptualisation, approximately 95% of the national park comprises upland landscapes (EHUs 1 to 4) including the topographic divide between the Fortescue River (north draining) and Turee Creek catchments (south draining) (Figure 17). Some of the upland areas include distinct gorge features. Broader valley areas, occupying approximately 4.8% of the national park, are associated with the Jamindie and Wannamunna Land Systems (EHU 6). These areas support *Acacia* shrublands and small areas of *E. victrix* woodlands.

River and floodplain landscapes (EHU 8) are restricted to sections of the Turee Creek and its tributaries in the southern portion of the national park, and drainages in the northeast portion of the national park. Restricted areas of calcrete plains (EHU 7) occur within some of the major drainages (about 400 ha in total).

7.1.2. Environmental values

The large size of the national park contributes to its conservation value, as it allows for buffers to disturbances from surrounding land uses. The primary habitats include hummock grasslands, mulga low-woodlands, as well as fringing vegetation associated with pools and streams. The vegetation and landscape provide faunal habitat for a wide range of invertebrates, amphibians, reptiles, birds and mammals.

The national park is managed by the Department of Parks and Wildlife (DPaW), in collaboration with Traditional Owners, with the stated conservation goal to "Conserve biological, physical, cultural and landscape resources and values" (DEC, 1999). The Karijini National Park Management Plan includes the following objectives relating to hydrology:

- Conserve groundwater and surface water resources.
- Provide for a safe and sustainable water supply for national park residents and visitors.
- Include unlicensed groundwater users when considering hydrological management.
- Protect the ecosystems from any adverse effects resulting from the lowering or raising of the watertable.

Key environmental values are summarised as follows (DEC, 1999; 360 Environmental, 2014):

- A total of 668 species of native flora, including the declared rare flora *Thryptomene wittweri* and *Lepidium catapycnon* and 44 Priority listed species have been recorded within the boundaries of the national park.
- Conservation significant fauna recorded from the national park include:
    - Northern Quoll (*Dasyurus hallucatus*) (EPBC Act Endangered, WC Act Schedule 1);
    - Peregrine Falcon (*Falco peregrines*) (WC Act Schedule 4); and
    - Pilbara Olive Python (*Liasis olivaceus barroni)* (EPBC – Vulnerable, WC Act – Schedule 1).
- Permanent pools support disjunct plant and animal populations. These pools are variably connected with local groundwater systems. Vegetation of riparian environments has potential to be groundwater dependent.
- Areas of *Eucalyptus victrix* woodland occur within Wannamunna Land System (EHU 6) to the south east of Mount Bruce, which constitute the Coolibah woodland over lignum and silky browntop (*Eulalia aurea*) PEC (Priority 1; DPaW 2014).

7.1.3. Ecohydrological conceptualisation

The majority of the national park consists of upland landscapes that are ecohydrologically disconnected from the landscapes of the study area to the east. Some upland areas in eastern portions of the national park constitute source areas for drainages that cross the western boundary of the study area (Figure 17). At the regional scale, geological structural complexity (Section 5.4), hydrogeological discontinuity (Section 5.5), topographic differences and distance of separation are all important factors that will contribute to disconnection in regional groundwater flow between the study area and the national park. This discontinuity suggests the minor groundwater drawdown estimates associated with Alligator South (Section 12.1) that extend into the national park are unlikely to influence the upland landscape and associated receptors (Section 16).

The valley areas (EHU 6) in the national park are also ecohydrologically disconnected from the study area by catchment boundaries, with the exception of one area straddling the national park boundary near its southeast corner. This area includes the Brockman Iron Cracking Clay Community PEC (Figure 17).

Also near the southeast corner of the national park is a riparian floodplain (EHU 8) associated with Turee Creek East drainage line. North of this area, the drainage passes through a gorge dissecting ridges of outcropping Brockman Formation, which is interpreted to constrain groundwater flow. The area upstream of the gorge supports a riparian woodland community and comprises a zone of potential surface water and groundwater interaction. Moving further upstream, the drainage line bifurcates into broad valleys extending north and east respectively into the southwest portion of the study area. Drainage networks in the northern valley of the Turee Creek East catchment may provide a degree of hydrological connection between Turee Creek East and BHP Billiton Iron Ore’s Mudlark mining area proposed within the Strategic Proposal and these potential hydraulic connection were considered in the regional assessment. Further studies would provide validation of the degree of hydraulic connection between Turee Creek East and BHP Billiton Iron Ore’s Mudlark mining area.

Rio Tinto’s West Angelas mine is also located in the Turee Creek East catchment approximately 20 km east of the southeast corner of the national park, and has been operating since 2001. A proportion of the West Angelas resource is below watertable, and surplus water from orebody dewatering is discharged to an ephemeral tributary of Turee Creek East near the mine site. A component of the water supply for West Angelas mine is obtained from the Turee Creek B Borefield, located approximately 30 km west of the mine site and south of the national park.

A number of permanent pools are associated with deeply incised creeks and gorges in the northern portion of the national park. These occur within EHUs 3 and 4. The gorges constitute a unique landform type that is not encountered in the study area. The pools form through seasonal surface water inundation and local groundwater discharge from the low permeability Brockman Formation (Hedley, 2009). The generalised gorge morphology includes spring discharge at the gorge head, steep sided walls which are predominantly dry (non-leaking) and a low discharge stream at its base. There is minimal alluvium development within the gorges. Hydrochemical analysis of the gorge waters suggests that the pools are supported by local aquifers that are hydrologically disconnected from the regional groundwater resources (Hedley, 2009).

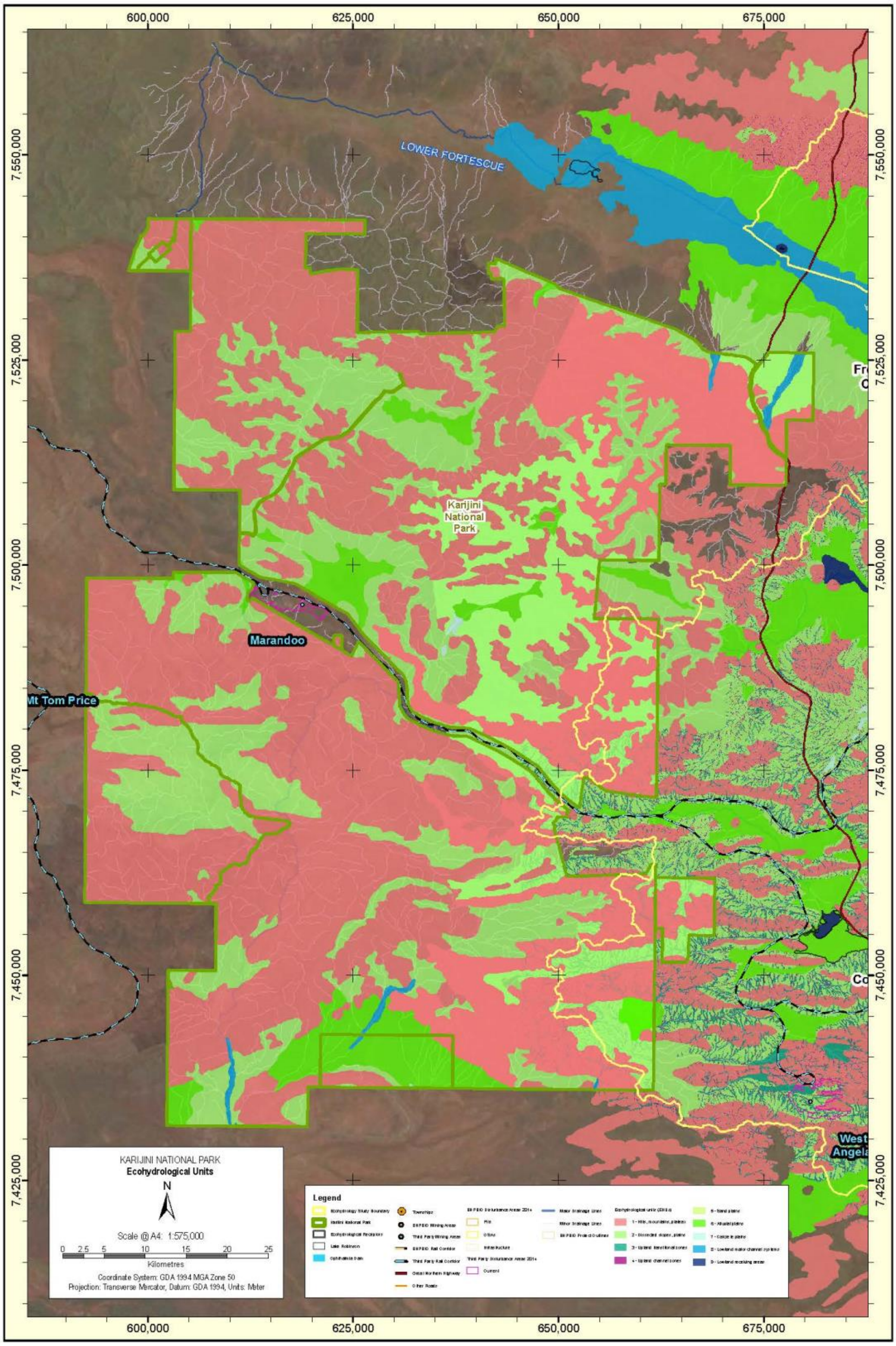

Figure 17 **Karijini National Park landscape context**

7.2. Tier 1 - Mungaroona Range Nature Reserve

7.2.1. Landscape context

Mungaroona Range Nature Reserve (Reserve Number 31429) lies about 40 kilometres north of Wittenoom and covers an area of 105 842 ha. It is a 'Class A' reserve consisting mostly of wilderness areas at the highest possible quality rating of 18 to 20 (National Wilderness Inventory, 1986).

Based on the ecohydrological conceptualisation, approximately 99% of the nature reserve consists of uplands (EHUs 1 and 4).The eastern portion comprises a rugged landscape with deep gullies and isolated waterholes, while central and western areas include tablelands dominated by hummock grass communities.

The nature reserve includes the headwaters of several major tributaries of the Yule River including Pilbara Creek, Powdar Creek and the Pilbaddy Creek. The western portion comprises the catchment divide between the Sherlock and Yule Rivers.

7.2.2. Environmental values

The Mungaroona Nature Reserve is considered to be important for preserving representative landforms and vegetation of the Chichester Range. However, few biological surveys have been conducted with flora and fauna assemblages being poorly characterised.

It includes examples of the four plant assemblages of the Wona Land System PEC (DPaW, 2014). These tussock grassland communities have previously been referred to as the 'Cracking clays of the Chichester and Mungaroona Range'.

7.2.3. Ecohydrological conceptualisation

The majority of the nature reserve includes upland landscapes that contribute catchment area to the Yule and Sherlock Rivers, but are otherwise largely ecohydrologically disconnected from surrounding landscapes. The four plant assemblages of the Wona Land System PEC are located in basalt uplands with restricted catchment areas. Direct rainfall and localised surface water redistribution is considered to be important for sustaining these unusual vegetation communities.

Within the nature reserve, there is a small portion of the Pilbaddy Creek floodplain that is mapped as the River Land System (EHU8) by van Vreeswyk et al. (2004). The narrow, moderately incised floodplain includes open riparian woodlands and several persistent pools.

The Strategic Proposal will not affect the hydrological regime of the Mungaroona Nature Reserve, as it is distant and ecohydrologically disconnected from any current or proposed BHP Billiton Iron Ore mining areas.

7.3. Tier 2 - Brockman Iron cracking clay communities of the Hamersley Range PEC

7.3.1. Landscape context

The Brockman Iron cracking clay communities of the Hamersley Range PEC (Priority 1) is a rare vegetation community occurring in a unique landform. It is known from various valley floor locations including:

- The Jamindie Land System (EHU 6) on the eastern edge of Karijini National Park;
- The Christmas Land System (EHU 6) near the northwest margin of the Fortescue Marsh; and
- The Jurrawarrina Land System (EHU 6) west of Karijini National Park.

7.3.2. Environmental values

The PEC includes rare tussock grassland typically (but not always) dominated by *Astrebla lappacea* (DPaW, 2014). It occurs on cracking clays soils in valley depositional areas. Recognised threats to the PEC include grazing and mining and infrastructure developments (DPaW, 2014).

7.3.3. Ecohydrological conceptualisation

The replenishment of soil moisture in these cracking clay ecological communities is important for their survival. This is most likely to occur via direct rainfall and surface water inflow from localised catchment areas. In locations where the PEC occurs, the groundwater is relatively deep (greater than 10 m bgl) and disconnected from surface ecosystems. The Strategic Proposal will not result in any ecohydrological change to these cracking clay vegetation communities, as the PEC is ecohydrologically disconnected from any current or proposed BHP Billiton Iron Ore mining areas.

7.4. Tier 2 - Mt Bruce Coolibah-Lignum Flats

7.4.1. Landscape context

The Mt Bruce Coolibah-Lignum Flats are located about 8 km southeast of Mount Bruce in Karijini National Park. The flats occur in a valley that is surrounded by peaks of the Hamersley Range and mapped as the Wannamunna Land System (EHU 6) by van Vreeswyk et al (2004).

7.4.2. Environmental values

The *Eucalyptus victrix* woodlands on the Mt Bruce Flats are classified as the 'Coolibah woodland over lignum and silky browntop (*Eulalia aurea*)' PEC (DPaW 2014). The wetland landform that supports this vegetation consists of red cracking clays within run-on zones and is listed in the Directory of Important Wetlands of Australia (Ref. WA113). Recognised threats to the PEC include dewatering, grazing, and clearing associated with infrastructure corridors (DPaW, 2014).

7.4.3. Ecohydrological conceptualisation

The Mt Bruce Coolibah-Lignum Flats vegetation community is likely to have ecohydrological similarities to the Coondewanna Flats, as the woodland vegetation community has a likely dependence on stored soil water derived from runoff. The Strategic Proposal will not result in any ecohydrological change to the woodland vegetation community, as the PEC is ecohydrologically disconnected from any current or proposed BHP Billiton Iron Ore mining areas.

7.5. Tier 2 - Sand dune vegetation of the Hamersley Range/Fortescue Valley PEC

7.5.1. Landscape context

The sand dunes of the Hamersley Range/Fortescue Valley PEC below the northern flanks of the Hamersley Range are associated with the Divide Land System, as mapped by van Vreeswyk et al (2004), and represented in the ecohydrological conceptualisation as EHU 5. The red, linear sand dunes are dominated by open shrubland vegetation communities that are uncommon in the Pilbara. The sand dunes are a rare landform being fragile and highly susceptible to disturbance.

7.5.2. Environmental values

The sand dune vegetation communities include unusual species assemblages. A small number are vegetated with *Acacia dictyophleba* scattered tall shrubs over *Crotalaria cunninghamii*, *Trichodesma zeylanicum* var. *grandiflorum* open shrubland (DPaW, 2014).

Recognised threats to the PEC include weed invasion especially Buffel Grass (*Cenchrus ciliaris*), grazing by cattle, too frequent fire, erosion and impacts of mining (DPaW, 2014). This PEC was previously referred to as the Fortescue Valley Sand Dunes PEC.

7.5.3. Ecohydrological conceptualisation

The sand dune vegetation is considered to be reliant on direct rainfall and localised redistribution of surface water. The sand dune areas do not receive significant surface water inflow from adjacent areas. Groundwater is relatively deep (greater than 10 m bgl) and disconnected from the surface ecosystem. The Strategic Proposalu will not result in any ecohydrological change to sand dune vegetation communities, as the PEC is ecohydrologically disconnected from any current or proposed BHP Billiton Iron Ore mining areas.

7.6. Tier 2 - West Angelas cracking clays communities PEC

7.6.1. Landscape context

The West Angelas cracking clay community (Priority 1) is a rare vegetation community occurring on a rare landform. It is known only from the West Angelas locality near the southeast corner of Karijini National Park associated with basalt-derived, cracking-clay loam depressions and drainages. Based on the ecohydrological conceptualisation, the PEC is associated with the Elimunna (EHU 2) and Rocklea (EHU 1) land systems.

7.6.2. Environmental values

The vegetation of the PEC includes open-tussock grasslands of *Astrebla pectinata*, *A. elymoides*, *Aristida latifolia*, in combination with *Astrebla squarrosa* and low scattered shrubs of *Sida fibulifera.* Recognised threats to the PEC include disturbance footprints increasing from mine, future infrastructure development, possible weed invasion and changes in fire regime (DPaW, 2014).

7.6.3. Ecohydrological conceptualisation

Soil moisture replenishment in the cracking clay ecological community is associated with direct rainfall and surface water inflow from localised catchment areas. Groundwater is relatively deep (greater than 10 m bgl) and is disconnected from the surface ecosystem. The Strategic Proposal will not result in any ecohydrological change to the cracking clay ecological community, as the PEC is ecohydrologically disconnected from any current or proposed BHP Billiton Iron Ore mining areas.

7.7. Tier 2 - Wona Land System PEC - Four plant assemblages

7.7.1. Landscape context

The Wona Land System, classified as an EHU 2, comprises areas of upland gilgai plains that support tussock grasses and minor hard spinifex grasslands (van Vreeswyk et al., 2004). The land system occurs throughout the Chichester Range in the Chichester-Millstream National Park, Mungaroona Range Nature Reserve and on adjacent pastoral leases.

7.7.2. Environmental values

A series of community types identified within the Wona Land System collectively comprise the 'Four plant assemblages of the Wona Land System PEC' including:

- Cracking clays of the Chichester and Mungaroona Range comprising a stony gibber plain community on the tablelands with very little vegetative cover during the dry season. During the wet season, it supports a suite of ephemerals/annuals and short-lived perennials, many of which are poorly known and range-end taxa (Priority 1);
- Annual Sorghum grasslands on self-mulching clays: a rare and restricted community in the Pannawonica-Robe valley end of Chichester Range (Priority 1);
- Mitchell grass plains (*Astrebela* spp.) on gilgai (Priority 3); and
- Mitchell grass and Roebourne Plain grass (*Eragrostis xerophila*) plain on gilgai of typical type and heavily grazed (Priority 3).

Recognised threats to the PEC include weed invasion, grazing and changes in fire regime (DPaW, 2014). This PEC was previously referred to as the cracking clays of the Chichester and Mungaroona Range PEC.

7.7.3. Ecohydrological conceptualisation

The PEC is confined to localised upland catchment areas, and relies on direct rainfall augmented by local area runoff. In locations where the PEC occurs, the groundwater is relatively deep (greater than 10 m bgl) and disconnected from surface ecosystems. The Strategic Proposal will not result in any ecohydrological change to the vegetation communities, as the occurrences of this PEC are ecohydrologically disconnected from any current or proposed BHP Billiton Iron Ore mining areas.

7.8. Contingent ecological assets

BHP Billiton Iron Ore recognises that new ecological assets may be identified within the development timeframe of the Strategic Proposal. It is also possible that the status of existing ecological assets may change. Ecohydrological conceptualisation of any newly identified or reclassified ecological assets will be undertaken on a case by case basis as required.

Tenure changes within the study area have been proposed in connection with the expiry of pastoral leases in 2015 relating to Hillside, Juna Downs, Marillana, Mulga Downs and Roy Hill Stations. These changes may alter the distribution of existing ecological assets and contribute to the recognition of new assets at a future time. For this change assessment, these proposed ecological assets have not been considered as their ecological values will require further characterisation once new tenure arrangements have been finalised.

8. Current mining operations

The study area includes a number of current BHP Billiton Iron Ore and third-party mining operations (Table 9 and Map 12). These operations form part of the baseline or pre-existing ecohydrological change conditions and therefore are considered in the change assessment. Third-party operations have been included owing to their potential to contribute to cumulative ecohydrological change.

8.1. BHP Billiton Iron Ore Operations

Most of BHP Billiton Iron Ore's Whaleback operations, located in the vicinity of Newman, commenced in the 1970s. Mining later expanded into Eastern Ridge (Orebodies 23, 24, 25 Pit 1, 25 Pit 3 and 25 Pit 4), Jimblebar, (South Jimblebar and Wheelarra 1, 2 and 3) and Shovelanna (Orebodies 17 and 18) mining areas. In the early 1990s, BHP Billiton Iron Ore's Yandi operation commenced mining of CID in the lower Marillana Creek. Mining Area C, located approximately 100 km northwest of Newman, was approved in 1998 and commenced mining in 2003. Mining Area C currently includes A, C, D, E and F Deposits.

Mining Area C is currently operating under Revision 5 of the Environmental Management Plan (EMP) which describes mining operations for A, B, C, D, E, F, P1, P3, P4 and Brockman Detrital deposits. Below watertable mining is currently planned in A, C, E, F, P1 and P3 deposits. The planned disturbance is approved under Ministerial Statement 491 with the EMP approving mining activities within the separate deposits as outlined in Table 9.

The Eastern Ridge mining area is currently operating under Ministerial Statement 478 for OB23, Ministerial Statement 834 for OB24 and Ministerial Statement 712 for OB25. An application to mine OB31 has recently been submitted to the OEPA. The OB17 and OB18 mining area is currently operating under Ministerial Statement 439.

The Jimblebar mining area, located approximately 40 km east of Newman commenced production in 1988 and the expansion commenced in 2013 under Ministerial Statements 683, 809 and 857.

Mining at the Whaleback mining area was commenced prior to the *Environmental Protection Act* (1986) being in force, BHP Billiton Iron Ore has a Native Vegetation Clearing Permit in place over the mining area. Additionally, Ministerial Statement 963 allows for below watertable mining of Orebodies 29, 30 and 35.

The Yandi mining area is currently operating under Ministerial Statement 679 which allows for below water table mining at W1-W6, C1-C5 and E1-E8 deposits with active dewatering and surplus discharge into Marillana Creek.

8.2. Third-Party Operations

Along the Chichester Range and northern extent of the Strategic Proposal area, there is active mining by Fortescue Metals Group (FMG) at its Cloudbreak and Christmas Creek operations. Hancock Prospecting Pty Ltd (HPPL) is currently developing its Roy Hill operations located to the east of Christmas Creek, with production forecast to commence in 2015.

In the Marillana Creek catchment, there are two active mining operations at Yandicoogina operated by RTIO and Phil's Creek operated by Mineral Resources Ltd (MRL). Further to the south, there are existing operations at Hope Downs (Hope North, Hope South and Hope Downs 4) and West Angelas that are all operated by RTIO.

Table 9 Active BHP Billiton Iron Ore and third-party mining operations

Mining Region	Mining area	Owner	Orebody name	Host geology*	Remarks**
CENTRAL PILBARA	Mining Area C	BHP Billiton Iron Ore	E Deposit	MM	BWT mining, active dewatering
			C Deposit	MM	BWT mining, active dewatering
			A Deposit	MM	BWT mining, active dewatering
			D Deposit	MM	BWT mining, active dewatering
			F Deposit	MM	May require minor dewatering
	Hope Downs	*RTIO*	*Hope North*	*MM*	*BWT mining, active dewatering*
			Hope South	*MM*	*BWT mining, active dewatering*
EASTERN PILBARA	Eastern Ridge	BHP Billiton Iron Ore	OB23	BRK	BWT, mining ceased
			OB24	BRK	AWT, mining commenced
			OB25 Pit 1	BRK	BWT, active dewatering
			OB25 Pit 3	BRK	BWT, active dewatering
			OB25 Pit 4	BRK	
	Jimblebar	BHP Billiton Iron Ore	South Jimblebar	MM	AWT, mining commenced
			Wheelarra 1,2 3	BRK	AWT, mining commenced
	Shovelanna	BHP Billiton Iron Ore	OB17	BRK	AWT, mining commenced
			OB18	BRK	AWT, mining commenced
	Whaleback	BHP Billiton Iron Ore	Whaleback	BRK	BWT, active dewatering
FORTESCUE MARSH	*Chichester*	*FMG*	*Christmas Creek*	*MM*	*BWT mining, active dewatering and reinjection*
			Cloudbreak	*MM*	*BWT mining, active dewatering and reinjection*
	Hope Downs 4	*RTIO*	*Hope Downs 4*	*BRK*	*BWT mining, active dewatering*
	Roy Hill	*HPPL*	*Roy Hill*	*MM*	*Proposed BWT mining, require active dewatering and reinjection*
MARILLANA CREEK	Yandi	BHP Billiton Iron Ore	Yandi	CID	BWT mining at W1, W4, C1, C5, E1, E2 and E356, active dewatering and surplus discharge
	Yandicoogina	*RTIO*	*Yandicoogina*	*CID*	*BWT mining at Junction Central and Junction South East, active dewatering and surplus discharge*
	Phil's Creek	*MRL*	*Phil's Creek*	*CID*	*AWT mining*

* Host geology – MM is Marra Mamba; BRK is Brockman; CID is channel-iron deposits.
** AWT is above watertable and BWT is below watertable
Third-party mining operations are highlighted in *italics*

Part III - Change Assessment

The change assessment provides an evaluation of the potential for regional scale ecohydrological change associated with the Strategic Proposal. The assessment includes consideration of BHP Billiton Iron Ore mining areas in the Central Pilbara, Eastern Pilbara, Fortescue Marsh and Marillana Creek regions respectively. Third-party mining operations have also been explicitly considered to provide an appreciation of potential cumulative change.

Aspects of the Strategic Proposal with potential to impact on surface water and groundwater regimes were characterised as threatening processes. These include groundwater drawdown, reduction in surface water availability, surplus water management, acid and metalliferous drainage (AMD), saline intrusion into groundwater systems, and pit lake formation. The assessment approach included spatial delineation of these processes across the study area.

Ecohydrological change potential was evaluated as a function of hydrological change and the sensitivity of EHUs to hydrological change, using a combination of conceptual and GIS-based spatial analysis approaches. Separate assessments were made for each threatening process respectively. More detailed evaluation of ecohydrological change potential was also undertaken for each of the ecohydrological receptors in the study area, taking into consideration the ecohydrological conceptualisations described in Part II. Three time stages over the life of the Strategic Proposal were considered including 2014 (current condition), 30% development scenario and full development scenario.

The change assessment delineates the relative significance of ecohydrological change potential within a landscape context. The assessment is conservative, assuming the implementation of existing normal business management practices used by BHP Billiton Iron Ore but without any targeted management to protect ecological assets. By highlighting areas of significant ecohydrological change potential, the assessment identifies focus areas for further investigations and management where required in accordance with the Water and Closure RMSs.

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9. Stressors

The current and proposed mining operations of the Strategic Proposal will result in modified surface water and groundwater regimes, which have the potential to result in ecohydrological change at the landscape scale and at ecohydrological receptors. These mining areas are considered to be stressors for the purposes of the change assessment. Existing third-party operations have also been considered as stressors in order to evaluate the potential for cumulative ecohydrological change.

9.1. Strategic Proposal projects

The study area was partitioned into four regions based on catchment extents, as follows (Map 1):

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

Each region includes a number of proposed mining areas with disturbance footprints comprised of individual deposits, orebodies and mines.

Map 13 shows the location of the proposed BHP Billiton Iron Ore mining area footprints for the 30% development scenario. It also shows current, approved and proposed third-party mining area footprints based on publicly available information.

Map 14 shows the location of the proposed BHP Billiton Iron Ore mining area footprints for the full development scenario. There is no publicly available information for proposed third-party footprints for this development stage; however, approved and proposed third party footprints as at September 2014 have been included in the full development scenario.

9.1.1. Central Pilbara region

The Strategic Proposal in the Central Pilbara region includes seven mining areas, as shown on Map 15 and summarised in Table 10**Error! Reference source not found.**. These comprise the expansion of BHP Billiton Iron Ore operations in the MAC mining area and new mining operations in the Jinidi, South Flank, Mudlark, Tandanya, South Parmelia and Gurinbiddy mining areas. Mine developments are expected to initially focus on the Jinidi, Mudlark, Mining Area C (including the Packsaddle deposits) and South Flank mining areas, before expanding into Gurinbiddy, South Parmelia and Tandanya mining areas.

The proposed mines are predominantly associated with Brockman and Marra Mamba Formation orebodies (Table 10), which are typically located in elevated parts of the Hamersley Range. These orebodies tend to form localised aquifers bound by aquitards. Dewatering requirements are likely to be comparatively minor with influences on groundwater being:

- Restricted, localised drawdown within the Brockman and Marra Mamba orebody aquifers;
- Limited potential for drawdown to extend beyond the immediate orebodies; and
- Minimal influence on local (or regional) groundwater throughflow.

Table 10 Proposed operations in Central Pilbara region

Mining area	Owner	Host geology*
GURINBIDDY	BHP Billiton Iron Ore	MM
JINIDI HILL	BHP Billiton Iron Ore	BRK
MUDLARK	BHP Billiton Iron Ore	MM (majority) and BRK
MAC	BHP Billiton Iron Ore	MM and BRK
SOUTH FLANK	BHP Billiton Iron Ore	MM (majority) and BRK
SOUTH PARMELIA	BHP Billiton Iron Ore	BRK
TANDANYA	BHP Billiton Iron Ore	MM, BRK and DET

* Host geology – MM is Marra Mamba,BRK is Brockman and DET is Detritals.

A small number of Marra Mamba and Brockman orebodies are positioned on ridge flanks intercepting valley Tertiary detritals. These have the potential to be hydraulically connected with the regional groundwater system. In some cases, there may be additional hydraulic connection associated with geological structures, such as thrust faulting in Marra Mamba orebodies and vertical faulting in Brockman orebodies. In these cases, dewatering requirements will be greater with influences on groundwater being:

- Localised drawdown within the Brockman and Marra Mamba orebodies, with some drawdown extending into the regional groundwater system;
- Some reduction in groundwater throughflow in the unmitigated case; and
- Possible reversal of regional groundwater flow into orebody aquifers.

The surface water regime may be modified through the diversion of surface water drainage lines around mine pits and mine infrastructure, interception of surface water flow behind overburden storage areas, and minor reductions in surface water outflows. In the pre-mining state, runoff yields from mining areas proximal to ridgelines are likely be proportionally higher than those in flatter catchment areas. The development of mines in these ridgeline areas may reduce landscape-scale surface runoff.

As part of normal business overburden infilling scheduling, a portion of the mined out pits will be infilled to above pre-mining water levels and will not form pit lakes (Refer to Section 11.7 for a more detailed discussion of overburden infilling). For the remainder of the pits, BHP Billiton Iron Ore has the ability to infill the pits to above pre-mining water levels, if required to meet closure objectives. Where pit lakes do develop, the pit lakes will more likely form groundwater sinks with no outflow to the surrounding environment. The final hydraulic gradient will prevent migration of pit lake water into the surrounding groundwater system.

The ecohydrological conceptualisation of the Central Pilbara region (Appendix C) provides a more detailed discussion of each mining area, in terms of likely dewatering rates and potential for connectivity with the regional groundwater system and key ecohydrological receptors including Coondewanna Flats and Weeli Wolli Spring.

9.1.2. Eastern Pilbara region

The Strategic Proposal in the Eastern Pilbara region includes nine mining areas, as shown on Map 16 and summarised in Table 11. Mining development will initially be focused in the Eastern Ridge, Homestead and Shovelanna mining areas; before expanding to include the Jimblebar, Ophthalmia, Prairie Downs and Western Ridge mining areas.

Table 11 Proposed operations in Eastern Pilbara region

Mining Area	Owner	Host geology*
EASTERN RIDGE	BHP Billiton Iron Ore	MM
EAST OPHTHALMIA	BHP Billiton Iron Ore	MM and BRK
HOMESTEAD	BHP Billiton Iron Ore	MM (majority) and BRK
JIMBLEBAR	BHP Billiton Iron Ore	MM and BRK
OPHTHALMIA	BHP Billiton Iron Ore	MM and CID
PRAIRIE DOWNS	BHP Billiton Iron Ore	MM
SHOVELANNA	BHP Billiton Iron Ore	MM and BRK
WESTERN RIDGE	BHP Billiton Iron Ore	MM and BRK
WHALEBACK	BHP Billiton Iron Ore	MM

* Host geology – MM is Marra Mamba, BRK is Brockman and CID is Channel Iron Deposit.

The proposed mines are all associated with Brockman and Marra Mamba Formation orebodies, with the exception of the Western Buttes CID in the Ophthalmia mining area (Table 11). These orebodies are typically located in elevated terrain, and form localised aquifers that are bound by aquitards. In such cases, dewatering requirements are likely to be comparatively minor with influences on groundwater being:

- Restricted, localised drawdown within the Brockman and Marra Mamba orebody aquifers;
- Limited potential for drawdown to extend beyond the immediate orebodies; and
- Minimal influence on local (or regional) groundwater throughflow.

Some of the Marra Mamba and Brockman orebodies occur in valleys that intercept the regional aquifer. In places, this hydraulic connection may be enhanced by fault zones. In such cases, dewatering requirements will be greater with influences on groundwater being:

- Localised drawdown within the Brockman and Marra Mamba orebodies, with some drawdown extending into the regional groundwater system;
- Some reduction in groundwater throughflow in the unmitigated case; and
- Possible reversal of regional groundwater flow into orebody aquifers.

The shallow aquifer that supports the Ethel Gorge TEC is recharged by leakage from Ophthalmia Dam and infiltration of surface water flow through stream channels. Despite Ophthalmia Dam being the primary hydraulic influence, surface water management relating to the drainages feeding directly into Ethel Gorge is still an important consideration.

The surface water regime may be modified through the diversion of surface water around mine pits and mine infrastructure, interception of surface water behind overburden storage areas, and minor reductions in surface water outflow. In the pre-mining state, runoff yields from mining areas proximal to ridgelines are likely be proportionally higher than those in flatter catchment areas. The development of mines in these ridgeline areas may reduce landscape scale surface runoff.

As part of normal business overburden infilling scheduling, a portion of the mined out pits will be infilled to above pre-mining water levels and will not form pit lakes (Refer to Section 11.7 for a more detailed discussion of overburden infilling). For the remainder of the pits, BHP Billiton Iron Ore has the ability to infill the pits to above pre-mining water levels, if required to meet closure objectives. Where pit lakes do develop, the pit lakes will more likely form groundwater sinks with no outflow to the surrounding environment. The final hydraulic gradient will prevent migration of pit lake water into the surrounding groundwater system.

The ecohydrological conceptualisation of the Eastern Pilbara region (Appendix D) provides a detailed discussion of each mining area, in terms of likely dewatering rates and potential for connectivity with the regional aquifer and the key ecohydrological receptor being the Ethel Gorge Stygobiont TEC.

9.1.3. Fortescue Marsh region

The Strategic Proposal in the Fortescue Marsh region includes the Marillana, Coondiner and Mindy mining areas on the southern side of the Fortescue River Valley, and at a later stage the Roy Hill mining area northwest of the Fortescue Marsh. These four mining areas are shown on Map 17 and summarised in Table 12**Error! Reference source not found.**. A number of third-party mining operations also occur in the region.

Table 12 Proposed BHP Billiton Iron Ore and third-party operations in the Fortescue Marsh region

Mining area	Owner	Host geology*
COONDINER	BHP Billiton Iron Ore	BRK / DET
MARILLANA	BHP Billiton Iron Ore	BRK / DET
MINDY MINDY	BHP Billiton Iron Ore	BRK / DET
ROY HILL	BHP Billiton Iron Ore	DET / MM
BROCKMAN MARILLANA	*Brockman Resources*	*DET / CID*
MINDY MINDY	*FMG*	*CID*
NYIDINGHU	*FMG*	*BRK*
MT LEWIN	*FMG*	*MM*
IRON VALLEY	*Iron Ore Holdings*	*BRK*
KOODAIDERI	*RTIO*	*BRK*

* Host geology – MM is Marra Mamba,BRK is Brockman, CID is Channel Iron Deposit and DET is Detritals.

The orebodies at Marillana, Coondiner and Mindy are associated with mineralised Tertiary detritals and underlying Brockman Formation. These are located in elevated terrain on the northern flank of the Hamersley Range. The orebodies tend to form localised aquifers with varying connectivity with the Tertiary detrital aquifer in the Fortescue River Valley. The level of connection has a direct influence on dewatering requirements and confers the potential for groundwater drawdown to propagate towards the Fortescue Marsh.

The proposed Marillana mining area is the closest to the Fortescue Marsh, and has the greatest potential to cause ecohydrological change associated with groundwater drawdown at the Marsh. The mining areas at Mindy and Coondiner are more distant from the Marsh and less likely to result in ecohydrological change at the Marsh. With respect to surface water management, there may be some modification to surface water drainages that deliver floodwater to the Marsh such as Weeli Wolli Creek.

BHP Billiton Iron Ore's Roy Hill mining is located west of the current FMG Cloudbreak operation on the southern flank of the Chichester Range. Most of the proposed mines are located along valley flanks with one or more pit walls intersecting saturated Tertiary detritals in the Fortescue River Valley. The Roy Hill mining area also intersects catchment areas of the Freshwater Claypans of the Fortescue Valley PEC.

The proximity of the mining areas to the Fortescue River Valley gives rise to the potential for groundwater drawdown to intercept and interact with the interface between fresh and saline aquifers in the Fortescue River Valley. Mine dewatering will require careful consideration of the fresh-saline water interface to minimise the possible ingress of saline groundwater.

As part of normal business overburden infilling scheduling, a portion of the mined out pits will be infilled to above pre-mining water levels and will not form pit lakes (Refer to section XX for a more detailed assessment on overburden infilling). For the remainder of the pits, BHP Billiton Iron Ore has the ability to infill the pits to above pre-mining water levels, if required to meet closure objectives. Where pit lakes do develop, the pit lakes will more likely form groundwater sinks with no outflow to the surrounding environment. The final hydraulic gradient will prevent migration of pit lake water into the surrounding groundwater system.

The ecohydrological conceptualisation of the Fortescue Marsh region (Appendix E) provides a detailed discussion of each mining area, in terms of likely dewatering rates and potential for connectivity with the regional aquifer and the key environmental receptor being the Fortescue Marsh.

9.1.4. Marillana Creek region

The Strategic Proposal in the Marillana Creek region will focus on the existing Yandi operation before expanding into the Munjina, Upper Marillana and Ministers North mining areas. The Sweet View operation in the Tandanya mining area of the Central Pilbara region straddles the Marillana Creek catchment boundary to the south of Munjina. The five mining areas are shown on Map 18 and summarised in Table 13. A number of third-party mining operations also occur in the region.

Table 13 Proposed BHP Billiton Iron Ore and third-party operations in the Marillana Creek region

Mining area	Owner	Host geology*
YANDI	BHP Billiton Iron Ore	CID
MINISTERS NORTH	BHP Billiton Iron Ore	BRK
MUNJINA	BHP Billiton Iron Ore	CID
UPPER MARILLANA	BHP Billiton Iron Ore	CID
TANDANYA – SWEET VIEW	BHP Billiton Iron Ore	BRK
IRON VALLEY	*MRL*	*BRK*
YANDICOOGINA SOUTH	*MRL*	*CID / WW*
YANDICOOGINA	*RTIO*	*CID*

* Host geology – BRK is Brockman, CID is Channel Iron Deposit, WW is Weeli Wolli and DET is Detritals.

The orebodies at Yandi, Munjina and Upper Marillana are hosted within channel-iron deposit (CID) ore types associated with Tertiary-infilled palaeochannel features. These CIDs form linear aquifers with large dewatering requirements and elongate groundwater drawdown that propagates along and within the palaeochannels. In areas of the CID aquifer that underlie or are otherwise hydraulically connected to the modern-day Marillana Creek, drawdown in the aquifer has the potential to affect riparian vegetation communities along the creek.

In the Munjina and Upper Marillana mining areas, several CID-infilled palaeotributaries coalesce to form broader orebodies that are overlain by alluvial and calcrete aquifers. Hydraulic connection between these aquifers is a defining hydrogeological characteristic at these locations, with proposed mines anticipated to require substantial dewatering. In contrast, the Tandanya - Sweet View orebody comprised of mineralised Brockman Formation in an upland setting will have comparatively minor dewatering requirements.

The surface water regime is dominated by Marillana Creek, which crosses the meandering CID palaeochannel at Yandi. In the Upper Marillana Creek catchment, the Munjina Claypan is an important surface water feature that captures surface water flow from tributaries and attenuates down-gradient flow into Marillana Creek. Substantial surface water management may be required to preserve the hydrological integrity of this feature, including creek diversions and possible creek realignment to divert flows around some mine pits.

The formation of pit lakes in the Munjina, Upper Marillana and Yandi mining areas will be dependent on the final closure strategy, as they are likely to act as throughflow systems and contribute increased salt loads into the

Marillana Creek groundwater system. In contrast, pit lakes at Ministers North and Tandanya - Sweet View mining areas are likely to be groundwater sinks and have no connectivity with Marillana Creek.

The ecohydrological conceptualisation of the Marillana Creek region (Appendix F) provides a detailed discussion of each mining area and individual orebodies, in terms of likely dewatering rates, and potential for connectivity with the regional aquifer.

9.2. Proposed Third-Party Operations

A number of additional third-party operations are proposed in the Central Pilbara, Marillana and Fortescue Marsh regions respectively, which are summarised as follows:

- Central Pilbara - Rio Tinto Iron Ore (RTIO) expansions to the Hope Downs 1, Hope Downs 4 and West Angelas mining areas.
- Eastern Pilbara - Davidson Creek mining area (Atlas Iron)
- Fortescue Marsh - Marillana Project (Brockman Resources), Nyidinghu and Mindy Mindy (FMG), and Koodaideri (RTIO).
- Marillana Creek - Iron Valley (Mineral Resources Limited - MRL), Yandicoogina South (Nexus Minerals Ltd, NML), and Pocket - Billiards South at Yandicoogina (RTIO).

10. Threatening processes

10.1. Groundwater drawdown

Groundwater drawdown is the decline or reduction in the watertable, or groundwater levels, related to abstraction for orebody dewatering or water supply. Orebody dewatering is necessary to control groundwater inflow into mine pits, permit mining below the watertable, enable use of explosives, provide access to dry ore and depressurise pit walls.

The extent of groundwater drawdown is a function of pumping rates, and hydraulic properties of the orebody aquifer and surrounding lithologies being dewatered. Groundwater abstraction may directly lower the watertable in unconfined aquifers, or indirectly lower groundwater levels via depressurisation of deeper aquifers. In the latter case, hydraulic connectivity with the overlying unconfined aquifer is necessary to facilitate downward movement of groundwater.

Ecological impacts from groundwater drawdown may occur when:

- There is sufficient hydraulic connectivity to enable the propagation of drawdown from dewatering zones to ecohydrological receptors; and
- The rate, magnitude and/or duration of groundwater level decline are sufficient to affect the functionality and values of ecohydrological receptors. For any given receptor, the level of impact will be influenced by its intrinsic characteristics (e.g. spatial and temporal level of dependence on groundwater, ecosystem adaptability and resilience to change in groundwater conditions).

10.1.1. Potential impacts

Potential environmental impacts associated with groundwater drawdown include vegetation health decline (phreatophytic vegetation communities), vegetation assemblage change, and the loss or modification of aquatic and subterranean habitats (Table 14). Existing and potential anthropogenic uses of groundwater resources may also be affected. Considerations for evaluating potential impacts on environmental factors include the nature of hydrological regime change, in particular where different to the natural range in watertable fluctuation, and the responsiveness of ecosystems to this change (Table 15).

Table 14 Potential environmental impacts associated with groundwater drawdown

Environmental factor	Change mechanism	Potential impacts
Flora and Vegetation (groundwater dependent vegetation)	Reduced availability of groundwater for dependent vegetation	• Vegetation health decline. • Changed vegetation structure and species composition, potentially including the loss of sensitive species.
Hydrological Processes	Reduced water discharge into groundwater-fed river pools or springs	• Changed hydrological regime of pools and springs, potentially including the loss of permanent or persistent waterbodies. • Changed wetland flora and fauna species composition, potentially including loss of species. • Diminished utility of water supply bores subjected to drawdown (e.g. pastoral water supply)
Subterranean Fauna	Reduction in the extent of saturated subterranean habitat utilised by stygofauna	• Changed composition of stygofauna species assemblages, potentially including loss of species.

Table 15 Key considerations of potential impacts associated with groundwater drawdown

Environmental factor	Key considerations
Flora and Vegetation (groundwater dependent vegetation	Baseline water levels, including natural fluctuations in depth to groundwater. The rate, magnitude and duration of watertable decline caused by dewatering, and the effect of this on water sources used by vegetation. The level of groundwater dependency of vegetation and the ability of vegetation to adapt and adjust to modified water regimes. Important aspects include vegetation root depth and the dynamics of plant available water storage in the vadose zone includingmechanisms of water replenishment in this zone. Although commonly hypothesised, no published studies have attributed groundwater drawdown to significant impacts on vegetation health in the Pilbara. However, operational experience suggests that *Melaleuca argentea* has a high reliance on groundwater and concomitant vulnerability to drawdown; whereas *Eucalyptus* species are typically highly resilient to drawdown ((Pfautsch et al., 2014; McLean 2014). Sites with a shallow and stable pre-disturbance water table (i.e. less than a few meters below the surface, and watertable fluctuations of less than about 1 meter) are likely to be the most susceptible to a reduction in groundwater levels. Potential impacts are likely to decline exponentially as the depth to watertable increases, due to the greater capacity of the vadose zone to store moisture and contribute to vegetation water use requirements. Vadose zone recharge is enhanced in habitats receiving surface inflows (e.g. creek systems). Particular groundwater regimes may also be important for vegetation reproduction dynamics such as flowering, seed production, germination and seedling recruitment (McGinness et al., 2013; Jensen et al., 2008).
Hydrological Processes	Groundwater system extent and connectivity. Baseline water levels, including natural fluctuations in depth to groundwater and the dynamics of recharge. The rate, magnitude and duration of water level decline caused by dewatering, and the effect of this on the overall water regime for pools. The importance of particular water regimes (e.g. permanent, persistent, seasonal or ephemeral) for the persistence of aquatic biota. The potential for permanent or persistent water bodies to provide refugia for aquatic biota, and the importance of refugia at landscape and regional scales. The location and operational status of water supply infrastructure, and future potential infrastructure.
Subterranean Fauna	Groundwater system extent and connectivity. Baseline water levels, including natural fluctuations in depth to groundwater. Stygofauna habitat characteristics such as spatial extent, saturated thickness, aquifer porosity / permeability, and groundwater quality (e.g. salinity). This includes consideration of habitat preferences of species/taxa within the stygofauna assemblage. In the Pilbara, shallow groundwater systems tend to have greater stygofauna abundance and species richness (Halse et al., 2014; Bennelongia, 2014). The rate, magnitude and duration of water level decline caused by dewatering and the effect of this on stygofauna habitat. Factors affecting stygofauna dispersal and recruitment, including following a drawdown disturbance event.

10.1.2. Change assessment methodology

The groundwater drawdown footprint was defined to include areas where groundwater levels are predicted to decline by greater than 1 m relative to the ‘no disturbance’ baseline. Drawdown of 1 m was considered to be a suitably conservative threshold for the purposes of the change assessment based on the level of uncertainty associated with drawdown predictions, application of the precautionary principle with respect to the ecohydrological change potential, and precedent in Western Australian environmental impact assessments. The assessment should be considered in the context that groundwater levels are variable in the study area (Section 5.6). Seasonal groundwater fluctuations typically exceed 1 m and these fluctuations are overprinted by longer-term groundwater level changes with respect to climate variability.

Groundwater drawdown at current BHP Billiton Iron Ore operations was determined based on observed groundwater levels in the bore networks, or estimated from numerical groundwater models developed for the Yandi, Mining Area C, Whaleback, Eastern Ridge and Jimblebar operations (calibrated model runs at June 2013).

For proposed BHP Billiton Iron Ore operations at the 30% development scenario and full development scenario, an analytical approach for estimating groundwater drawdown was applied. Estimated dewatering requirements were based on the degree of hydraulic connectivity of proposed mine pits (generic mine type). The orebodies were classified in terms of their degree of hydraulic connection with regional aquifers as outlined in Section 5.5.2 and further explained in Appendix C to F. Map 19 shows the locations of the generic mine types showing orebodies with low dewatering requirements for hydraulically isolated pits and high dewatering requirements for hydraulically connected pits.

For each orebody, the period of dewatering was based on BHP Billiton Iron Ore's projected below watertable mining schedule. Analytical methods were used to estimate the extent of the 1 m drawdown zone of influence using the hydraulic parameters (permeability and storage coefficients) of the rock types adjacent to the pits. The derived groundwater drawdown extents, although only indicative, were validated against existing data for currently operating sites. A more detailed description of the methodology for determining the extent of groundwater drawdown is provided in Appendix B.

The potential for water level recovery following the cessation of dewatering was not accounted for in the methodology, owing to the complexity of recharge processes at any given location. This applied to BHP Billiton Iron Ore and third-party operations. In general terms, groundwater recharge rates are likely to be modest unless facilitated by MAR schemes (e.g. in proximity to Ophthalmia Dam) and therefore natural water level recovery is likely to be slow (i.e. timescales of many decades to centuries). However, groundwater systems receiving concentrated rainfall recharge (for example in connection with major creek systems) would be expected to recover more quickly. As such, the long-term ecohydrological change potential footprint for groundwater drawdown used in the change assessment is precautionary, particularly for the full development scenario.

Drawdown extents for third party operations based on the 1 m drawdown threshold were obtained from public documents, where available. For Atlas Iron's Davidson Creek, only 10 m drawdown contours were available. Most of Koodaideri and Iron Valley are planned to be above the watertable. The drawdown extent at RTIO's Hope Downs 1 was based on the Central Pilbara Groundwater Study (Johnson and Wright, 2001). This drawdown extent was included in the assessment to provide context to the complex hydrological setting around Weeli Wolli Spring.

Areas with the potential for ecohydrological change associated with groundwater drawdown were delineated based on the interception of EHUs within the estimated drawdown footprint. The significance of potential change was classified as low, moderate or high based on a matrix of drawdown interception and the ecohydrological sensitivity of different EHUs, as shown in Figure 18 (for further discussion of ecohydrological sensitivity refer to Part II). Areas with high change potential may include zones of shallow groundwater systems supporting groundwater dependent vegetation, pools and stygofauna communities. Stygofauna habitat may also occur in areas of moderate change potential; however, these areas are not anticipated to support phreatophytic vegetation and/or wetlands. Areas with low change potential are not anticipated to include any groundwater dependent ecosystems. The analysis was undertaken for the baseline, 30% development and full development scenarios respectively. In each case, BHP Billiton Iron Ore operations included in the Strategic Proposal were considered separately and in combination with third-party operations.

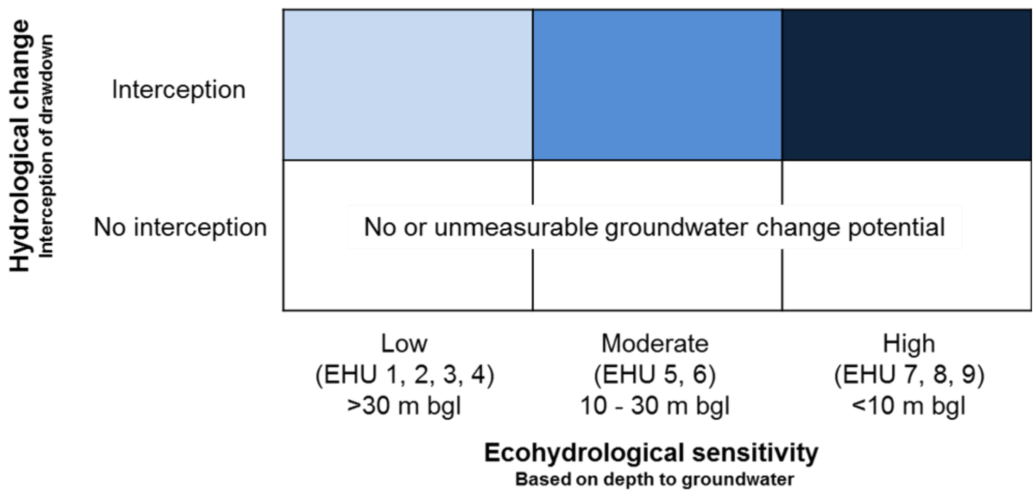

Figure 18 Ecohydrological change potential matrix – groundwater drawdown

10.2. Reduced surface water availability

The diversion of drainages around mining operations is necessary for the protection of mine infrastructure and human safety. These diversions involve modifications to natural flow regimes (either temporary or permanent). The effect of these modifications depends on the antecedent flow regime, magnitude of disturbance and fate of the diverted surface water flows. For example, diverted flows may be captured for human use (e.g. mine water supply) or delivered back into the environment down gradient from the mining operations.

Open pit mining also reduces the size of catchment source areas for drainages. When assessing the impact of surface water diversion, the effect of catchment area reduction on the flow regime resulting from mine pit development is of importance. Other mine infrastructure, such as linear infrastructure, can also affect landscape drainage by directing flows into culverts and creating drainage shadows.

10.2.1. Potential impacts

Potential environmental impacts associated with modified surface water availability include vegetation health decline, vegetation assemblage change (including the spread of weeds) and the loss or modification of aquatic habitats (Table 16). Key considerations for the evaluation of potential impacts on environmental factors include the nature of hydrological regime change (spatially and temporaly), and the responsiveness and resilience of ecosystems to this change (

Table 17).

Table 16 Potential environmental impacts associated with modified surface water availability

Environmental factor	Change mechanism	Potential impacts
Flora and Vegetation	Reduced availability of surface water inflows for vegetation down gradient of disturbance areas. Water ponding and waterlogging in association with obstructed drainage. Dispersal of weeds.	• Vegetation health decline, due to a reduction in plant available soil water without runoff replenishment. • Vegetation health decline, due to prolonged saturation of root systems. • Altered vegetation recruitment patterns. Changed vegetation structure and species composition, potentially including loss of species. • The introduction and/or spread of weeds in downstream areas.
Hydrological Processes and Inland Waters Environmental Quality	Modified flow volumes and velocities in drainages.	• Modified stream morphology resulting from erosion and deposition processes. Reduced flows are often associated with sediment accumulation, and increased flows with sediment loss. • Changed hydrological regime of wetland habitats (e.g. pools, claypans, floodplain environments). • Changed wetland flora and fauna species composition, including loss of species.

Table 17 Key considerations of potential impacts associated with modified surface water availability

Environmental factor	Key considerations
Flora and Vegetation	Baseline surface flow regimes, including creek channel morphology dynamics and processes of water storage and vegetation uptake associated with rainfall and surface inflows. Effect of modified drainages and run-off volumes on sources of water used by vegetation. The level of dependence of vegetation on surface water inflows, and the resilience of vegetation to modified water regimes. Particular flow regimes may be important for vegetation ecology (e.g. flowering, seed production, seed germination and seedling recruitment dynamics). Although not documented in the Pilbara, studies in other dryland environments have demonstrated a range of ecological impacts of modified surface water availability on vegetation communities (Doody et al., 2014; Jensen et al., 2008, Kingsford, 2000; McGinness et al., 2013; Steinfeld and Kingsford, 2011; Rolls et al., 2012). The presence of weed species in drainage systems, the potential for new weeds to be introduced and ecological factors affecting the spread of particular weed species.
Hydrological Processes and Inland Waters Environmental Quality	Baseline (antecedent) water regimes in drainages and their termini. Many Pilbara wetlands experience highly variable and dynamic water regimes, characterised by frequent droughts punctuated by pulse flow events. Relationships between particular water regimes (e.g. permanent, persistent, seasonal or ephemeral) and the persistence of wetland biota. Important hydrological parameters include the timing, duration, magnitude, seasonality, rate of change, and frequency of flow events (Kennard et al., 2010). In many situations the frequency, duration and severity of drought events proundly influences biota and ecological processes. Riparian ecosystems are likely to be vulnerable to a loss of hydrological connectivity in drainage networks. Habitat refugia within drainage systems may be important for the persistence of some biota (Leigh et al. 2010). The role of surface flows in the distribution of energy and nutrients in Pilbara environments. The effects of modified flow regimes on biogeochemical cycling may also need to be considered, particularly with respect to the long term impacts of enduring hydrological modifications.

10.2.2. Change assessment methodology

The surface water availability disturbance footprint was delineated based on the interception or 'loss' of catchment areas associated with mining ground disturbance areas. Loss of catchment area was considered to be a reasonable indicator of hydrological change in downstream areas, given its suitability for GIS spatial analysis and the paucity of stream gauge data and other hydrological information sources in the study area to inform a more complex spatial analysis (for further details refer to Appendix B). However, the interpretation of the change assessment findings requires careful consideration owing to limitations of this approach.

In practice, heterogeneity in rainfall patterns and land surface characteristics gives rise to non-uniformity in the generation of runoff within a given catchment area (Bracken et al., 2013; Chapi et al., 2015; Devito et al., 2005a; Fiener et al., 2011; McGlynn and McDonnell, 2003). Sub-areas within catchments contributing a disproportionately large amount to catchment runoff are referred to as variable source areas (VSAs).Due to VSAs, considered to be similar catchments based on size and topography may exhibit quite different runoff responses pre and post catchment disturbance. In general, VSAs are concentrated in lowland areas proximal to drainage zones (Devito et al. 2005b; Chapi et al., 2015; Klaus et al., 2015); particularly in arid environments where runoff discontinuities can be significant (van Wesemael et al., 1999; Lavee and Yair, 1990).

Mining disturbance areas are typically located in upland settings that are unlikely to function as VSAs, especially over larger catchment scales. It follows that the assumption of a linear relationship between catchment area reduction and runoff reduction is likely to overstate the potential for reduced surface water availability caused by mining disturbance. However, the approach is consistent with the objective of providing a conservative, regional scale assessment of ecohydrological change potential in the study area.

Relationships between catchment area reduction and hydrological processes of potential ecological importance are further summarised as follows:

- Runoff volume – where catchment characteristics are relatively homogenous, runoff would be expected to proportionately reduce as catchment area is reduced thereby reducing the availability of water for ecosystem maintenance and groundwater recharge;
- Runoff frequency and timing – typically a reduction in catchment area will not impact on the frequency of runoff generation events, as this is primarily influenced by rainfall intensity and duration. Runoff

frequency would only be affected in cases where catchment area is drastically reduced to the point where runoff source areas are effectively eliminated. The timing of runoff events is unlikely to change significantly unless natural flow attenuation structures are significantly enhanced;

- Peak runoff – a generalised relationship between catchment area and peak flow is described by proportionate catchment area reduction raised to the power of 0.7 (Institution of Engineers Australia, 1987). For example, a 20% reduction in catchment area would reduce the peak runoff by about 14%. In many cases peak runoff is likely to be less sensitive to changes in catchment area than runoff volume. The peak runoff is considered to be more important for infrastructure design and less relevant for evaluating ecohydrological change;
- Flood level is relatively insensitive to catchment reduction because as peak flow increases depth increases, resulting in increases in both the velocity of flow and width of flow. Examination of previous BHP Billiton Iron Ore flood studies has shown that the flow depth is typically proportional to the catchment area raised to the power of 0.4; suggesting that a 20% reduction in catchment area would decrease flow depth by about 9%. As such, floodplain areas are unlikely to experience reduced flooding frequency as a result of moderate reductions in catchment area; and
- The return interval of significant runoff events, such as the pre-disturbance 1 in 10 year ARI (average recurrence interval) event, is proportional to the amount of catchment area reduction. Hence where catchment area is reduced there will be a decreased frequency of runoff events of a given volume.

Ground disturbance areas, including pit areas and ore stockpile areas (OSAs), were delineated for current operations (2014) and proposed operations included in the 30% development and full development scenarios. These were then used to estimate areas of likely flow reduction down-gradient of the disturbance areas using a GIS-spatial analysis. Proposed infrastructure corridors, such as railway lines, were not considered to reduce flow as they would be designed within business-as-usual practices that maintain flow paths and prevent accumulation of floodwaters on the upgradient side. By default, a high degree of hydrological change was assigned to areas up to 1 km downstream of ground disturbance areas, based on the assumption that water from the upper catchment is diverted and returned to the downstream catchment 1 km down-gradient consistent with business-as-usual management practices. Further details of this analysis are provided in Appendix B.

For areas less than1 km downstream of ground disturbance areas, the degree of hydrological change was categorised based on the ratio of ground disturbance area to catchment area, as follows:

- <5% catchment area reduction – no or unmeasurable hydrological change;
- 5 to 20% catchment area reduction – low level of hydrological change; and
- >20% catchment area reduction – high level of hydrological change.

These categories were selected based on statistical analysis of runoff volumes in the study area using stream gauge data from the Flat Rocks gauging station. This analysis showed that runoff in the Pilbara is naturally highly variable, with annual runoff volumes ranging from 0.25% of the median up to 1 580% of the median. To smooth out these events and to take into account antecedent catchment conditions, moving averages for various inter-annual periods were also evaluated. For the 5 year moving average, the runoff volume in the driest 5 year period was approximately 20% of that for the median period. The runoff volume in the wettest five year period was approximately 200% of that for the median period. The 5 year moving average runoff value had a standard deviation of around 50%. Hence even over long periods there is a large amount of natural variation in annual runoff.

The analysis indicated that runoff reductions of less than 5% are within the error range of historical measurements, and are an order of magnitude lower than natural variations. Accordingly runoff reductions of less than 5% would not be expected to have any noticeable effect on the hydrological regime. Consistent with a precautionary approach, the potential for a high degree of hydrological change was considered to apply where catchment area is reduced by greater than 20%.

Areas with the potential for ecohydrological change associated with reduced surface water availability were delineated based on the interception of EHUs with zones of potential hydrological change categorised as above. This approach recognises the importance of EHUs 8 and 9 as regionally-significant areas of surface water accumulation. The significance of potential ecohydrological change was classified as low, moderate or high using the matrix presented in Figure 19, which relates the degree of potential hydrological change to EHU sensitivity to this change. Key factors affecting the sensitivities of EHUs to hydrological change include the frequency, duration and timing of flood events and the degree to which natural variability in the flow regime is preserved. The analysis was undertaken for the baseline, 30% development and full development scenarios respectively. In each case, BHP Billiton Iron Ore operations included in the Strategic Proposal were considered separately and in combination with third-party operations.

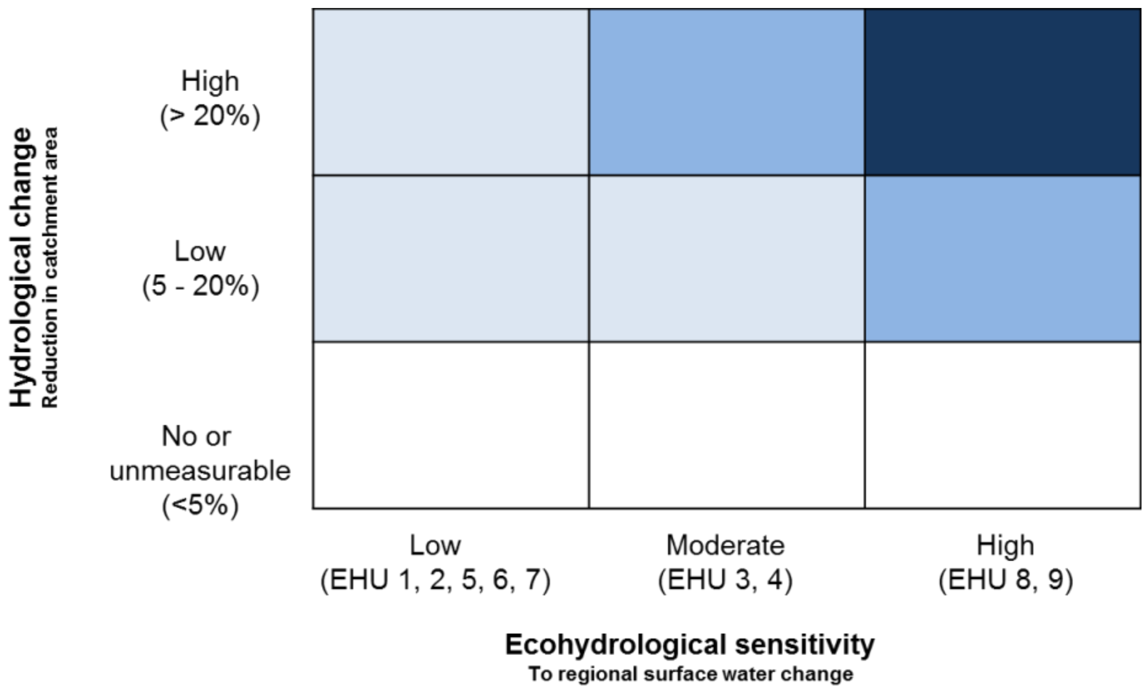

Figure 19 Ecohydrological change potential matrix – surface water availability

10.3. Surplus water management

Dewatering rates sufficient to enable resource extraction are predicted to exceed operational water demands for a number of the proposed mining operations included in the Strategic Proposal. The disposal of surplus dewatering volumes can be managed by transfer to operational uses elsewhere (e.g. other mining operations) or return to the environment. The return of surplus water to the environment provides an opportunity to offset and manage changes within the aquifer.

BHP Billiton Iron Ore's surplus water management approach takes into consideration beneficial use, water efficiency and water stewardship (BHP Billiton Iron Ore, 2014a); and is consistent with Department of Water guidelines (Department of Water, 2013). Surplus water is preferentially used onsite and to support environmental water provisioning, with any remaining surplus managed in accordance with the following sustainability and beneficial use hierarchy:

- Move water to a local demand point;
- Inject and infiltrate back into an aquifer;
- Store locally and reuse later; and
- Controlled discharge to ephemeral streams (least preferred option).

10.3.1. Potential impacts

Potential environmental impacts associated with surplus water disposal options include modified flow regimes in drainages, increased water availability for riparian vegetation, weed dispersal, and water quality changes in surface wetland and stygofauna habitats (Table 18). Key considerations for the evaluation of potential impacts on environmental factors include the response of vegetation and other ecosystems to altered water regimes and elevated water levels (

Table 19).

Table 18 Potential environmental impacts associated with surplus water management

Environmental factor	Change mechanism	Potential impacts
Controlled release to the surface environment		
Flora and Vegetation	Increased water availability	• Changed vegetation structure and species composition, potentially including vegetation health decline and loss of sensitive species under conditions of prolonged waterlogging. • Adaptation of vegetation communities to increased water availability and then failure to readapt to pre-disturbance conditions following the cessation of artificial supply (i.e. system state change).
	Dispersal of weeds	• The introduction and spread of weeds.
Hydrological Processes and Inland Waters Environmental Quality	Modified flow regime in drainages.	• Modified stream morphology resulting from erosion and deposition processes. Reduced flows may associate with sediment accumulation, and increased flows with sediment loss. • Changed hydrological regime of wetland habitats (e.g. pools, claypans, floodplain environments). • Changed wetland flora and fauna species composition, potentially including loss of sensitive species.
Managed aquifer recharge		
Flora and Vegetation Hydrological Processes	Mounding of groundwater around injection points	• Interaction of mounded groundwater with the vegetation root zone (e.g. waterlogging) resulting in vegetation health decline. • Salt accumulation in vegetation root zones, where MAR increases salt loads in the receiving environment.
Inland Waters Environmental Quality	Water quality changes in aquifers	• Impacts on existing and potential uses of groundwater resources.
	Water quality changes in wetlands	• Water quality changes in wetlands receiving discharge waters either directly or via aquifer connectivity.
Subterranean Fauna	Water quality changes in stygofauna habitat, principally relating to the salinity of disposal volumes relative to the receiving environment	• Changed composition of stygofauna species assemblages, potentially including loss of sensitive species.

Table 19 Key considerations of potential impacts associated with surplus water management

Environmental factor	Key considerations
Flora and Vegetation	Baseline water levels, including natural fluctuations in depth to groundwater. The rate, magnitude and duration of elevated water levels caused by surplus water disposal, and the effect on water sources used by vegetation. The ability of vegetation to adapt and adjust to modified water regimes. Important aspects include vegetation root system depth and the ability of vegetation to tolerate root system inundation. Recent research suggests that *Eucalyptus victrix* trees in the Weeli Wolli Creek floodplain are highly resilient to watertable elevations, where an adequate depth of unsaturated profile remains accessible to root systems (Pfautsch et al. 2014; Argus et al., 2014). Particular water level regimes may be important for vegetation dynamics (e.g. flowering, seed production, seed germination and seedling recruitment dynamics). The potential creation of new vegetation dependency on artificial water supply. The reversibility of vegetation change following the cessation of surplus water disposal.
Hydrological Processes	Groundwater system extent and connectivity Baseline water levels, including natural fluctuations in depth to groundwater and the dynamics of recharge. The location and operational status of water supply infrastructure, and future potential infrastructure.
Inland Waters Environmental Quality	Baseline water levels, including natural fluctuations in depth to groundwater. The rate, magnitude and duration of water level changes, and the effect of this on the overall water regime for wetland environments. The importance of particular water regimes (e.g. permanent, persistent, seasonal or ephemeral) for the persistence of aquatic biota.
Subterranean fauna	Baseline groundwater regime including groundwater quality. The rate, magnitude and duration of water level and water quality changes and the effect on stygofauna habitat. Stygofauna habitat characteristics such as spatial extent, saturated thickness, aquifer porosity/permeability, water quality (e.g. salinity). This includes consideration of habitat preferences of species/taxa within the stygofauna assemblage. Factors affecting stygofauna dispersal and recruitment.

10.3.2. Change assessment methodology

The indicative water balances suggest that some mining areas will remain predominantly water deficient; although, there may be periods with relatively low volumes of surplus water that are generated over a short to medium timeframe (1 to 5 years). The ecohydrological change potential for these mining areas are considered low, as surplus water can be managed in accordance with BHP Billiton Iron Ore's water management practices, and any water surplus is likely to be relatively small and of short duration.

For other mining areas, surplus water may be generated over longer timeframes and involve larger volumes of surplus water. The ecohydrological change potential for these mining areas is considered moderate in regions where surplus water volumes can be managed within BHP Billiton Iron Ore's existing water surplus management schemes being:

- Ophthalmia Dam MAR scheme, which manages surplus water from the Eastern Ridge and Whaleback mining areas; and
- Marillana Creek scheme, which currently manages surplus water from the Yandi mining area.

Both surplus water management methods have been in operation for a long period (more than 10 years) with comprehensive monitoring systems and dedicated management plans. As such, there is a greater understanding of the ecohydrological conditions and associated ecohydrological responses for both schemes. Surplus water re-infiltrates the underlying aquifers and has therefore a limited influence on ecohydrological receptors. In the case of Marillana Creek discharge, surface ponding does occur at the discharge location, but surplus water infiltrates and re-enters the underlying aquifer over a relatively short distance.

Mining areas in other regions with potentially significant volumes of water surplus been categorised as having high ecohydrological change potential, given that surplus water management schemes are yet to be developed in these regions. The surplus water management approach will be developed, in accordance with the feasible water options outlined in the Water RMS.

Based on the above, three change potential categories can be summarised as:

- Low change potential – net water deficit at the mining area scale requiring minimal surplus water management and can be addressed as part of normal business practices.
- Moderate change potential – net water surplus at the mining area scale with the ability to be managed through an existing regional surplus water management scheme, such as Ophthalmia Dam MAR or Marillana Creek scheme.
- High change potential – potentially significant volumes of water surplus at the mining area scale that require the development of a regional surplus water management scheme.

10.4. Acid and metalliferous drainage

The Strategic Proposal mining operations could expose potentially acid forming (PAF) materials that could result in Acid and Metalliferous Drainage (AMD). AMD includes the release of low pH drainage waters otherwise described as Acid Rock Drainage (ARD) from overburden containing PAF or exposed PAF material along the pit wall surface. AMD also include metals release or saline drainage in acidic or non-acidic waters. This section addresses only AMD from overburden placed in ex-pit OSAs. AMD derived from drainage through or over final pit walls and from overburden placed in the pit void (infill) are discussed in Section 11.7.

A high-level AMD source term risk assessment exercise was completed based on available geological and mine footprint data. The aim was to quantify the relative magnitude of environmental risk presented by disturbance of geological materials at iron ore deposits within the Strategic Proposal area.

10.4.1. Potential Impacts

Certain Pilbara lithologies, most notably the Mount McRae Shale and other shales (Table 3), are known to contain rock types with acid-forming potential. The degree of AMD risk is related to the presence of sulphide minerals, which are generally more prevalent in geological settings where oxidation is impeded (e.g. below the water table), and the capacity of natural mineral assemblages to neutralise acid generation. Current mining practice aims to minimise the interception of PAF overburden lithologies.

As a result of mining disturbance, PAF materials can be transported to the surface and placed into ex-pit OSAs. Without appropriate management, exposure of these materials to oxidation processes may result in acidification and the generation of metalliferous leachates with the potential to migrate into surface water systems and/or leak into groundwater. In any environment, a proportion of AMD will be subject to natural attenuation processes including pH buffering and acid neutralisation, adsorption at the mineral-water interface, mineral precipitation, and dilution/dispersion (Wilkin, 2008).

If improperly managed, AMD has potential to degrade the quality of surface water and groundwater resources, and may have follow-on impacts to ecohydrological receptors that utilise these water resources. Potential environmental impacts associated with AMD may include groundwater contamination, surface water contamination and exposing ecosystems to toxic substances (

Table **20**). The evaluation of potential impacts on environmental factors requires consideration of groundwater resource potential, source-pathway-receptor risk potential with respect to contaminant movement, and the resilience of biota and ecosystems to contaminant exposure (Table 21).

Table 20 Potential environmental impacts associated with acid and metalliferous drainage

Environmental factor	Change mechanism	Potential impacts
Inland Waters Environmental Quality	Contamination of surface water and groundwater resources with acidic and/or metalliferous pollutants.	• Reduced water quality • Disposal and handling of contaminated water
	Exposure of wildlife to acidic and/or metalliferous pollutants	• Effects on flora and fauna • Changed flora and fauna species composition, potentially including loss of species.

Table 21 Key considerations of potential impacts associated with acid and metalliferous drainage

Environmental factor	Key considerations
Inland Waters Environmental Quality	Baseline water quality, including natural variability (seasonal and spatial) in water quality. The rate, magnitude and duration of water quality change caused by AMD and its effect on current and future use of surface water and groundwater resources. Factors affecting the immobilisation and attenuation of acid and metalliferous contaminants in surface water and groundwater systems. Connectivity pathways between AMD sources and ecological receptors. Ecotoxicology of acid and metalliferous contaminants for flora and fauna species (terrestrial and subterranean species).

A number of factors contributing to AMD potential can be identified using the source-pathway-receptor approach including: the characteristics of the source material (namely the disturbed geological material), volume of source materials disturbed, and transport pathways between AMD source areas and environmental receptors. There are three ways in which the source-pathway-receptor linkage can be broken:

- source reduction - reducing the likelihood of materials acidification, such as the management of potentially acid forming (PAF) materials through encapsulation;
- pathway management - limiting hydraulic connectivity through considered mine design and planning; and
- modifying exposure of the receptor, such as the introduction of mitigation or other engineered solutions.

BHP Billiton Iron Ore has developed an AMD Management Standard (BHP Billiton Iron Ore, 2014b) which outlines minimum requirements for consistent and practicable AMD management across all its functions and operations.

10.4.2. Change assessment methodology

The change assessment methodology focuses on the overall AMD risk for BHP Billiton Iron Ore's mining areas and orebodies. It aims to identify mining areas where the potential for AMD development is greatest and will require management consideration.

The relative risk of AMD source materials was evaluated based on overburden lithology and BWT overburden volumes. The assessment approach did not consider potential transport pathways owing to the complex and site-specific nature of these considerations, and their sensitivity to closure management strategies. Similarly, the moderating effects of natural attenuation processes were not considered. As such the assessment approach is likely to overestimate the risk of AMD impacts for a given potential source area and the risk assessment is precautionary. Further details of the methodology are provided in Appendix B.

AMD potential classifications for geological materials were informed by geochemical considerations including the leachable AMD content within the source material and factors affecting its mobilisation. The assessment was completed at a mining area scale, consistent with a regional-scale assessment of current and planned deposits in the Strategic Proposal; as such, it is complementary to BHP Billiton Iron Ore's ongoing programs for detailed AMD characterisation at individual deposits.

AMD source potential was characterised based on:

- Estimated tonnage of material disturbed below the watertable – un-weathered materials below the watertable are considered as having a higher source potential; and
- Relative PAF risk of the host geology – Brockman orebodies are considered as having high source potential when compared with Marra Mamba (moderate source potential) and CID (low source potential) orebodies.

The AMD source potential is classified as low, moderate or high by qualitatively combining these two metrics (Figure 20). These three AMD potential categories can be considered in terms of:

- Low AMD source potential - unlikely to generate acidic conditions;
- Moderate AMD source potential - may generate acidic conditions requiring AMD management, but unlikely to be significant where normal business management practices are employed.
- High AMD source potential –may generate significant acidic conditions that require a more targeted management approach.

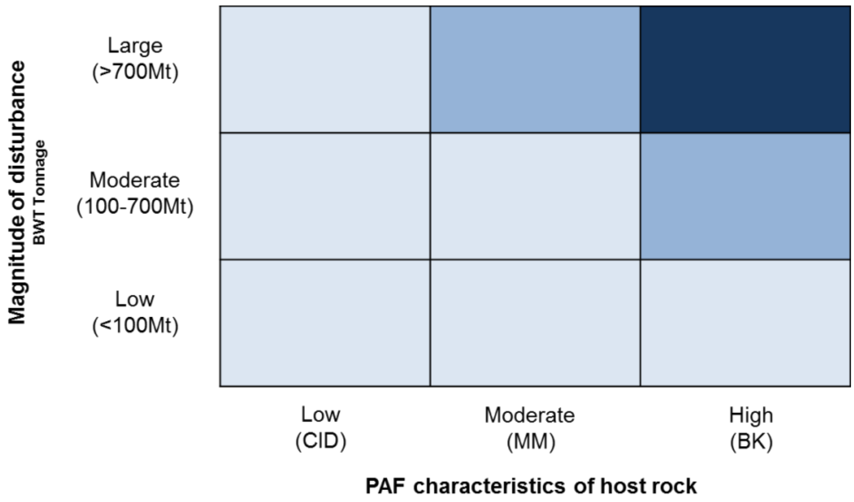

Figure 20 AMD source potential matrix

10.5. Groundwater quality - saline intrusion

Groundwater salinity in the Pilbara is typically fresh to brackish throughout the Eastern Pilbara, Central Pilbara and Marillana Creek regions. In the Fortescue Marsh region, the Fortescue River Valley supports a naturally occurring saline to hypersaline groundwater system associated with the Fortescue Marsh. Mine dewatering in the vicinity of the Marsh has the potential to modify and intercept the fresh water-saltwater interface, potentially resulting in the movement of saline water into fresh aquifers and mining areas.

10.5.1. Potential impacts

Potential environmental impacts associated with saline groundwater intrusion include degradation of groundwater resources, and potential loss or modification of subterranean habitats (Table 22). Improper disposal of abstracted saline groundwater may also impact surface ecosystems. Key considerations for the evaluation of potential impacts on environmental factors include groundwater resource potential, and the resilience of ecosystems and biota to salinity exposure (Table 23).

Table 22 Potential environmental impacts associated with saline intrusion

Environmental factor	Change mechanism	Potential impacts
Inland Waters Environmental Quality	Changed hydraulic balance results in the migration of saline groundwater into fresh groundwater systems	• Reduced groundwater quality for human uses • Where saline groundwater is abstracted, segregation and safe disposal is required.
	Influx of abstracted saline groundwater	• Changed ecosystem species composition, potentially including loss of sensitive species in groundwater dependent ecosystems.

Table 23 Key considerations for the evaluation of potential impacts associated with saline intrusion

Environmental factor	Key considerations
Inland Waters Environmental Quality	Groundwater system extent and connectivity Baseline water quality, including natural variability in water quality. The rate, magnitude and duration of water quality change caused by saline intrusion and the effect of this on the groundwater resource, including consideration of future use of the resource. Hydrogeological factors affecting the ability of the aquifer to recover from salinisation. Handling and disposal of abstracted saline water. Resilience of ecosystems and biota to exposure to salinity (terrestrial and subterranean ecosystems)

10.5.2. Change assessment methodology

The potential for saline intrusion is a function of the level of interaction between mine dewatering operations and the position of the saltwater interface within the Fortescue River Valley. Groundwater salinity data from bores in the Fortescue River valley were used to develop isohalines (i.e. spatially referenced lines of equal groundwater salinity) to define the likely position of the saltwater interface (represented where groundwater salinity exceeds 10 000 mg/L TDS) relative to BHP Billiton Iron Ore's proposed mining areas.

Previously developed groundwater drawdown footprints (Section 10.1) for mining operations in the Fortescue Valley were intersected with the isohalines using a GIS-spatial analysis. Zones of intersection with the saltwater interface represent areas with potential for saline intrusion.

10.6. Surface water quality change

Surface water drainages within the study area are predominantly ephemeral. Permanent surface water bodies are rare, typically being associated with terminal parts of the drainage network where surface water accumulates and interacts with zones of shallow groundwater (e.g. Weeli Wolli Spring). Mining activities have potential to modify drainages resulting in increased sediment loads, as well as surface water interaction with pollutants (such as sediment, hydrocarbons and other contaminants) that may be transported or dispersed within the landscape.

10.6.1. Potential impacts

Potential environmental impacts associated with surface water quality are provided in Table 24. The improper management of surface water may also impact surface ecosystems. Key considerations for the evaluation of potential impacts require an appreciation of potential sources of pollutants and their dispersion within the surface water regime (Table 25).

Table 24 Potential environmental impacts associated with surface water quality

Environmental factor	Change mechanism	Potential impacts
Inland Waters Environmental Quality	Dispersion of pollutants (e.g. sediment, contaminants) Exposure of wildlife to pollution.	• Pollution of wetland habitats. • Changed wetland flora and fauna species composition, including loss of species.

Table 25 Key considerations for the evaluation of potential impacts associated with surface water quality

Environmental factor	Key considerations
Inland Waters Environmental Quality	Baseline water quality, including natural fluctuations in relevant water quality parameters. This requires consideration of past and present land use impacts (e.g. pastoral activities) on water quality, and other landscape scale processes such as fire regimes. Characterisation of potential sources of pollution. Landscape modifications associated with mining have the potential to increase sediment loads in drainages. Contaminants may be associated with hydrocarbon storage and use, and overburden with the capacity to generate AMD. The environmental fate of pollutants as dictated by transportation pathways, dilution, attenuation and transformation processes including abiotic and biotic interactions. The ecotoxicology of pollutants. Species specific responses may be important, and also interactions between exposure and life history for a given species (e.g. adult vs juvenile, reproduction and recruitment stages).

10.6.2. Change assessment methodology

No specific methodology was developed for assessing change at a regional-scale relating to surface water pollution, on the basis that the potential for regional change is negligible following the application of normal business management practices employed by BHP Billiton Iron Ore for surface water management. This conclusion is supported by several decades of operational experience in the study area. As outlined in Section 4.2, the normal business approach includes measures for the prevention and containment of sediment, hydrocarbons and other contaminants; identification and encapsulation of acid-forming materials; and the delivery of diverted flows back into the natural drainage network.

10.7. Pit lake impacts

Following the cessation of mine dewatering, groundwater levels will gradually equilibrate with the surrounding environment resulting in pit lake formation within some final mine voids. In the Pilbara, full water level recovery is likely to be slow (i.e. in the order of many decades to centuries) owing to minimal recharge. Pit lakes will, in most cases, become permanent groundwater sinks with evaporation exceeding surface and groundwater inflows, with no outflows to the environment.

Low rainfall and high evaporation rates in the Pilbara provide a mechanism for changing water chemistry in pit lakes, driven by evaporation and reactive chemistry with surrounding rocks. These changes in water chemistry are influenced by complex, inter-related factors such as rock-water chemical interactions, climatic influences, biological activity and hydraulic connectivity with groundwater systems. Without significant groundwater contribution, most pit lakes will become progressively more saline over time until equilibrium is reached.

Salinisation may increase the potential for migration of dense, saline solution towards the base of pit lakes into connected groundwater systems (McCullough et al 2012). In practice, there are many uncertainties about the process of density-driven groundwater contamination. Despite an extensive search of the literature, as part of this change assessment, there are no published case studies of density-driven groundwater contamination associated with pit lakes.

In the case of Brockman and Marra Mamba mines, there is the possibility that some pit lakes may become acidic over time depending on the acid-forming potential of exposed lithologies in the final pit walls (e.g. exposure of Mount McRae Shale and other pyritic shales). Acidic pit lakes have the potential to increase the mobilisation and bioavailability of metals and other toxic substances, and therefore have increased ecohydrological change potential relative to non-acidic pit lakes. Where there is the potential for pit lake acidification to occur, detailed closure assessments to determine the need for backfilling or the ability to manage as a pit lake at mine closure are required.

10.7.1. Potential impacts

Potential environmental impacts associated with pit lakes include are summarised in Table 26. Key considerations for the evaluation of potential impacts on environmental factors include the final level of the pit lake, its connectivity with surrounding groundwater systems, the hydrodynamics in the pit lake and its influence on water quality evolution, and pit lake accessibility to biota (Table 27).

Table 26 Potential environmental impacts associated with pit lakes

Environmental factor	Change mechanism	Potential impacts
Inland Waters Environmental Quality	Migration of saline water into groundwater systems	• Reduced groundwater quality for human uses • Where saline / contaminated groundwater is abstracted, special handling and disposal practices are necessary.
	Exposure to acidic, saline and/or contaminated pit lake water	• Toxic effects on biota, in particular waterbirds.
	Exposure to acidic, saline and/or contaminated groundwater	• Toxic effects on stygobitic taxa • Changed stygofauna species composition, potentially including loss of species.

Table 27 Key considerations for the evaluation of potential impacts associated with pit lakes

Environmental factor	Key considerations
Inland Waters Environmental Quality	Baseline water quality, including natural variability in water quality. The change / evolution of pit lake water quality in terms of rate, magnitude and duration. Hydraulic connectivity between the pit lake and neighbouring aquifers, and ecohydrological receptors. Factors affecting the immobilisation and attenuation of contaminants in groundwater systems. Biogeochemical factors affecting the ability of the aquifer to attenuate acid and metalliferous contaminants. Ecotoxicology of pit lake water for biota, including stygofauna species and assemblages. Fauna mobility and ability access to other (better quality) water sources spatially and temporally.

10.7.2. Change assessment methodology

The change assessment approach aims to assess BHP Billiton Iron Ore's ability to manage the potential impacts of pit lakes by the backfilling of final mine voids. There may be environmental drivers for the backfilling of below watertable mine voids rather than allowing the formation of a pit lake, for example to avoid the formation of an acidic pit lake or long-term altering of the water regime associated with an ecohydrological receptor. Consistent with a regional scale approach, the assessment distinguishes mining areas where backfilling is a mine closure option (based on backfill materials availability), and mining areas where insufficient material may be available for backfilling.

As part of BHP Billiton Iron Ore's normal business approach to overburden optimisation, a portion of overburden is often placed in the mine void for economic considerations (referered to as infilling). The proportion of normal business infilling practices varies between pits and depends on a range of factors including the geometry of the mine void and mine scheduling. Generally between 30% and 60% of overburden material will be infilled.

After the cessation of dewatering operations, groundwater levels tend to slowly recover to below pre-mining groundwater levels. In many cases under a normal business approach, infilling will be at an elevation higher than the pre-mining water table thereby preventing pit lake development. In cases where infilling is completed to an elevation lower than the pre-mining watertable, there is the potential for a pit lake to form. In such cases, backfilling (i.e. over and above infilling) above the pre-mining watertable may be considered as a means of achieving mine closure objectives.

Many of the proposed BWT pits within the Strategic Proposal have sufficient ex-pit overburden material to infill the pit void to an elevation above the pre-mining watertable. In some cases, overburden derived from other pits in the mining area may be available for backfilling. Mining areas associated with channel-iron deposits tend to have insufficient overburden for the infilling and backfilling of mine voids to above pre-mining watertable, which suggests that pit lake formation is a likely mine closure scenario.

Five mine void types were considered in the change assessment corresponding with three ecohydrological change potential categories (Table 28). High change potential is associated with cases of insufficient material to infill mine voids, such that the formation of pit lakes is a necessary closure outcome. Low change potential is associated with sufficient backfill being available to prevent the pit lake formation at the orebody or mining area level; however, this may require integrated overburden scheduling across the mining area to meet closure objectives (i.e. movement of infill materials between pits). No or negligible change potential is associated with above watertable mines, or where infilling is anticipated to be scheduled as part of normal business practices.

Table 28 Ability to manage potential pit lake impacts through infilling and backfilling

Mine type category	Description	Potential for pit lake formation	Ecohydrological change potential
Above the watertable (AWT) mine voids	Mining will occur above the watertable and the watertable will not be encountered during mining	No potential for pit lake formation	None
Infilled pit void through normal business overburden scheduling	Mining will take place below the watertable, but the mine void will be infilled with overburden to an elevation above pre-mining water levels through normal business overburden scheduling	No potential for pit lake formation through normal business overburden scheduling	None
Adequate ex-pit overburden available to infill pit void.	Mining will take place below the watertable and normal business infilling will be to an elevation below the pre-mining watertable. However, there is sufficient ex-pit overburden material to infill the mine void to above pre-mining water levels if required to meet the closure objectives.	Potential for pit lake formation. Adequate ex-pit overburden is available to infill pit void and prevent pit lake formation, if required to meet closure objectives	Low
Overburden scheduling required at the mining area level to backfill pit void	Mining will take place below the watertable and normal business infilling will be to an elevation below the pre-mining watertable. Ex-pit overburden material will not be sufficient to infill the mine void; however, there is sufficient material across the wider mining area. Mining area based overburden scheduling will be required to infill the mine void to above the pre-mining watertable (if required) to meet the closure objectives	Potential for pit lake formation. Mining area based overburden scheduling is required to infill pit void and prevent pit lake formation, if required to meet the closure objectives	Low
Insufficient overburden available in mining area to backfill pit void.	Mining will take place below the watertable and normal business infilling will be to an elevation below the pre-mining watertable. There is insufficient overburden in the mining area for the backfilling of the mine void to above pre-mining water levels (if required) to meet the closure objectives	Potential for pit lake formation. There is insufficient overburden in the mining area to prevent pit lake formation.	High

11. Regional Change Assessment

The regional change assessment describes the potential for ecohydrological change in the landscapes of the study area associated with the Strategic Proposal; within the ecohydrological conceptual framework described in Part II. The assessment addresses each threatening process (refer to Section 11) for the baseline, 30% development and full development scenarios respectively. The influence of third-party mining operations has also been explicitly considered in all scenarios to provide an indication of pre-existing and cumulative change potential.

Interpretation of the regional change assessment requires consideration of the following aspects:

- The assessment constitutes a regional appraisal of ecohydrological change potential, which highlights key threatening processes in different landscape settings and contexts. It also provides a regional perspective for receptor-level change assessment.
- The assessment is based on conservative assumptions consistent with a precautionary approach (refer to Section 4.2). The 30% development and full development scenarios assume the implementation of normal business management practices, but not the the implementation of management options under BHP Billiton Iron Ore's Water RMS.
- Management approaches and options can be considered in the context of the landscape conceptualisation based on EHUs. This provides basis for evaluating the potential application of the Water RMS to the assessment findings for 30% and full development scenarios.
- Over time, management approaches and options are anticipated to be informed by accumulated knowledge and experience gained via implementation of the adaptive management process embodied in the Water RMS. On this basis, the efficacy of management can be expected to continuously improve during the implementation of the Strategic Proposal.

11.1. Groundwater drawdown

Areas of potential ecohydrological change associated with groundwater drawdown are characterised as areas where groundwater levels are likely to decline by more than 1 m relative to the 'no disturbance' baseline. These areas are shown in Maps 20 to 22, which depict the combined effects of BHP Billiton Iron Ore and third-party operations for the baseline, 30% development and full development scenarios respectively. Key findings include:

- In the baseline scenario (2014) areas of ecohydrological change potential associated with groundwater drawdown are spatially restricted with little interaction between operations (Map 23). The areas of largest drawdown influence occur along Marillana Creek in association with BHP Billiton Iron Ore's Yandi and RTIO's Yandicoogina, as well as substantial groundwater drawdown associated with RTIO's Hope Downs operation with some cumulative interaction associated with mine dewatering in Mining Area C. With respect to ecohydrological receptors, groundwater drawdown arising from mining operations has resulted in some degree of ecohydrological potential change at Weeli Wolli Spring, Marillana Creek, Ethel Gorge and Fortescue Marsh (discussed with respect to each receptor in Section 13).
- In the 30% development scenario groundwater drawdown has expanded, with increased areas of cumulative drawdown linked to multiple operations (Maps 24 and 25). This is most noticeable along the northern flank of the Fortescue River Valley associated with FMG's and HPPL's operations; along Marillana Creek owing to progressive development of BHP Billiton Iron Ore's Yandi and RTIO's Yandicoogina operations; around Weeli Wolli Spring and toward the Coondewanna Flats catchment; and the Eastern Ridge and Homestead mining areas in the Eastern Pilbara region (further discussed with respect to each receptor in Section 12).
- In the full development scenario relatively extensive areas may be subject to groundwater drawdown (Maps 26 and 27), with proposed BHP Billiton Iron Ore mining areas significantly contributing to cumulative drawdown. Areas potentially subject to significant ecohydrological change related to groundwater drawdown include:
  - Central Pilbara region
    - BHP Billiton Iron Ore's Mudlark, Tandanya, North and South Flank mining areas which influence Coondewanna Flats; and
    - BHP Billiton Iron Ore's MAC and Jinidi mining areas, as well as residual groundwater drawdown associated with RTIO's Hope Downs operation.
  - Eastern Pilbara region
    - BHP Billiton Iron Ore's Eastern Ridge, Homestead and East Ophthalmia mining areas which influence Ethel Gorge.

- Marillana Creek region
    - Operations in the Lower and Upper Marillana Creek.
- Fortescue Marsh region
    - BHP Billiton Iron Ore's Marillana mining area may influence the southern fringe of the Marsh.

11.1.1. Ecohydrological units

Ecohydrological change potential associated with groundwater drawdown for the different EHUs in the study area, considering scenarios addressing both BHP Billiton Iron Ore and third-party operations in the baseline, 30% development and full development scenarios, is described in Maps 20 to 22. Regional change in EHUs, expressed as percentage change by area, was determined for each scenario with respect to BHP Billiton Iron Ore only (Figure 21), and the cumulative effect of BHP Billiton Iron Ore and third-party operations (Figure 22).

Key findings include:

- In the baseline scenario (2014) the regional change potential in EHUs is spatially restricted. Groundwater drawdown is most pronounced in the EHUs with the least sensitivity to groundwater change, being the upland (EHU 1 and 2) and transitional units (EHU 3 and 4) of the Eastern Pilbara and Central Pilbara regions.
- Regional change potential related to third-party operations in the baseline scenario is most apparent in the EHUs with low sensitivity to groundwater change, being the upland unit (EHU 1) in the Central Pilbara, Fortescue Marsh and Marillana Creek regions, and transitional units (EHU 3 and 4) in the Central Pilbara region. A small proportion of alluvial plains in the Fortescue Marsh region (EHU 6) of moderate sensitivity are subject to drawdown, and also small areas of high sensitivity calcrete plains (EHU 7) at Weeli Wolli Spring in the Central Pilbara region and receiving drainage areas (EHU 8) along Marillana Creek .
- In the 30% development scenario increased cumulative groundwater drawdown occurs in the least sensitive upland (EHU 1 and 2) and transitional units (EHU 3 and 4) within the Central Pilbara and Fortescue Marsh regions. A modest increase in areas subject to drawdown is also apparent in the highly sensitive calcrete plains (EHU 7) associated with BHP Billiton Iron Ore's proposed Munjina and Upper Marillana mining areas and sections of Marillana Creek (EHU 8).
- In the full development scenario the extent of drawdown is significant in the least sensitive transitional units (EHU 3 and 4) in the Central Pilbara, Fortescue Marsh and Marillana Creek regions; highly sensitive receiving drainage areas (EHU 8) associated with Marillana and Weeli Wolli Creeks in the Marillana Creek and Fortescue Marsh regions respectively; and moderately sensitive alluvial drainages (EHU 6) in the Central Pilbara and Fortescue Marsh regions. A modest degree of drawdown incursion occurs in the moderately sensitive sandplain unit (EHU 5) of the Fortescue Marsh and Eastern Pilbara regions, and a slight increase in the least sensitive upland units (EHU 1 and 2) relative to the 30% development scenario. There is only a small increase in the extent of drawdown affecting highly sensitive, lowland receiving (drainage termini) areas associated with Munjina Claypan in the Marillana Creek region, and the Fortescue Marsh.

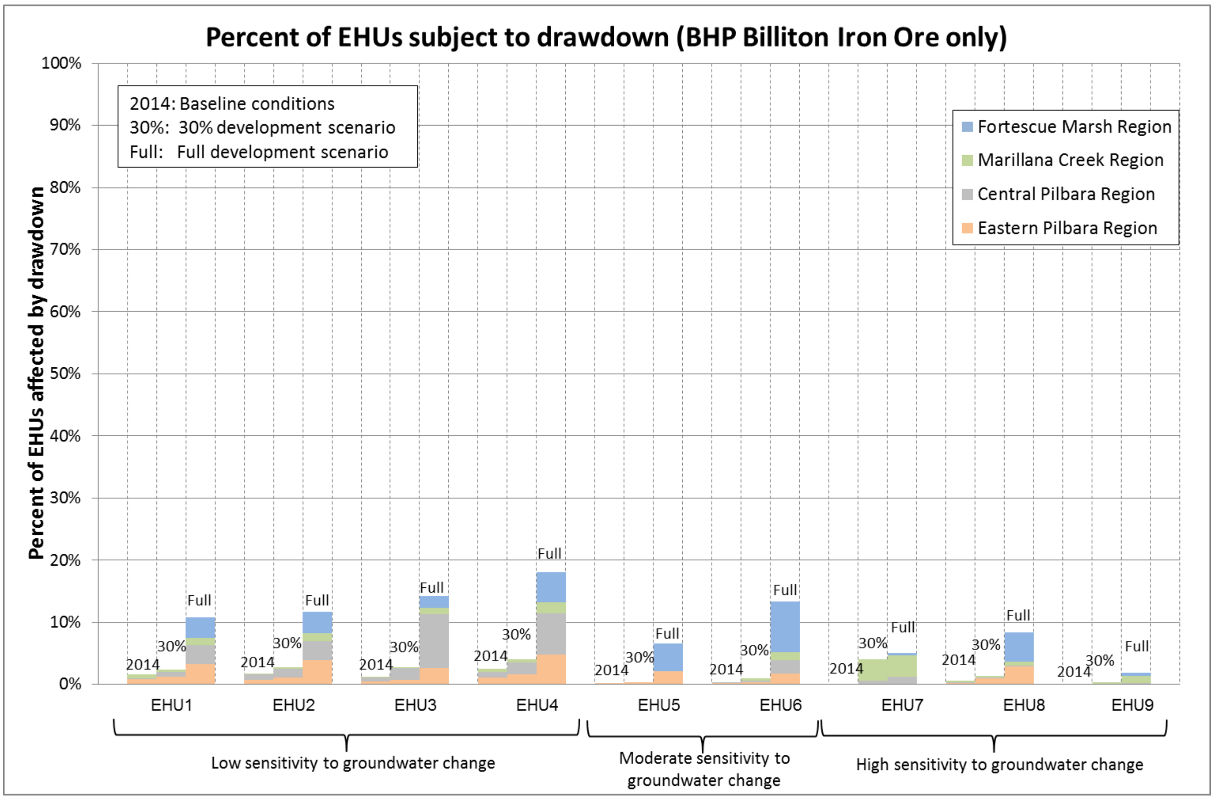

Figure 21 EHUs subject to groundwater drawdown - BHP Billiton Iron Ore only

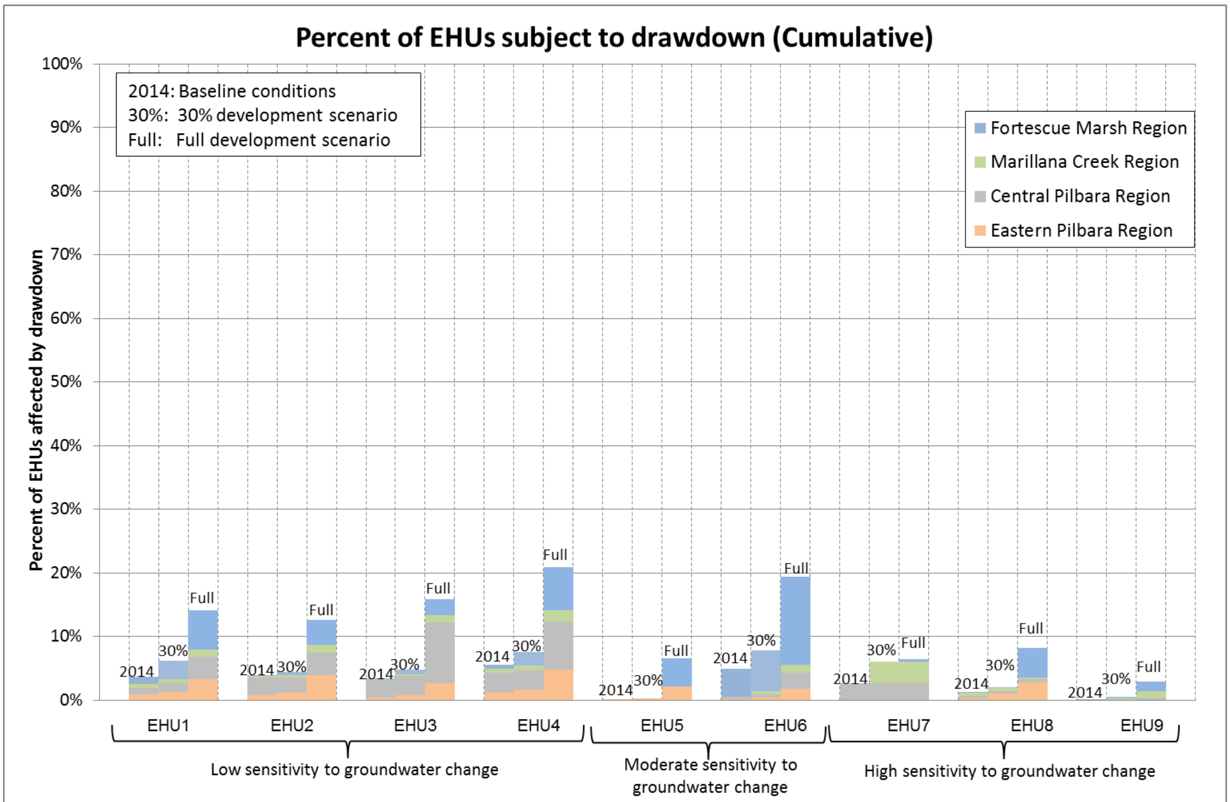

Figure 22 EHUs subject to groundwater drawdown - cumulative

11.1.2. Groundwater resources

A separate analysis was undertaken to gain a regional appreciation of potential change in groundwater resources across the study area associated with groundwater drawdown. As groundwater recharge is intermittent, variable and mainly associated with infiltration along creek lines, it is readily exceeded by groundwater abstraction resulting in progressive depletion of groundwater storage. The estimation of groundwater resource or storage depletion considers regional-scale volumetric change of the groundwater resource related to the Strategic Proposal and the influence of third-party abstraction.

No published studies have attempted to quantify stored groundwater resources in the Central Pilbara region including the study area; as such, new estimates of groundwater storage were developed for the change assessment (Table 29). Storage estimates were based on broad-scale assumptions with respect to the areal extent, saturated thickness and specific yield of the regional aquifer comprising Tertiary detritals and underlying Wittenoom Formation. Estimates of specific yield were obtained from the regional study reports (Appendices C to F). Outside of the regional aquifer, groundwater resources are localised and associated with zones of fractured rock and mineralisation including orebody aquifers; the storage in these systems is minor in a regional context and therefore not considered in the storage estimate.

Table 29 Groundwater storage in the regional aquifer

Region	Regional aquifer area (km^2)	Regional aquifer storage (GL)
Central Pilbara	1 039	2 600
Eastern Pilbara	1 873	4 700
Fortescue Marsh	5 360	13 400
Marillana Creek	523	1 300
Total		22 000

The groundwater storage estimates only considered low-salinity groundwater (salinity less than 7 000 mg/L TDS), in recognition of the potential beneficial uses of this water (e.g. stock watering). The large volume of saline to hypersaline groundwater in the Fortescue River Valley beneath the Fortescue Marsh (about 5 000 GL) was excluded from the regional estimate, as it is largely unsuitable for beneficial uses and its exclusion provides a more meaningful (and conservative) estimation of groundwater resource change. A full description of the storage estimation methodology is provided in Appendix B.

The change in groundwater resources considers water balance estimates developed to determine surplus water for each mining area (as discussed in Section 11.4).

Change in storage = (recharge + 50% excess dewatering) - (dewatering + groundwater supply)

The inflows comprise rainfall recharge (based on estimates of streamflow contribution) and the placement of excess dewatering water back into the aquifer (assumed 50% return) in line with BHP Billiton Iron Ore's water stewardship policy (BHP Billiton Iron Ore, 2014a). The estimation of natural rainfall and creek recharge was obtained from the regional study reports (Appendices C to F), and is based on chloride ion (Cl) water balances and potential infiltration of streamflow. The outflows are the sum of dewatering requirements and additional sources required (such as borefields and/or regional water transfer) to supply groundwater in the event of water deficiencies.

The cumulative change in groundwater resources accounts for the influence of third-party mining operations. The change associated with the third-party operations was estimated as the operational water requirements or demands provided in the publicly-available documents. Mine dewatering above supply requirements was not considered for third party mines, as guidance was often not available on the management of the surplus. Further detail on the methodology is provided in Appendix B.

A positive change in groundwater storage indicates that the groundwater resource is not impacted but rather has potential for increased storage – this is observed in the Eastern Pilbara region for the 30% development scenario associated with leakage from Ophthalmia Dam. Conversely a negative change indicates groundwater storage depletion. The storage depletion in each region was expressed in terms of percentage change in the regional aquifer storage in the 30% and full development scenarios respectively relative to the baseline scenario. Separate analysis was undertaken for BHP Billiton Iron Ore operations only, and the cumulative effects of BHP Billiton Iron Ore and third-party operations.

Key findings from the groundwater resource assessment include (Figure 23):

- The change in groundwater resources associated with BHP Billiton Iron Ore only for the the 30% development scenario relative to the baseline scenario is less than 5%. This change is most apparent in the Central Pilbara and Marillana Creek regions associated with Mining Area C, Mudlark and Yandi mining areas. In the Eastern Pilbara region, Ophthalmia Dam is recognised as an important source of groundwater recharge.
- Cumulative change for the the 30% development scenario relative to the baseline scenario (i.e. BHP Billiton Iron Ore and third parties) is less than 20%. The majority of this change is associated with third-party mining operations including RTIO's Hope Downs 1 in the Central Pilbara region, FMG's Cloudbreak and FMG's Christmas Creek expansion in the Fortescue Marsh region, and RTIO's Yandicoogina in the Marillana Creek region.
- Change associated with BHP Billiton Iron Ore only for the the full development scenario relative to the baseline scenarioincludes prominent areas of potential storage depletion within the Central Pilbara (Tandanya and Mudlark) and Marillana Creek (Munjina and Upper Marillana) regions. Storage depletion may be negligible in the Eastern Pilbara region owing to the moderating influence of facilitated recharge from Ophthalmia Dam, and in the Fortescue Marsh region owing to the large stored groundwater resource within the Fortescue River Valley.
- Cumulative change for the the full development scenario relative to the baseline scenario reflects the development of significant new third-party operations. The most noticeable of these are FMGs Nyidinghu project in Fortescue Marsh region, and RTIOs Yandicoogina expansion including Pocket and Billiards South deposits in the Marillana Creek region.

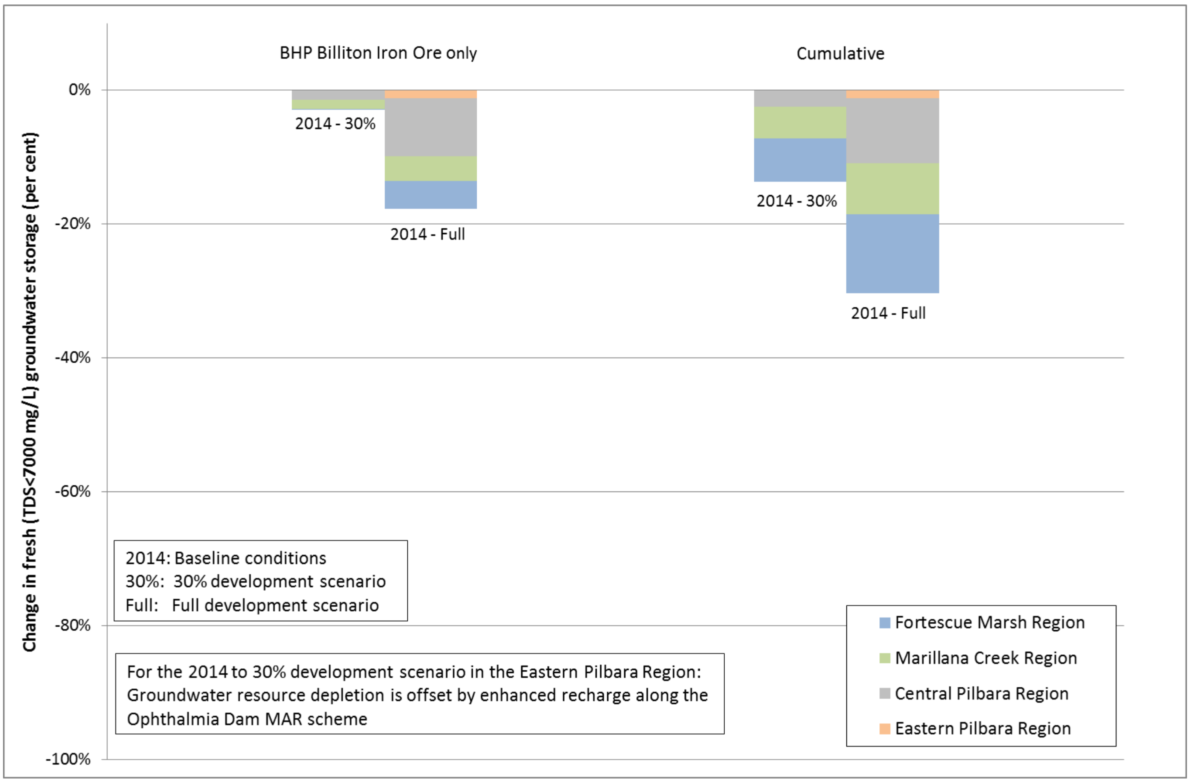

Figure 23 Change in groundwater resource in the study area

11.1.3. Stygofauna habitat

As part of the Strategic Environmental Assessment, a comprehensive study of regional subterranean fauna across the Pilbara was compiled using existing survey data to determine subterranean fauna distribution and potential habitat (Bennelongia, 2014). Data sources included information collected by BHP Billiton Iron Ore operations and some publicly-available information such as the Pilbara Biodiversity Survey (Halse *et al*., 2014).

Groundwater drawdown was considered to be a threatening process for stygofauna but not troglofauna; hence, only stygofauna was considered as a factor in the change assessment.

The EHU approach provided a basis for developing a regional stygofauna habitat sensitivity map, taking into account potential stygofauna abundance across the study area. The presence of stygofauna is strongly correlated with groundwater depth (Halse *et al*, 2014). Abundance is highest where associated with shallow groundwater (less than 10 m bgl) and typically very low where depth to groundwater is deeper than 30 m. In addition, abundance is highest in areas with a strong groundwater-surface water connectivity, in particular creek recharge areas, which allows inflows of nutrients into the groundwater.

Areas with shallow water tables associated with alluvial and/or calcrete aquifers have significant groundwater – surface water connectivity. These habitat types tend to occur in EHUs 7, 8 and 9. In EHUs 5 and 6 the depth to groundwater is typically between 10 and 30 m bgl, with reduced groundwater - surface water connectivity and moderate potential for stygofauna abundance. Deep groundwater levels occur in the upland and transitional ecohydrological units, suggesting a low level of habitat suitability for stygofauna beneath EHUs 1 to 4.

Maps 28 and 29 depict stygofauna habitat sensitivity throughout the study area with dark blue zones indicating a higher potential for stygofauna abundance and light blue zones indicating lower potential of stygofauna abundance. The stygofauna survey data is included to demonstrate the spatial extent of the dataset and validate the relationship between stygofauna abundance and depth to groundwater.

The predicted groundwater drawdown extents around BHP Billiton Iron Ore and third-party mining areas for the 30% development and full development scenarios are shown on Maps 21 and 22 respectively. Both the groundwater drawdown (areas of less than 1 m of groundwater drawdown) and potentially sensitive stygofauna habitat extents are likely to be overestimated (i.e. based on conservative assumptions). The analysis reflects that little is known about the potential stygofauna richness and abundance under the Fortescue Marsh associated with hypersaline groundwater. Note that the area of potential ecohydrological change does not imply nor suggest a direct impact on stygofauna health, but provides an indication of areas in which impacts are most likely to occur. This provides the basis for more detailed validation assessments to be conducted as part of with mine planning and implementation schedules.

In the 30% development scenario, areas where stygofauna habitat has the greatest potential to be influenced by groundwater drawdown include:

- Central Pilbara region
    - Alluvial and calcrete units along Pebble Mouse Creek and Weeli Wolli Spring associated with groundwater drawdown from RTIO's Hope Downs 1 mining area, and BHP Billiton Iron Ore's Mining Area C and Jinidi mining areas; and
    - North of Coondewanna Flats associated with BHP Billiton Iron Ore's Mining Area C and Mudlark mining areas.
- Eastern Pilbara region
    - The Ethel Gorge area associated with groundwater drawdown from BHP Billiton Iron Ore's Eastern Ridge, Homestead and East Ophthalmia mining areas. A more detailed discussion on the potential hydrological change in the Ethel Gorge area is presented in the Ethel Gorge Case Study.
- Marillana Creek region
    - Parts of the Lower and Upper Marillana Creek, and Weeli Wolli Creek associated with groundwater drawdown from BHP Billiton Iron Ore's Yandi and RTIO's Yandicoogina mining areas.

- Fortescue Marsh region
    - Potential zones of moderate stygofauna habitat sensitivity along the northern margin of the Marsh in the vicinity of BHP Billiton Iron Ore's Roy Hill mining area, FMG's Cloudbreak and Christmas Creek mining areas, and the HPPL's Roy Hill mining area;
    - There may be additional areas south of the Marsh associated with FMG's Nyidinghu mining area.

In the full development scenario areas where stygofauna habitat has the greatest potential to be influenced by groundwater drawdown include:

- Central Pilbara region
    - Similar to the 30% development scenario, but also extending into the Coondewanna Flats catchment associated with BHP Billiton Iron Ore's Mudlark and South Flank mining areas;
- Eastern Pilbara region
    - Similar to the 30% development scenario;
- Marillana Creek region
    - Similar to the 30% development scenario, but also extending towards the Upper Marillana mining area; and
- Fortescue Marsh region
    - Similar to the 30% development, but also including areas of moderate stygofauna habitat sensitivity along the southern part of the Marsh in the vicinity of BHP Billiton Iron Ore's Marillana, Mindy and Coondiner mining areas.

11.2. Surface water availability

At the regional-scale, ecohydrological change associated with surface water availability is represented as areas, or footprints, where there is loss or interception of catchment area associated with ground disturbed by mining for pits or OSAs. This regional change in surface water availability for of the baseline, 30% development and full development scenarios are shown in Maps 30 to 32 respectively.

Key findings include:

- In the baseline scenario the reduction in surface water availability across the study area is relatively restricted (Map 33). The areas of largest influence occur along Marillana Creek in association with BHP Billiton Iron Ore Yandi and RTIO Yandicoogina; the cumulative effect of RTIO's Hope Downs operation and BHP Billiton's MAC mining area; and the FMG's operations along the Chichester Range. Additional minor areas of reduced surface water availability occur proximal to Weeli Wolli Spring, Marillana Creek, Ethel Gorge and Fortescue Marsh (discussed with respect to each receptor in Section 12).
- In the 30% development scenario, areas of cumulative surface water reduction have increased relative to the baseline scenario (Maps 34 and 35). The key areas subject to change include: T:
    - Northern flank of the Fortescue River Valley associated with FMG's and HPPL's operations;
    - Southern flank of the Fortescue River Valley associated with RTIO's Koodaideri, BHP Billiton Iron Ore's Marillana mining area, and FMG's Nyidinghu operations;
    - Marillana Creek owing to progressive development of CID operations;
    - Drainages that flow towards Weeli Wolli Spring from BHP Billiton Iron Ore's MAC and Jinidi mining areas, as well as RTIO's Hope Downs operation;
    - Surrounding catchment of Coondewanna Flats associated with BHP Billiton Iron Ore's Mudlark, North and South Flank mining areas; and
    - Drainages that contribute to flow through Ethel Gorge in the Eastern Pilbara region.

- In the full development scenario areas of cumulative surface water reduction have significantly increased relative to the 30% development scenario (Maps 36 and 36). The key areas subject to change include:
  - Northern flank of the Fortescue River Valley associated with FMG's and HPPL's operations, and also BHP Billiton Iron Ore's Roy Hill operation in the west;
  - Lower Weeli Wolli Creek associated with influence of southern flank of the Fortescue River Valley (RTIO's Koodaideri, BHP Billiton Iron Ore's Marillana and FMG's Nyidinghu operations); changes within Marillana Creek owing to progressive development of CID operations; and drainages that flow towards Weeli Wolli Spring from BHP Billiton Iron Ore's MAC and Jinidi mining areas;
  - Catchment areas surrounding Coondewanna Flats associated with BHP Billiton Iron Ore's Mudlark, Tandanya, North and South Flank mining areas; and
  - Drainages that contribute flows to Ethel Gorge in the Eastern Pilbara region.

11.2.1. Ecohydrological units

The extent of potential ecohydrological change associated with reduced surface water availability for the different EHUs considering baseline, 30% development and full development scenarios addressing BHP Billiton Iron Ore operations with and without the cumulative effects of third-party operations respectively are shown on Maps 33 to 37. Regional change in EHUs, expressed as a percentage of the area of each EHU subject to change in each region, has been calculated for BHP Billiton Iron Ore operations only (Figure 24) and combined BHP Billiton Iron Ore and third-party operations (Figure 25).

Key findings include:

- In the baseline scenario, there is only minor (less than 5%) potential change in surface water availability for all EHUs associated with BHP Billiton Iron Ore only across the study area. The EHUs subject to change are low sensitivity upland units (EHU 1 and 2) and moderate sensitivity transitional units (EHU 3 and 4) of the Eastern Pilbara and Central Pilbara regions (as discussed in Section 5.8.2). Regional change potential related to third-party operations at 2014 is most apparent in the moderate sensitivity transitional units (EHU 3 and 4) and low sensitivity lowland alluvial plains (EHU 6) in the Central Pilbara region. EHUs in the Fortescue Marsh region are subject to negligible change relative to the size of the Fortescue River Valley catchment.
- In the 30% development scenario increased reduction in surface water availability associated with BHP Billiton Iron Ore operations is apparent in moderate sensitivity transitional units (EHU 3 and 4) within the Central Pilbara region; and to a lesser extent, low sensitivity upland units (EHU 1 and 2) in the Central Pilbara region, moderately sensitive calcrete plains (EHU 7) associated with BHP Billiton Iron Ore's proposed Munjina and Upper Marillana mining areas; and high sensitivity receiving drainage areas (EHU 8) at Ethel Gorge, Marillana Creek and Weeli Wolli Creek. The potential change associated with third-party operations is pronounced in low sensitivity lowland plains (EHU 6) in the Fortescue Marsh region, high sensitivity receiving drainage areas (EHU 8) at Ethel Gorge, Marillana Creek and Weeli Wolli Creek, moderate sensitivity transitional units (EHU 3 and 4) within the Central Pilbara and Fortescue Marsh region, and low sensitivity upland units (EHU 1 and 2) in the Central Pilbara, Fortescue Marsh and Marillana Creek regions.
- In the full development scenario areas of cumulative surface water reduction associated with BHP Billiton Iron Ore's operations have significantly increased relative to the 30% development scenario, however the majority of study area remains unaffected. Prominent areas subject to change include moderate sensitivity transitional (EHU 3 and 4) and low sensitivity upland units (EHU 1) in the Central Pilbara, Fortescue Marsh and Marillana Creek regions; low sensitivity lowland plains (EHU 6) in the Fortescue Marsh region; and high sensitivity receiving drainage areas (EHU 8) at Ethel Gorge, Marillana Creek and Weeli Wolli Creek. There are modest changes in low sensitivity areas associated with upland areas (EHU 2) in the Central Pilbara, Fortescue Marsh and Marillana Creek regions; sandplain areas (EHU 5) of the Fortescue Marsh and Eastern Pilbara regions, and moderately sensitive calcrete plains (EHU 7) associated with BHP Billiton Iron Ore's proposed Munjina and Upper Marillana mining areas.

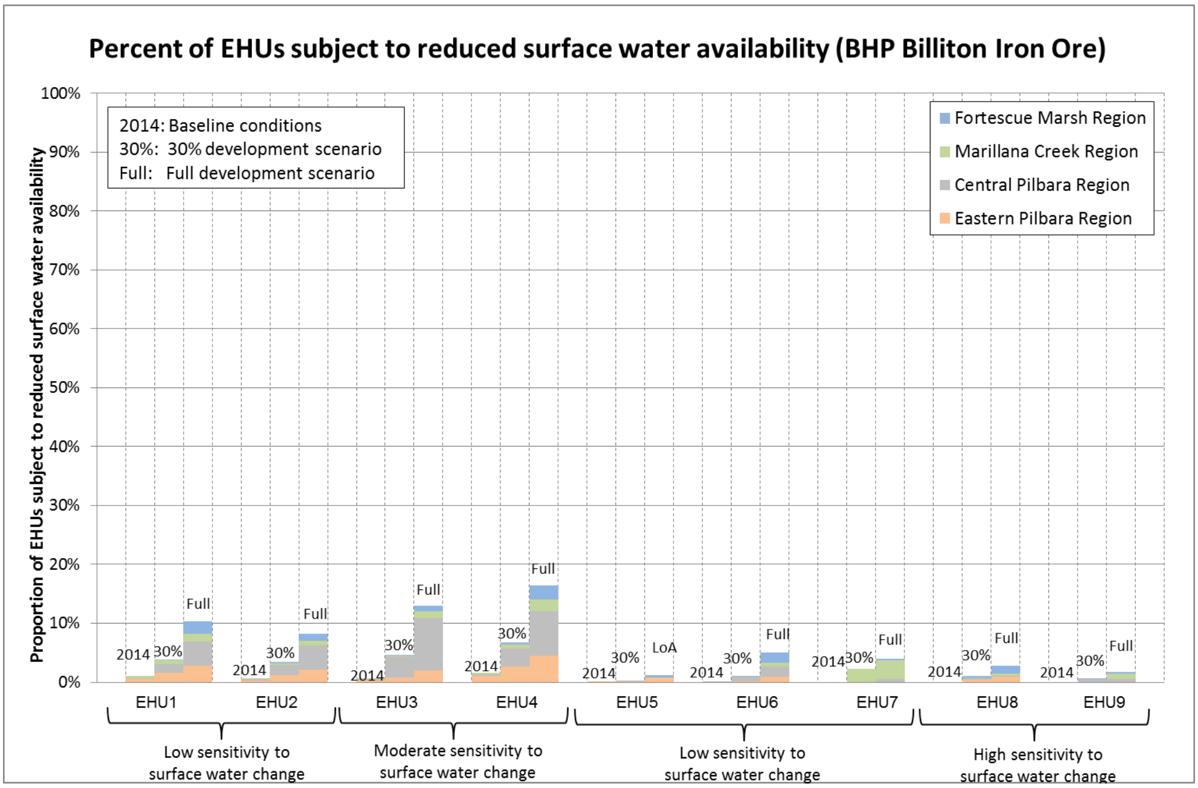

Figure 24 Proportion of EHUs subject to reduced surface water availability - BHP Billiton Iron Ore

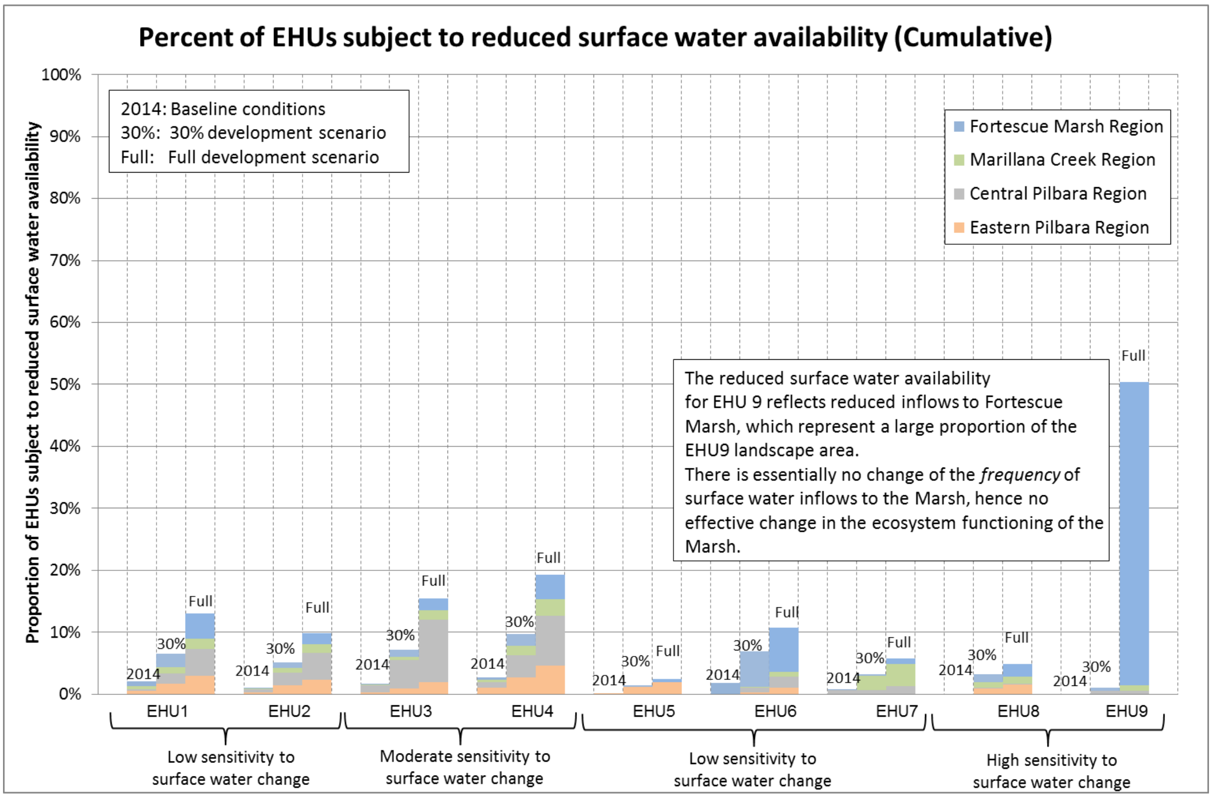

Figure 25 Proportion of EHUs subject to reduced surface water availability - cumulative

- In the full development scenario taking into account the cumulative effects of BHP Billiton Iron Ore and third party operations the high sensitivity, lowland receiving area (EHU 9) associated with Fortescue Marsh is predicted to experience a moderate level of hydrological change. Although catchment area reductions by BHP Billiton Iron Ore and third-party mining operations respectively each equate to less than 5% of the Fortescue Marsh catchment area, the combined catchment area reduction slightly exceeds the threshold value 5% used in the change assessment. Given that the methodology is likely to overstate the potential effects of catchment area reduction on the hydrological regime due to the functionality of VSAs in the valley landforms surrounding the Marsh (refer to Section 11.2), this finding is considered to be highly precautionary. Note that the Fortescue Marsh accounts for a large (approximately 50%) proportion of the area extent of EHU9 in the Fortescue Marsh region (Figure 25).

  For other EHUs across each region within the study area, third party operations contribute only small incremental reductions in catchment area relative to BHP Billiton Iron Ore's operations.

11.3. Surplus water

Regional-scale ecohydrological change associated with surplus water is characterised as areas either mostly water deficient (also referred to as water negative operations) or water surplus (also referred to as water positive operations). Water deficient mining areas have a low ecohydrological potential owing to the fact that surplus water (if any) will have relatively low volumes and will occur over a short duration (1 to 5 years) and therefore, water surplus can be managed within the existing feasible water options. Mining areas where water surplus can be managed within an existing BHP Billiton Iron Ore surplus management scheme have a moderate ecohydrological change potential. Mining areas that have a potentially significant water surplus that requires implementation of feasible water surplus management options have a high ecohydrological change potential. This regional change in surplus water for the baseline, 30% development and full development scenarios are shown in Maps 38 to 40 respectively.

Key findings include:

- In the baseline scenario, there is surplus water management associated with the Ophthalmia Dam MAR scheme in the Eastern Pilbara region and Marillana Creek scheme in the Marillana Creek region. Mining Area C in the Central Pilbara, and mine operations at Jimblebar and Wheelarra in the Eastern Pilbara are water deficient with any short-term and small volumes of surplus water being utilised to supplement process and/or mine water supply. There are also a number of smaller scale and trial surplus water management practices which include:
  - Trial groundwater injection at Jimblebar and MAC mining areas
  - Trial discharge of surplus water from the Jimblebar mining area into Jimblebar Creek
  - Temporary storage of surplus water in mined out pit voids at MAC mining area
- In the 30% development scenario, there is additional surplus water associated with the Shovellana, Jimblebar, East Ophthalmia, Homestead and Western Ridge mining areas in the Eastern Pilbara region that BHP Billiton Iron Ore has the ability to manage using the Ophthalmia Dam MAR scheme. BHP Billiton Iron Ore identified potential capacity constraints of the Ophthalmia Dam MAR scheme if surplus water volumes are higher than anticipated. BHP Billiton Iron Ore identified contingency water surplus methods which include injection to aquifers and controlled release to Jimblebar Creek which is currently being evaluated.

  In a similar way, surplus water from Munjina and Yandi mining areas can be managed through BHP Billiton Iron Ore's Marillana Creek scheme. Most mining areas in the Central Pilbara region are likely to be water deficient and only require water surplus management over a relatively short duration; however, Mining Area C may have surplus water that will be managed within the Water RMS' framework of feasible water options and/or transfer to mining areas with water deficiency. In the Fortescue Marsh region, the Marillana mining area is likely to be water deficient requiring no dedicated management options.
- In the full development scenario, surplus water management may be associated with the Ophthalmia Dam MAR scheme in the Eastern Pilbara and Marillana Creek scheme in the Marillana Creek region related to the Munjina and Upper Marillana mining areas. There may be potentially large surplus water volumes to be managed associated with the Marillana, Mindy and Coondiner mining areas in the Fortescue Marsh region, which will require the implementation of feasible water surplus management

options as per the Water RMS. In contrast, most mining areas in the Central Pilbara region and Roy Hill mining area in the Fortescue Marsh region are likely to be water deficient requiring water surplus management over a relatively short duration.

The regional-scale, annual water balance, shown in Figure 26, suggests that surplus water related to the 30% development and full development scenarios are likely to be of a similar volume to the baseline (2014) surplus water being currently managed by BHP Billiton Iron Ore. As such, it is expected that future surplus water volumes will be managed within the existing management tools and feasible water options outlined in the Water RMS.

Cumulative surplus water requiring management within the study area was estimated for the baseline using publicly available information. Projections of future third party surplus water were also made based on publically available information. Appendix B provides a more detailed explanation of BHP Billiton Iron Ore and third party surplus water projections. Surplus water generated by third-party operations in 2014 and at the 30% development scenario is substantially larger than that estimated for BHP Billiton Iron Ore's operations (Figure 26).

The largest volumes of surplus water are commonly associated with the dewatering of high-yielding mineralised Marra Mamba, calcrete and dolomite aquifers. Surplus water in the Central Pilbara and Marillana Creek regions is typically fresh and currently discharged into creek lines as at RTIO's Hope Downs 1 and Yandicoogina operations. In contrast, surplus water in the Fortescue Marsh region can be a mixture of fresh, brackish and hypersaline water. Current and proposed management by third party operators in this region uses managed aquifer recharge (MAR) schemes and evaporation systems.

11.4. Acid and metalliferous drainage

The majority of the proposed orebodies in the Strategic Proposal were assessed to have low AMD source potential, as shown on Map 41 (see Section 11.4.2 for methodology). Orebodies assessed to have high AMD source potential are:

- Whaleback mining area in the Eastern Pilbara region, and
- Two deposits in the Mindy mining area of the Fortescue Marsh region.

The high AMD source potential at Whaleback mine is currently and will continue to be actively managed with normal business practices including minimal interception, separation and encapsulation of PAF material. The AMD potential in the Mindy mining area is based on the indicative size of the ore resource, as no mine plans have been developed for the individual orebodies.

Several orebodies are classified as having moderate AMD source potential, all of which are below watertable operations of moderate scale (between 100 and 700 Mtpa) that target Brockman ore types. These are shown on Map 41 and include:

- Central Pilbara region - Two orebodies in the Jinidi and Tandanya mining area each;
- Eastern Pilbara region - One orebody in the Shovelanna and Wheelarra mining area each and two orebodies in the East Jimblebar mining area.;
- Fortescue Marsh region - Three orebodies in the Marillana mining area; Two orebodies in the Mindy mining area; and three orebodies of the Coondiner mining area and
- Marillana Creek region – one orebody in the Ministers North mining area.

Factors affecting the potential transportation of AMD from final pit landforms (including contaminant attenuation and degradation processes) are complex and site specific. Orebodies assessed to have a high AMD source potential require management focus. Orebodies with a moderate or low AMD source potential can be managed through normal business management practices.

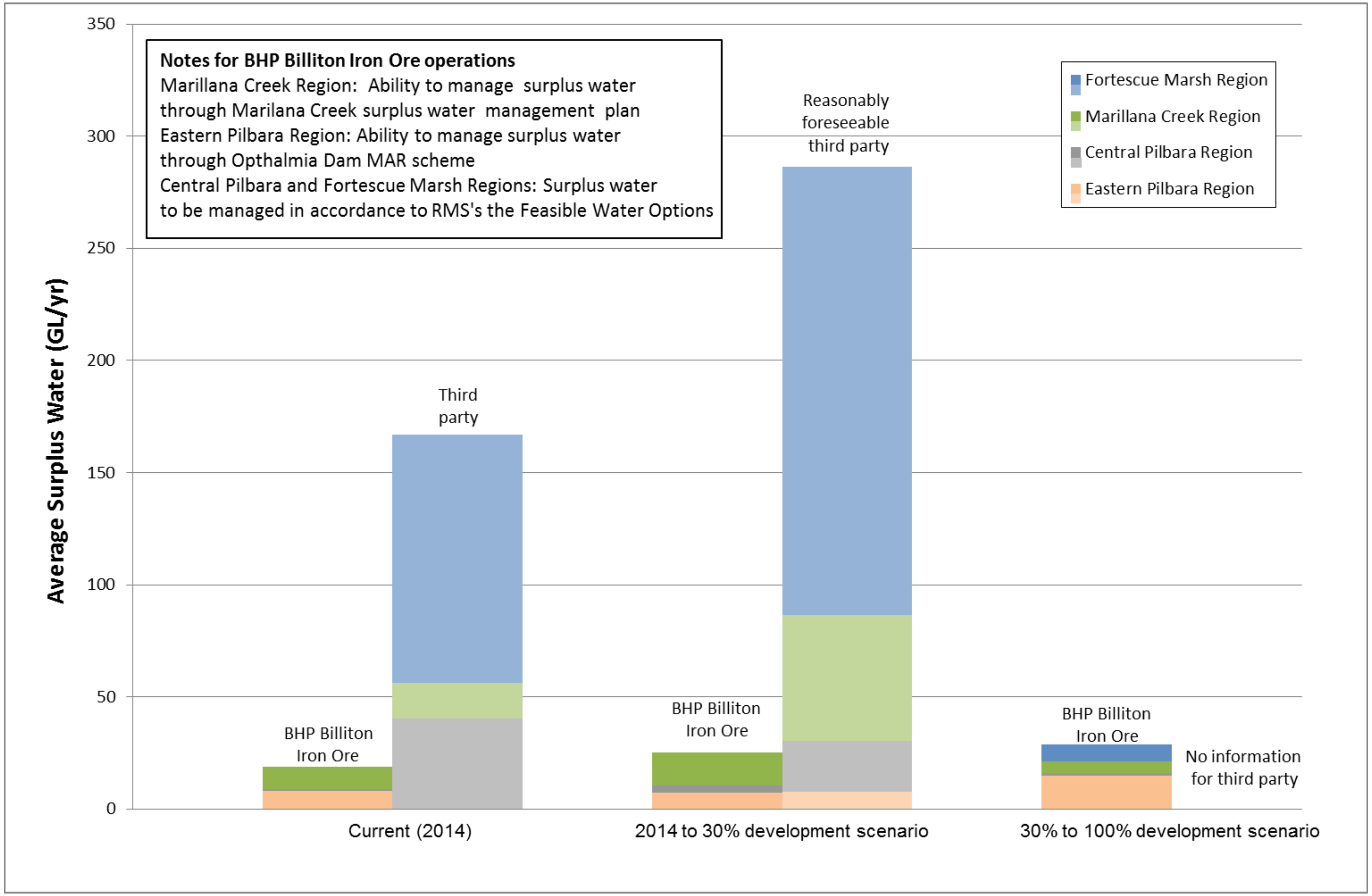

Figure 26 Indicative water balance for BHP Billiton Iron Ore and third-party mining areas

11.5. Groundwater quality - saline intrusion

The greatest potential for saline intrusion is in the Fortescue Marsh region associated with mine dewatering in the Marillana, Mindy and Coondiner mining areas. The predicted maximum extent of saline intrusion on the southern side of the Fortescue River Valley is presented in Maps 42 to 44 for the baseline, 30% development and full development scenarios respectively. Note that the actual extent is likely to be complicated by cumulative drawdown effects associated with multiple mining projects including third-party operations (i.e. Brockman Resources' Marillana Project and FMG's Nyidinghu Project), which have not been taken into account in the analysis due to data limitations.

Areas with a high potential for saline intrusion require management focus. MAR may be a viable approach for managing potential impacts associated with saline intrusion.

11.6. Surface water quality

There is negligible potential for regional change to surface water quality, assuming that surface water is managed in accordance with normal business practices used by BHP Billiton Iron Ore. As outlined in Section 4.2 components of the normal business approach include:

- Operational controls for minimising sediment generation,
- use of structures for capturing and containing sediment, hydrocarbons and other potential contaminants;
- identification and encapsulation of acid-forming materials; and
- the delivery of diverted flows back into the natural drainage network downgradient of mining areas.

11.7. Pit lakes

Mine voids that extend below the pre-mining watertable have potential to form pit lakes, as groundwater levels recover following the cessation of mine dewatering. Some mine voids are anticipated to be infilled as part of normal business infilling practices; whilst in other situations, the level of backfilling will be dependent on mine closure objectives, economic considerations, and the availability of backfill materials.

Owing to the high rates of evaporation compared with rainfall in the study area, most pit lakes that form within mine voids are expected to become permanent groundwater sinks with no outflow to the environment. These pit lakes will become saline over time. In some Brockman and Marra Mamba mines, there is potential for pit lakes to become acidic requiring consideration of backfill to prevent AMD development. In a limited number of situations, pit lakes may experience groundwater through flow associated with regional aquifer connectivity which has the potential to affect groundwater quality. The factors to be considered associated with pit lake development varies from mine void to mine void and the implimentation of management options depends on the mine closure objectives. However, infilling and backfilling (if required) were identified as one of the management options to meet the environmental objectives in the context of pit lake formation,

Map 45 shows the likely regional distribution of final pit voids across study area from the Strategic Proposal, categorised with respect to the availability of backfill materials (refer to Section 11.7). It is anticipated that more than 50% of final pit voids will either be above the water table or infilled to above pre-mining water levels and will therefore not form pit lakes.

For most of the remaining final mine voids, there are sufficient ex-pit overburden material to backfill the mine voids to pre-mining water levels, if that is the closure objective.

Mining areas with insufficient backfill materials to prevent the formation of pit lakes include Yandi, Munjina and Upper Marillana in the Marillana Creek region, and Coondiner in the Fortescue Marsh region.

12. Receptor change assessment

The findings of the regional change assessment were augmented by more focused analysis of the potential for ecohydrological change at each of the five ecohydrological receptors located in the study area being:

- Coondewanna Flats - Coolibah and Lignum Flats;
- Ethel Gorge Stygobiont Community;
- Fortescue Marsh;
- Freshwater Claypans of the Fortescue Valley; and
- Weeli Wolli Spring.

As with the landscape change assessment (Section 12), the receptor level assessment considers the potential effects of identified threatening processes under the baseline, 30% development and full development scenarios respectively for BHP Billiton Iron Ore's operations only (i.e. the Strategic Proposal) and taking into account cumulative impacts including third-party operations. The assessment was informed by the receptor level ecohydrological conceptualisations described in Section 6.

The findings of the receptor level assessment are summarised in Table 30, with additional discussion related to each receptor provided in the following sections.

12.1. Coondewanna Flats - Coolibah and Lignum Flats

The Coondewanna Flats is located in the Central Pilbara region. Key characteristics include:

- The Coondewanna Flats (EHU 6) is a receiving area for surface water runoff from surrounding catchments. Significant inflows occur episodically. Floodwaters accumulate on the low lying areas of the flats including Lake Robinson (EHU 9), replenishing soil moisture and contributing to groundwater recharge.
- The watertable lies at 20 to 30 m bgl within an unconfined calcrete aquifer that is overlain by unsaturated Tertiary detritals. The vadose zone has relatively large water storage capacity.
- Coondewanna Flats support regionally unusual *Eucalyptus victrix* woodland communities with two being classified as PECs. The ecological water requirements of these woodlands are primarily met by stored soil moisture, which is replenished by surface water inflow. Studies completed by BHP Billiton Iron Ore indicate these trees are able to obtain soil moisture for prolonged periods from horizons within the unsaturated zone above the watertable (Astron, 2014). Evidence accumulated from ecohydrological investigations conducted by BHP Billiton Iron Ore suggests that the *E. victrix* woodlands at Coondewanna Flats are unlikely to rely on groundwater; however, a precautionary approach has been adopted until additional validation studies are completed.

As there are no third-party mining projects within the Coondewanna Flats catchment area, the assessment findings relate solely to BHP Billiton Iron Ore's mining areas.

12.1.1. Baseline scenario

There are active BHP Billiton Iron Ore operations in the MAC mining area. The nature and significance of threatening processes relevant for Coondewanna Flats under the baseline scenario are summarised as follows:

- Groundwater drawdown - No change potential; drawdown is confined to a zone proximal to the MAC mining area and is distant from the receptor.
- Surface water availability - Negligible change potential, on the basis that <5% reduction of the catchment area of the receptor is subject to mining disturbance.
- Surplus water - Negligible change potential. Mining below the watertable at several of the MAC mining area deposits generates a minor surplus that is managed with MAR. The MAR operation is distant from and has no hydrological interaction with the Flats.
- AMD potential - Negligible change potential; the MAC mining area has a low AMD source potential.

- Surface water quality - Negligible change potential; surface water quality is maintained via the implementation of normal business surface water management practices
- Saline intrusion - No change potential; owing to a regional absence of saline groundwater systems.
- Pit lakes - No change potential; no mines have been closed.

12.1.2. 30% development scenario

Under the 30% development scenario, additional BHP Billiton Iron Ore operations will have commenced at the Mudlark and South Flank mining areas. The MAC mining area has also been expanded. The nature and significance of threatening processes relevant for Coondewanna Flats include:

- Groundwater drawdown - Moderate change potential. The cumulative effect of dewatering at the MAC mining area results in drawdown extending to the northern margin of Lake Robinson. This has the potential to affect stygofauna habitat. There is no groundwater drawdown associated with the Mudlark and South Flank mining areas, owing to mining above the watertable in these areas.
- Surface water availability - Moderate change potential; on the basis that cumulative mining disturbance affects 5 to 20% of the catchment area of the receptor.
- Surplus water - Negligible change potential; all mining areas, except the MAC mining area, are forecast to be water deficient at the 30% development stage.
- AMD potential - Negligible change potential; all operations have a low AMD source potential.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No risk of saline intrusion, owing to a regional absence of saline groundwater systems.
- Pit lake formation - Negligible change potential. A number of mine pits at the MAC mining area are closed at the 30% development stage. There are sufficient quantities of overburden in the mining area to backfill all pits. If pit lakes are included in closure landforms, they will function as groundwater sinks and be characterised by increasing groundwater salinity and low potential for acidification.

12.1.3. Full development scenario

Under the full development scenario, additional BHP Billiton Iron Ore mining operations have been implemented at the Tandanya mining area. The MAC mining area, Mudlark and South Flank mining areas have also been expanded relative to the 30% development scenario. The nature and significance of threatening processes relevant for Coondewanna Flats include:

- Groundwater drawdown - Moderate change potential. A cumulative groundwater drawdown footprint associated with dewatering of the MAC mining area, South Flank and Mudlark mining areas intersects the receptor. This has the potential to affect stygofauna habitat. Vegetation communities are not anticipated to be affected by drawdown (subject to validation of ecohydrological studies).
- Surface water availability - High change potential; on the basis that cumulative mining disturbance affects more than 20% of the catchment area of the receptor.
- Surplus water - Negligible change potential. Most mining areas are forecast to be water deficient, with short periods of minor surplus during the progression of the Strategic Proposal from 30% to full development.
- AMD potential - Negligible change potential; all operations have a low AMD source potential with the exception of one deposit in the Tandanya and Jinidi mining areas each which has a moderate AMD source potential.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No risk of saline intrusion, owing to a regional absence of saline groundwater systems.
- Pit lake formation - Negligible change potential. A large proportion of pits within the catchment are anticipated to be backfilled as part of normal business practices. There are sufficient quantities of overburden in each respective mining area to backfill all pits. If pit lakes are included in closure

landforms, they will function as groundwater sinks and be characterised by increasing groundwater salinity and low potential for acidification.

12.2. Ethel Gorge Stygobiont Community

The Ethel Gorge receptor is located in the Eastern Pilbara region. Key characteristics include:

- Ethel Gorge is a zone of confluence of surface water and groundwater flows from the headwaters of the Upper Fortescue River catchment.
- The Ethel Gorge groundwater system occurs in detrital sediments bound by low-permeability basement rocks. The shallow unconfined aquifer is variably disconnected from a deeper confined aquifer by an extensive low-permeability clay aquitard.
- The shallow alluvial and calcrete aquifers of Ethel Gorge support a unique and diverse stygofauna assemblage, classified as the Ethel Gorge Aquifer Stygobiont Community TEC. The area also supports riparian woodland communities with potential groundwater dependence.
- Ophthalmia Dam has a strong influence on the hydraulic response of the Ethel Gorge shallow unconfined aquifer. Since the early 1980s, the dam and associated MAR has resulted in increased groundwater recharge and hydraulic loading to this aquifer.

As there are no third-party mining projects within the Ethel Gorge catchment area, the following assessment findings relate solely to BHP Billiton Iron Ore's mining areas.

12.2.1. Baseline scenario

There are active BHP Billiton Iron Ore operations at the Eastern Ridge, Shovelanna and Whaleback mining areas. The nature and significance of threatening processes relevant for Ethel Gorge under the baseline scenario are summarised as follows:

- Groundwater drawdown - There is moderate change potential in accordance with the assessment methodology; based on groundwater drawdown from the Eastern Ridge mining area propagating into Ethel Gorge. However, taking into account the buffering effect of infiltration from Ophthalmia Dam on groundwater levels at the receptor may reduce the potential change to a low rating. There is no potential for ecohydrological change related to the Whaleback mining area, as drawdowns are localised and disconnected from Ethel Gorge, and Orebodies 29, 30 and 35 are being mined above the watertable.
- Surface water availability - Negligible change potential; on the basis that aggregate mining disturbance affects <5% of the catchment area of the receptor.
- Surplus water - Moderate change potential; owing to surplus water generated by the Eastern Ridge and Whaleback mining areas, which is discharged into Ophthalmia Dam, which is a proven surplus water management scheme with a long monitoring record and no adverse impacts on the environment.. Infiltration from Ophthalmia Dam contributes to the maintenance of groundwater levels at the receptor. It also provides a mechanism by which salt loads in the dam and groundwater system could be increased over time. This issue is further discussed in the Ethel Gorge case study (Section 16).
- AMD potential - Most of the operations have a low AMD source potential. The exception being the Whaleback mining area with high AMD source potential.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No risk of saline intrusion, owing to a regional absence of saline groundwater systems.
- Pit lakes – No change potential; there are no existing pit lakes.

12.2.2. 30% development scenario

Under the 30% development scenario, BHP Billiton Iron Ore operations have been expanded in the Eastern Ridge and Shovelanna mining areas. Mining has also commenced at the Homestead mining area. The nature and significance of threatening processes relevant for Ethel Gorge are summarised as follows:

- Groundwater drawdown – There is moderate change potential in accordance with the assessment methodology; related to cumulative drawdown associated with the Eastern Ridge and Homestead mining areas. However, taking into account the buffering effect of seepage from Ophthalmia Dam on groundwater levels at the receptor, the significance of the potential change can be reduced to a low rating (refer to the Ethel Gorge case study). There are isolated, residual groundwater drawdown effects in the Shovelanna and Whaleback mining areas associated with closed operations; however these are disconnected from Ethel Gorge.
- Surface water availability - Moderate change potential; on the basis that aggregate mining disturbance affects 5% to 20% of the catchment area of the receptor.
- Surplus water - Moderate change potential owing to surplus water generated at the Whaleback, Homestead, Shovelanna and Jimblebar mining areas. Surplus water management is anticipated to include discharge to Ophthalmia Dam MAR scheme which is a proven surplus water management scheme with a long monitoring record and no adverse impacts on the environment to date The ongoing disposal of surplus water into Ophthalmia Dam has potential to increase salt loads. This issue is further discussed in the Ethel Gorge case study (Section 16).
- AMD potential - Negligible change potential in all mining areas, with the exception of the Whaleback mining area that has high AMD source potential. However, taking into account that the Whaleback mining area is disconnected from the regional aquifer, the significance of the potential change can be reduced to a low rating.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No risk of saline intrusion, owing to a regional absence of saline groundwater systems.
- Pit lake formation - Low change potential. Closed mine voids in the Eastern Ridge and other mining areas could form pit lakes, but these pits may be backfilled depending on closure objectives. There are sufficient quantities of overburden in each respective mining area to backfill all pits. If pit lakes are included in closure landforms, they are likely to function as groundwater sinks and be characterised by increasing groundwater salinity and low potential for acidification.

12.2.3. Full development scenario

- Under the full development scenario, additional BHP Billiton Iron Ore mining operations have been implemented at the Ophthalmia, Prairie Downs and East Ophthalmia mining areas. Expansions at the Western Ridge and other mining areas have also been implemented relative to the 30% development scenario. The nature and significance of threatening processes relevant for Ethel Gorge include: Groundwater drawdown - putatively there is high change potential in accordance with the assessment methodology; related to cumulative drawdown associated with the Shovelanna, Eastern Ridge Homestead and East Ophthalmia mining areas. However, taking into account the buffering effect of seepage from Ophthalmia Dam on groundwater levels at the receptor, the significance of the potential change is considered to be low. Groundwater drawdown zones associated with the Ophthalmia, Prairie Downs, Western Ridge and Whaleback mining areas are localised and disconnected from Ethel Gorge.
- Surface water availability - High change potential; on the basis that aggregate mining disturbance affects >20% of the catchment area of the receptor.
- Surplus water – High change potential; owing to periods of surplus water forecast to occur in the Eastern Pilbara region over the life of the Strategic Proposal, most prominently in the Shovelanna and Eastern Ridge mining areas. Surplus water management is anticipated to include discharge to Ophthalmia Dam.
- AMD potential - Negligible change potential in all mining areas, with the exception of the Whaleback mining area that has high AMD source potential. However, taking into account that the Whaleback mining area is disconnected from the regional aquifer, the significance of the potential change can be reduced to a low rating.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No risk of saline intrusion, owing to a regional absence of saline groundwater systems.

- Pit lake formation – Low change potential. The various mining areas proximal to the receptor may include pit lakes depending on mine closure objectives. There are sufficient quantities of overburden in each respective mining area to backfill all pits. If pit lakes are included in closure landforms, they will function as groundwater sinks and be characterised by increasing groundwater salinity and low potential for AMD development. The possibility of AMD migration away from the mining area is therefore unlikely.

12.3. Fortescue Marsh

The Fortescue Marsh is a regional-scale, endorheic basin in the Fortescue Marsh region. Key characteristics include:

- An extensive drainage terminus landform that receives inflows from the Upper Fortescue River catchment.
- The water regime is dominated by episodic surface water inflows, with the majority of inflows contributed by the Fortescue River and to a lesser extent Weeli Wolli Creek. Numerous smaller drainages from surrounding catchments also contribute directly into the Marsh.
- Groundwater discharge is minimal and likely to be spatially restricted within portions of the Marsh.
- Recognised at the State and Commonwealth level as a high conservation asset with multiple ecological values.

Multiple existing and proposed BHP Billiton Iron Ore and third party mining operations are located around the periphery of the Marsh. The geographic scale of the Marsh contributes to a heightened potential for these operations to have cumulative effects on the ecohydrology of the Marsh. It also increases the possibility of local scale effects within sub-areas of the Marsh.

12.3.1. Baseline scenario

There are no existing BHP Billiton Iron Ore operations interacting with the Marsh; however several third party mines are located around the periphery of the Marsh. This includes active mining by FMG at the Cloudbreak and Christmas Creek mining areas located along the northern fringe, as well as construction activities at HPPL's Roy Hill mining area on the northeast fringe. The nature and significance of threatening processes relevant for the Marsh under the baseline scenario are summarised as follows:

- Groundwater drawdown - No change potential at the receptor; on the basis that FMG is conditioned to maintain groundwater levels at the Marsh fringe through MAR under the EP Act.
- Surface water availability - Negligible change potential; on the basis that aggregate mining disturbance affects <5% of the catchment area of the receptor. However, a higher degree of catchment area reduction in small drainages between the Cloudbreak and Christmas Creek mining areas and the receptor may contribute to increased change potential at a localised scale proximal to these drainages.
- Surplus water - No change potential at the receptor; on the basis that FMG is conditioned to maintain groundwater levels at the Marsh fringe through MAR under the EP Act.
- Saline intrusion - Negligible change potential; on the basis that FMG is conditioned to manage saline intrusion under the EP Act. The impact assessment completed for the approved projects at Cloudbreak and Christmas Creek (FMG, 2010 and FMG, 2012) indicated that dewatering activities may induce saltwater movement from the Fortescue Marsh toward the Chichester Range, but that potential environmental impacts can be acceptably managed.
- AMD potential – unable to be assessed for third party operations.
- Surface water quality - unable to be assessed for third party operations.
- Pit lakes - No change potential; there are no existing pit lakes.

12.3.2. 30% development scenario

Under the 30% development scenario, above watertable mining operations have commenced at BHP Billiton Iron Ore's Marillana mining area. Third party mines have been expanded around the periphery of the Marsh. The nature and significance of threatening processes relevant for the Fortescue Marsh are summarised as follows:

- Groundwater drawdown - No change potential; on the basis that third-party mines north of the Marsh (FMG and HPPL) are conditioned to maintain groundwater levels at the Marsh fringe through MAR under the EP Act. There is no drawdown associated with BHP Billiton Iron Ore's Marillana mining area. Mining at FMGs proposed Nyidinghu operation is above the watertable.
- Surface water availability - Negligible change potential; on the basis that aggregate mining disturbance affects <5% of the catchment area of the receptor. However, a higher degree of catchment area reduction in small drainages proximal to the Cloudbreak, Christmas Creek, Roy Hill and Koodaideri third-party mining areas may contribute to greater change potential at localised scales. At the Marillana mining area, local area drainages and sections of Weeli Wolli Creek proximal to the operations may be similarly affected and have a minor effect on surface flows reaching the receptor.
- Surplus water - No change potential at the receptor; owing to above watertable mining only at the Marillana mining area. Third parties are conditioned to maintain groundwater levels at the Marsh fringe under the EP Act.
- AMD potential - No change potential associated with the Marillana mining area (above watertable mining).
- Surface water quality - Negligible change potential associated with the Marillana mining area. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No change potential associated with the Marillana mining area (above watertable mining).
- Pit lake formation - No change potential associated with the Marillana mining area (above watertable mining).

12.3.3. Full development scenario

Under the full development scenario, additional BHP Billiton Iron Ore mining operations have been implemented at the Roy Hill, Marillana, Mindy and Coondiner mining areas. The nature and significance of threatening processes relevant for the Fortescue Marsh include:

- Groundwater drawdown - High potential for ecohydrological change restricted to a localised area at the southern fringe of the Marsh, associated with groundwater drawdown from BHP Billiton Iron Ore's Marillana mining area. The majority of the Marsh area (approximately 99%) remains unaffected by drawdown. Groundwater drawdown for BHP Billiton Iron Ore's Roy Hill, Mindy and Coondiner mining areas are likely to be distant from the Marsh; although, there may be localised areas subject to high change potential associated with areas proximal to the Mindy and Coondiner Creeks. With respect to third-party operations, areas with high potential for ecohydrological change are restricted to a small zone subject to cumulative drawdown from multiple projects influencing the southern fringe of the Marsh.
- Surface water availability - There is moderate potential for ecohydrological change considering the cumulative effects of BHP Billiton Iron Ore and third-party operations, based on the reduction in the catchment area of the Marsh exceeding 5%. The lower Weeli Wolli Creek is subject to potential change being influenced by operations along the southern fringing of the Fortescue River Valley, as well as operations further upgradient along Marillana Creek and beyond Weeli Wolli Spring. Change potential associated with the BHP Billiton Iron Ore's Marillana mining area is moderate within local drainages and high along the lower Weeli Wolli Creek through to the Marsh. Change potential associated with the Mindy and Coondiner mining area is low to moderate within local drainages, but reduces to either low or negligible towards the southeast of the Marsh. Change potential associated with BHP Billiton Iron Ore's Roy Hill mining area is low within local drainages, but there are several creeks subject to high change potential that drain into the northwest portion of the Marsh.
- Surplus water - High change potential; on the basis that BHP Billiton Iron Ore's Marillana and Mindy mining areas have periods of large surplus water and a regional water management strategy is not developed under the baseline scenario . The Coondiner and Roy Hill mining areas are forecast to have

only a minor water surplus for short durations, and therefore have low change potential with respect to surplus water.

- AMD potential - The Mindy mining area has a moderate to high AMD source potential owing to the large tonnages below the watertable and Brockman ore type. This rating reflects considerable uncertainty of the orebody characteristics and may be revised lower once further geological information becomes available. Coondiner and Marillana mining areas have low to moderate AMD source potential; whereas, Roy Hill mining area has low AMD source potential.
- Saline intrusion - Potential for change; based on groundwater drawdown from the Marillana, Mindy and Roy Hill mining areas potentially extending to the saltwater interface within the Fortescue River Valley groundwater system.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Pit lake formation – High change potential associated with the Coondiner mining area, where overburden may be insufficient to backfill all pits. Low change potential in the Mindy mining area, where there are sufficient quantities of overburden to backfill all pits. Negligible change potential in the Marillana and Roy Hill mining areas, where all pits are anticipated to be backfilled as per normal business practices.

12.4. Freshwater Claypans of the Fortescue Valley

The Freshwater Claypans of the Fortescue Valley PEC is located in the Lower Fortescue River Valley immediately west of the Goodaidarrie Hills. Key characteristics include:

- Of the five claypans in the Lower Fortescue Valley classified as the Freshwater Claypans of the Fortescue Valley PEC, the three easternmost claypans are proximal to the Strategic Proposal.
- Claypan water regimes are dominated by episodic surface water inflows and localised catchments.
- Interaction with the groundwater regime is poorly understood, but is considered likely to be minimal or negligible.
- Ecological values include unusual vegetation types and diverse aquatic invertebrate assemblages.

As there are no current or proposed third-party mining projects within the Freshwater Claypans of the Fortescue Valley PEC catchment area, the following assessment findings relate solely to BHP Billiton Iron Ore's mining areas.

12.4.1. Baseline scenario

- No BHP Billiton Iron Ore or third party operations. No change potential.

12.4.2. 30% development scenario

- No BHP Billiton Iron Ore or third party operations. No change potential.

12.4.3. Full development scenario

Mining at BHP Billiton Iron Ore's Roy Hill mining area will be completed. The nature and significance of threatening processes relevant for the receptor include:

- Groundwater drawdown - No change potential; on the basis that groundwater drawdown will be localised and distant from the claypans.
- Surface water availability - Negligible change potential, on the basis that mining disturbance affects <5% of the catchment area of the receptor
- Surplus water - Negligible change potential; as the Roy Hill mining area is forecast to be water deficient.
- AMD potential - Low AMD source potential; owing to the orebody types at the Roy Hill mining area.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.

- Saline intrusion - Potential for change; based on drawdown from the Roy Hill mining area potentially extending to the saltwater interface within the Fortescue River Valley groundwater system.
- Pit lakes – Negligible change potential; all pits in the Roy Hill mining area are anticipated to be backfilled as per normal business practices.

12.5. Weeli Wolli Spring Community

Weeli Wolli Spring is located in the Central Pilbara region. Key characteristics include:

- Weeli Wolli Spring occurs in a zone of confluence of surface water and groundwater flows from the headwaters of the Upper Weeli Wolli Creek catchment.
- The groundwater system comprises an unconfined aquifer sequence including calcrete and detritals. Groundwater is shallow at less than 10 m bgl and becomes shallower towards the spring. As the aquifer thins and narrows towards Weeli Wolli Spring, groundwater flow is concentrated and discharged over near-surface basement as baseflow.
- Weeli Wolli Spring supports permanent and persistent pools and riparian woodland communities with a groundwater dependency. The groundwater system supports a diverse stygofauna assemblage. These values collectively contribute to the Weeli Wolli Spring's PEC conservation status.
- Weeli Wolli Spring is currently impacted by RTIO's Hope Downs operations. RTIO have implemented measures to artificially maintain the water regime.
- Elements of the Weeli Wolli Spring PEC also occur at Ben's Oasis, located about 20 km further upstream and south of Weeli Wolli Spring. At this location, the vegetation is concentrated along a relatively narrow creek channel adjacent to some surface water pools. There is very little documented information about the geology, hydrology and ecology of this area.

12.5.1. Baseline scenario

There are active BHP Billiton Iron Ore operations in the MAC mining area. The nature and significance of threatening processes relevant for Weeli Wolli Spring under the baseline scenario are summarised as follows:

- Groundwater drawdown - No change potential; on the basis that drawdown is confined to a zone proximal to the MAC mining area and is distant from the receptor.
- Surface water availability - Negligible change potential, on the basis that <5% reduction of the catchment area of the receptor is subject to mining disturbance.
- Surplus water - Negligible change potential. Mining below the watertable at several of the MAC mining area deposits generates a minor surplus that is managed with MAR. The MAR operation is distant from and has no hydrological interaction with the Flats.
- AMD potential - Negligible change potential; the MAC mining area has a low AMD source potential.
- Surface water quality - Negligible change potential; surface water quality is maintained via the implementation of normal business surface water management practices
- Saline intrusion - No change potential; owing to a regional absence of saline groundwater systems.
- Pit lakes - No change potential; no mines have been closed.

Third-party operations include RTIO's Hope Downs mining area located within 10 km of Weeli Wolli Spring. A summary of the potential threatening processes are:

- Groundwater drawdown - No change potential at the receptor; on the basis that RTIO is conditioned to maintain groundwater levels at Weeli Wolli Spring under the EP Act. Under RTIO's management strategy, a portion of excess dewatering water from the Hope Downs operation is being irrigated upstream of the spring to sustain riparian vegetation and surface water flows at the Weeli Wolli Spring.
- Surface water availability - Negligible change potential; on the basis that RTIO is conditioned to maintain groundwater levels at Weeli Wolli Spring under the EP Act. Under RTIO's management strategy, a portion of excess dewatering water from the Hope Downs operation is being irrigated upstream of the spring to sustain riparian vegetation and surface water flows at the Weeli Wolli Spring.

- Surplus water - High change potential; based on the discharge of surplus water into Weeli Wolli Creek downstream of Weeli Wolli Spring.

12.5.2. 30% development scenario

Under the 30% development scenario, BHP Billiton Iron Ore's operations include active mining in the MAC, Jinidi, Mudlark and South Flank mining areas. The nature and significance of threatening processes relevant for Weeli Wolli Spring include:

- Groundwater drawdown - Low change potential; associated with cumulative drawdown associated with the MAC mining area and RTIO's Hope Downs. There is no drawdown effect from the Jinidi mining area, as there is no below watertable mining.
- Surface water availability - Moderate change potential; on the basis that cumulative mining disturbance affects 5 to 20% of the catchment area of the receptor. Of BHP Billiton Iron Ore's operations, the MAC mining area makes the greatest contribution to overall cumulative change.
- Surplus water - High change potential; on the basis that the MAC mining area has periods of large surplus water and a regional water management strategy is not developed under the baseline scenario . Other BHP Billiton mining areas are forecast to have only a minor water surplus for short durations, and therefore have low change potential with respect to surplus water.
- AMD potential - Negligible change potential; all operations have a low AMD source potential.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No risk of saline intrusion, owing to a regional absence of saline groundwater systems.
- Pit lake formation - Low change potential. A number of mine pits at the MAC mining area are closed at the 30% development stage. There are sufficient quantities of overburden in the mining area to backfill all pits.

Third-party operations - RTIO's Hope Downs is planned for closure in 2024. Key findings relating to the Hope Downs operation include:

- Groundwater drawdown - High change potential; on the basis that the Hope Downs operation has generated substantial watertable drawdown and influenced the groundwater regime at Weeli Wolli Spring. Dewatering is planned to cease in 2024 and it is proposed that the pit will be backfilled. There will be residual drawdown that RTIO has predicted will recover by about 2050.
- Surface water availability - Moderate change potential; on the basis that cumulative mining disturbance affects 5 to 20% of the catchment area of the receptor, and assuming the Hope Downs closure strategy addresses surface water management. As RTIO's Hope Downs mine is to be partially backfilled with the removal of OSAs, there is potential for a reduced disturbance footprint that would lessen the potential for changed surface water availability at Weeli Wolli Spring.

12.5.3. Full development scenario

Under the full development scenario, BHP Billiton Iron Ore mining operations have been implemented at the MAC, Jinidi, Mudlark, South Flank, Tandanya, South Parmelia and Gurinbiddy mining areas. The nature and significance of threatening processes relevant for Weeli Wolli Spring include:

- Groundwater drawdown – High change potential; owing to cumulative drawdown effects associated with the MAC and Jinidi mining areas. Dewatering of individual operations has low change potential, but they contribute to a larger cumulative drawdown effect. The ecohydrological conceptualisation of the regional groundwater system indicates that recharge reduction and groundwater drawdown in the Coondewanna Flats catchment may influence future groundwater levels and throughflow at Weeli Wolli Spring. This requires further validation. Consistent with the methodology, it has been assumed there is no drawdown recovery following the closure of RTIO's Hope Downs operation; however, it is noted that RTIO predicts that water levels will be fully recovered by about 2050.
- Surface water availability - High change potential; on the basis that cumulative mining disturbance affects > 20% of the catchment area of the receptor. Of BHP Billiton Iron Ore's operations, the mining footprints in the Jinidi and MAC mining areas have the greatest influence on change potential owing to

their proximity to the spring. There may be some cumulative interaction with the closed RTIO Hope Downs mining area; however as RTIO's Hope Downs mine is proposed to be partially backfilled with the removal of OSAs, which may lessen the cumulative change potential. There is high potential for change in drainages proximal to the South Parmelia mining area; however, this reduces to low change potential downgradient before reaching the spring. The Gurinbiddy mining area has low potential to cause ecohydrological change at Weeli Wolli Spring and Ben's Oasis.

- Surplus water – Low change potential; on the basis that all BHP Billiton mining areas are forecast to have only a minor water surplus for short durations post the 30% development scenario.
- AMD potential - Moderate change potential; owing to some orebodies in the Jinidi mining area having AMD source potential. All other BHP Billiton mining areas have low AMD source potential.
- Surface water quality - Negligible change potential. Surface water quality is maintained via the implementation of normal business surface water management practices.
- Saline intrusion - No risk of saline intrusion, owing to a regional absence of saline groundwater systems.
- Pit lakes – Low change potential. At the MAC, Tandanya, Jinidi and Gurinbiddy mining areas there are sufficient quantities of overburden to backfill all pits. Negligible change potential in the Mudlark, South Flank and South Parmelial mining areas, where all pits are anticipated to be backfilled as per normal business practices.

Part IV - Management

The change assessment presented in Part III provides an appreciation of the potential for ecohydrological change over the life of the Strategic Proposal, and highlights landscape elements and ecohydrological receptors with the greatest potential for change. Each of the assessment scenarios reflects a largely unmitigated case; prior to the implementation of targeted management options for avoiding, minimising and mitigating environmental impacts.

Part IV explores management considerations addressing the findings of the change assessment; within the context of BHP Billiton Iron Ore's regional management strategies (RMSs). This includes a high level discussion of feasible and site specific management approaches that are available to manage ecohydrological change.

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13. High-level management objectives

BHP Billiton Iron Ore recognises the following high-level management objectives for the different classes of ecological assets:

- Tier 1 ecological assets - BHP Billiton Iron Ore shall:
    - Avoid or mitigate risks to an acceptable level;
    - Prepare an Asset Management Plan in consultation with relevant decision-making authorities, to the satisfaction of the CEO of the OEPA. Ensure that any impact does not exceed the triggers and thresholds identified in the Key Asset Management Plan; and
    - Where necessary, submit a Residual Impact Offset Strategy to the satisfaction of the CEO of the Office of the Environmental Protection Authority (OEPA).
- Tier 2 ecological assets - BHP Billiton Iron Ore shall:
    - Avoid or mitigate risks to an acceptable level;
    - Where necessary, prepare an Asset Management Plan in consultation with relevant decision-making authorities, to the satisfaction of the CEO of the OEPA. Ensure that any impact does not exceed the triggers and thresholds identified in the Asset Management Plan; and
    - Where necessary, submit a Residual Impact Offset Strategy to the satisfaction of the CEO of the OEPA.
- Tier 3 ecological assets - BHP Billiton Iron Ore shall avoid or mitigate risks to an acceptable level.

14. Regional level management considerations

The landscape conceptualisation based on EHUs provides a useful framework for considering regional-scale management approaches that address hydrological processes and inland waters environmental quality. For each EHU, a common set of management themes linked to the surface water regimes, groundwater regimes and ecological components within the EHU can be identified. The relative importance of particular management aspects across all of the EHUs can also be evaluated.

A higher level of management focus is anticipated for areas corresponding with EHU 7, 8 and 9 owing to the direct dependency of ecosystems in these areas on water influx from the surrounding landscape, and also the potential for surface and groundwater interactions (Figure 27). Further discussion of the major water management considerations for individual EHUs is provided as follows:

- EHU 1 and 2 - Terrestrial ecosystems are rain-fed and disconnected from groundwater. The focus of management is to maintain surface runoff from source areas including drainage pathways into EHUs 3 and 4 and their downstream connectivity to EHU 8. This is achievable using normal business management practices. No requirement for groundwater level management.

- EHU 3 and 4 - Terrestrial ecosystems rely on surface water inputs and are disconnected from groundwater. The focus of management is to maintain the ephemeral surface water flow regime in drainage lines, including the passage of flow into downstream areas and associated soil profile moisture replenishment processes. Use creek diversions for surface water management. This is achievable using normal business management practices. No requirement for groundwater level management. Surplus water management in accordance with options under the Water RMS may be required.

- EHU 5 - Terrestrial ecosystems that are predominantly rain-fed and disconnected from groundwater, but there are localised areas that receive surface water flow from up-gradient. Zones of deep, sandy soil profiles may facilitate higher rates of groundwater recharge compared with surrounding landscapes. The focus of management is to maintain the ephemeral surface water flow regime. This is achievable using normal business management practices.

- EHU 6 - Terrestrial ecosystems rely on surface water inputs and are predominantly disconnected from groundwater. Significant local scale redistribution of surface water may occur in these areas, as influenced by topographic and vegetation patterns. The focus of management is to maintain and preserve patterns of surface water flow, and allow sheetflow and channel flow pathways to remain open. This is achievable using normal business management practices. Management and monitoring discharge of surplus mine dewatering. Generally no requirement for groundwater level management, however case specific exceptions at a local scale may occur (for example where relevant for aquifer recharge processes). Surplus water management in accordance with options under the Water RMS may be required.

- EHU 7 - Terrestrial ecosystems rely on surface water inputs and are predominantly disconnected from groundwater. Significant local scale redistribution of surface water may occur in these areas. Zones of karstic calcrete where runoff accumulates may facilitate higher rates of groundwater recharge compared with surrounding landscapes. Karstic groundwater systems are considered to have high stygofauna habitat values. The focus of management is the preservation of recharge mechanisms and stygofauna habitat. Enable flows from upgradient to continue reaching calcrete area to maintain surface water to groundwater linkages. Watertable control in calcrete aquifers to preserve adequate habitat for stygofauna; as such approaches for mitigating drawdown effects (e.g. MAR) may be applicable. Surplus water management in accordance with options under the Water RMS may be required.

- EHU 8 - Riparian ecosystems rely on the surface water flow regime, and in some places interact with groundwater via recharge and/or discharge processes. At a regional scale EHU8 includes important zones of concentrated recharge. The focus of management is the preservation of the water balance and water quality. Local area management plans developed under the Water RMS may be required. Large surface water flows have the potential to impact on infrastructure in major floods. Permit and maintain drainage pathways - avoid obstruction of drainages. Maintain and allow streamflow over aquifers to enable recharge. Manage and monitor discharge of surplus mine dewatering. Monitor and maintain water levels in riverine pools and other areas of high surface water and groundwater connectivity. Watertable control is important as ecosystems may be prone to groundwater drawdown influence.

Monitor and appreciate variability in water levels, and consider mitigations to maintain the water balance as required - a form of MAR and/or augmentation of soil moisture, into pools etc. may be applied.

- EHU 9 - Terminal areas for surface water flows, which may include zones of concentrated recharge and/or discharge. Vulnerable to changes in the water balance from modifications to surface inflows and the watertable. The focus of management is the preservation of the water balance and water quality. Local area management plans developed under the Water RMS may be required. Seek to maintain the magnitude and frequency of inundation. Monitor sediment accumulation. Monitor the potential for salinity increases in waterbodies over time. Watertable control is important as ecosystems may be prone to groundwater drawdown influence. Recognise that areas can be groundwater recharge and discharge areas, which will dictate appropriate management approaches. Monitor and appreciate variability in water levels, and consider mitigations to maintain the water balance as required – this may involve a form of MAR and/or augmentation of soil moisture and/or into pools.

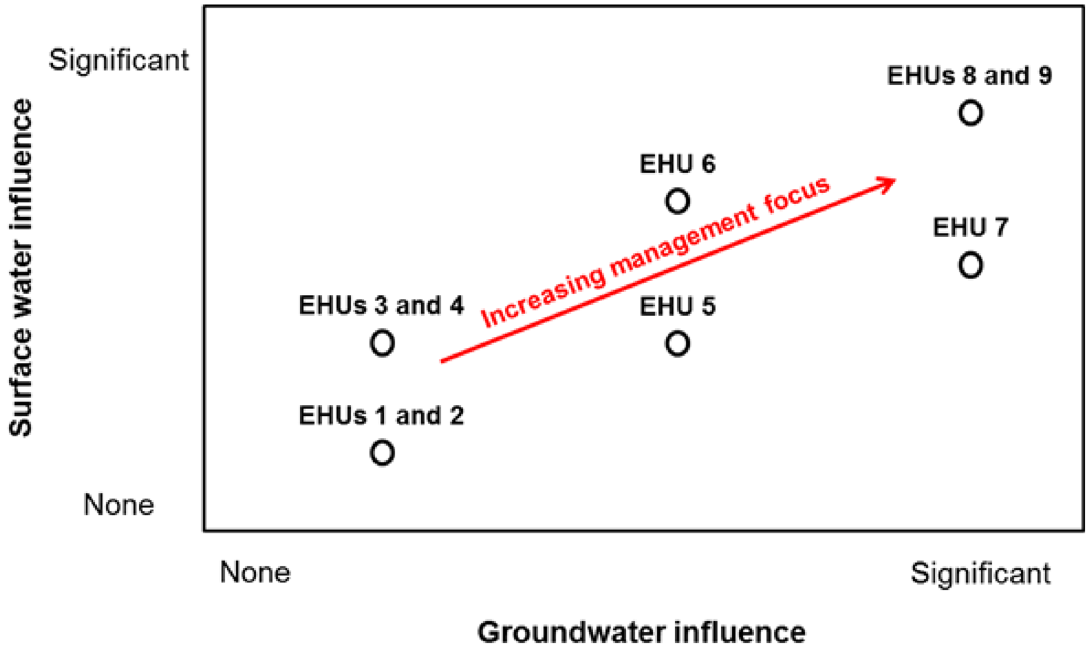

Figure 27 Water management focus based on EHU conceptualisation

15. Receptor-level management considerations

Under BHP Billiton Iron Ore's adaptive management framework, the overall management approach for key ecohydrological receptors includes the following components:

- Knowledge improvement actions:
  - Validate and refine receptor ecohydrological conceptualisations, Note that that the baseline scenario used in the change assessment represent a wet phase, therefore regional declines in groundwater levels and reduced surface water flows are possible if the climate trajectory returns to a dry phase,
  - Inform the selection and design of management approaches addressing relevant threatening processes,
  - Reduce management uncertainty, and
  - Contribute to the development and implementation of outcome-based management thresholds;
- Preventative control options – designed to separate receptors from potentially threatening processes as per outcomes-based objectives for the receptor; and
- Mitigating control options – designed to mitigate or counteract potentially threatening processes as per outcomes-based objectives for the receptor.

Based on the receptor level ecohydrological conceptualisations (Part II) and aggregate findings of the change assessment[7] (Part III), a set of key management considerations have been identified with respect to each threatening process. These are summarised below, with receptor level summaries further described in Table 20.

15.1. Groundwater drawdown

The receptor level change assessment identified high ecohydrological change potential associated with groundwater drawdown at Ethel Gorge and Weeli Wolli Spring. In both cases, groundwater dependent ecosystem elements including riparian vegetation and stygobiont fauna may be potentially affected. These ecosystems require hydrological conditions to be managed within a threshold range to ensure their persistence and maintain environmental functions and values. Recharge processes associated with a regime of reduced surface water availability may also interact with groundwater drawdown footprints, thereby contributing to ecohydrological change.

Under the full development scenario, high potential for ecohydrological change has also been identified in a portion of the lower Weeli Wolli Creek system, potentially extending to the southern fringe of the Fortescue Marsh. Moderate potential for ecohydrological change associated with drawdown was identified at Coondewanna Flats, and also an area to the west of the Mudlark mining area potentially extending into Karijini National Park. In all cases, the change assessment findings are precautionary.

Key management considerations include the maintenance of recharge processes and groundwater levels at Ethel Gorge and Weeli Wolli Spring. Management strategies have already been developed and implemented at these receptors under the baseline scenario (i.e. Hope Downs MAR at Weeli Wolli Spring implemented by RTIO; Ophthalmia Dam MAR scheme at Ethel Gorge implemented by BHP Billiton Iron Ore), which provide a foundation for ongoing management approaches under the Strategic Proposal. Further details of the Ophthalmia Dam MAR scheme are provided in Section 17. The postulated lack of sensitivity of Coondewanna Flats to drawdown requires validation (refer to Section 6.1). Similarly, postulated hydrological linkages and discontinuities between the Mudlark mining area and Karijini National Park (refer to Section 7.1), and the Marillana mining area and Fortescue Marsh need to be validated

[7] i.e. aggregate findings for the 30% and full development scenarios taking into account BHP Billiton Iron Ore and third party influences.

15.2. Reduced surface water availability

The receptor level change assessment identified high ecohydrological change potential associated with reduced surface water availability at Coondewanna Flats and Weeli Wolli Spring, based on the extent of catchment disturbance to these ecohydrological receptors arising from multiple mining operations. Vegetation communities at Coondewanna Flats are considered to rely on periodic soil water replenishment associated with the influx and infiltration of flood waters. Direct surface inflows also make a modest but significant contribution to the water balance of wetland habitats at Weeli Wolli Spring. Recharge at Coondewanna Flats is considered to be a significant contributor to the groundwater flux ultimately discharging at Weeli Wolli Spring. The ecosystems of both receptors are considered to require the maintenance of surface water regimes (i.e. flood duration and inter-flood periods) within a hydrological condition threshold range to ensure their persistence and maintain environmental values.

The degree of reduced water availability for other ecohydrological receptors (being Ethel Gorge, Fortescue Marsh and Freshwater Claypans of the Fortescue Valley) is not predicted to be significant under the 30% development scenario. Under the full development scenario, there is moderate ecohydrological change potential at the Fortescue Marsh associated with cumulative catchment area reduction (combined BHP Billiton Iron Ore and third party projects); however, this finding is precautionary. At Ethel Gorge, the effects of reduced catchment area will be mitigated by the functionality of Ophthalmia Dam in maintaining the water regime at this receptor.

Key management considerations include surface water controls that adequately provide for the ecological water requirements of the ecosystem elements associated with the receptors. Postulated hydrological linkages between Coondewanna Flats and Weeli Wolli Spring need to be validated with respect to the importance of groundwater recharge contribution for Weeli Wolli Spring. The effect of catchment area reduction on the surface water regime of the Fortescue Marsh also needs to be validated.

15.3. Surplus water

Varying surplus water volumes may be generated in the Central Pilbara, Eastern Pilbara and Marillana Creek regions over the life of the Expansion Project. In each case, a range of water management options are available for consideration and implementation under the Water RMS.

In the Marillana Creek region, surplus water is principally associated with BHP Billiton Iron Ore's Yandi operations and is discharged into Marillana Creek in accordance with existing environmental approvals. It is anticipated that this current water management approach will be continued over the life of the Yandi operations. Similarly, in the Eastern Pilbara region surplus water is managed via the Ophthalmia Dam MAR scheme and it is anticipated that this current water management approach will be continued for the Expansion Project.

Mining areas in other regions with potentially significant volumes of water surplus do not currently have operational surplus water management schemes (i.e. the Central Pilbara and Fortescue Marsh regions); however, since the Central Pilbara region is mainly water deficient BHP Billiton Iron ore has the ability to transfer surplus water between mining areas in the Central Pilbara region for operational use. As part of the Strategic Proposal, these will be developed as required in accordance with the feasible water options outlined in the Water RMS.

Key management considerations include matching water availability to operational needs within and between mining areas where possible, as well as surplus management options that enable hydrological regimes at receptors to be maintained within threshold limits.

15.4. AMD source potential

The existing Whaleback mine in the Eastern Pilbara region (high AMD source potential) is being managed in accordance with normal business practices. All proposed mines included in the Strategic Proposal under the 30% development scenario have low AMD source potential. Under the full development scenario, two mines in the Mindy mining area are classified as having high AMD source potential; however, this finding is precautionary. Additionally, several mines in each region are classified as having moderate AMD source potential (refer to Section 12.4).

BHP Billiton Iron Ore's normal business practices for AMD management, as detailed in the AMD Management Standard (BHP Billiton Iron Ore, 2014b), are considered to be fit-for-purpose for preventing AMD movement from

OSA's to ecohydrological receptors. These practices will apply to the Strategic Proposal and be subject to continuous improvement in accordance with BHP Billiton Iron Ore's adaptive management framework. Elements of the AMD management approach include:

- Mineral waste characterisation procedures,
- Source-pathway-receptor analysis,
- Appropriate waste encapsulation including backfill,
- Surface water drainage controls, and
- Progressive closure planning during operations in accordance with the Closure RMS.

15.5. Groundwater quality - saline intrusion

The potential for saline intrusion is limited to areas of the Fortescue River valley in the Fortescue Marsh region, associated with BHP Billiton Iron Ore's proposed Marillana, Mindy and Roy Hill mining areas and several third party operations.

Key management considerations include the management and mitigation of potential saline water ingress associated with orebody dewatering using options such as MAR.

15.6. Surface water quality

BHP Billiton Iron Ore has well developed surface water quality management systems and approaches that are employed as part of normal business practices. These are considered to be fit-for-purpose for maintaining surface water quality at ecohydrological receptors. These practices will apply to the Strategic Proposal and be subject to continuous improvement, in accordance with BHP Billiton Iron Ore's adaptive management framework.

15.7. Pit lakes

Under the full development scenario, all mining areas will be closed. In deposits where below watertable mining has occurred there is the potential for pit lakes to form in mine voids.

As part of normal business overburden scheduling practices, a portion of the overburden will placed in the mined-out void (infilling). It is anticipated that more than 50% of mine voids will be ether above the water table or will be infilled to pre-mining groundwater levels, thereby preventing pit lake formation.

Where pit voids are not infilled to above pre-mining groundwater levels, post-mining landforms associated with these mines may form pit lakes, most of which will function as groundwater sinks. These pit lakes are expected to become progressively more saline in the decades following mine closure owing to evaporative concentration of salts.

BHP Billiton Iron Ore has existing management practices for pit lakes that are applicable to the Strategic Proposal. Pit lake management options are outlined in the Closure RMS including leaving the pit as an open void, or alternatively partial or complete backfill (to above post-mining recovery watertable). Options are to be selected and implemented based on the outcomes of targeted studies and potential impacts. Preliminary mine closure plans that address AMD and pit lakes management are developed for new operations. Factors considered as part of mine void closure include:

- AMD source risk
- Source – pathway – receptor analysis.
- Saline pit lake water as part of mine closure planning.
- Throughflow potential and implications for water quality in groundwater systems.

These practices are considered to be fit-for-purpose for preventing pit lakes affecting ecohydrological receptors. These practices will apply to the Strategic Proposal and be subject to continuous improvement in accordance with BHP Billiton Iron Ore's adaptive management framework.

Table 30 Change assessment findings and management for ecohydrological receptors

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential: Drawdown	Ecohydrological change potential: Surface water availability	Ecohydrological change potential: Other	Management considerations: Normal business practices	Management considerations: Targeted management (RMS')	Management considerations: Knowledge improvement
Coondewanna Flats	2014	Cumulative	None	Negligible	Excess dewatering from MAC mining area.	Environmental monitoring: • Groundwater levels beneath Coondewanna Flats, between the stressor and receptor (i.e. the pathway) and the down-gradient groundwater system, with a focus on its responsiveness to flooding events (i.e. the recharge regime); • Surface water inflows into Coondewanna Flats; and • Vegetation health of the Coondewanna Flats PECs. Surface water: • Diversion and flow dynamics in major drainages that contribute inflows to Lake Robinson and the broader Coondewanna Flats. AMD: • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	Water RMS: • Outcome-based objectives for Coondewanna Flats. • Management triggers and thresholds for Coondewanna Flats. • Groundwater levels and surplus water - surplus water from the MAC mining area may be returned to the groundwater system where practicable and appropriate. The use of MAR may minimise the spatial extent of groundwater drawdown. Closure RMS: • Outcome-based closure objectives for Coondewanna Flats. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms.	Targeted ecohydrological studies: • Validation and refinement of the current ecohydrological conceptualisation for Coondewanna Flats; including the contribution of groundwater to vegetation water use. • Quantitative analysis of flooding, soil moisture replenishment and recharge. • Ecosystem responses to modified hydrological regimes (i.e. flood duration, flood timing and inter-flood periods). • Validation of potential land surface modifications/catchment reduction on the hydrological regime at Coondewanna Flats. Targeted surplus studies: • Improved accuracy of mining area level water balance forecasts. • Trials of surplus water management options including MAR. Targeted closure studies: • Optimal surface water management designs in closure landforms.
	30% development	BHP Billiton Iron Ore Only	**Moderate** Small area of drawdown from MAC mining area reaches northern extent of receptor.	**Moderate** Aggregate catchment reduction from MAC, Parallel Ridge, South Flank and Mudlark mining areas.	n/a			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
	Full development	BHP Billiton Iron Ore Only	**Moderate** Drawdown from MAC, South Flank and Mudlark mining areas.	**High** Aggregate catchment reduction from MAC, Parallel Ridge, South Flank, Mudlark and Tandanya mining areas.	n/a The Tandanya mining area has a moderate AMD potential.			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
Ethel Gorge	2014	**Cumulative**	**Moderate**, but change potential offset by infiltration from Ophthalmia Dam. Consequently the residual change is **Low.**	None Minor (<5%) catchment reduction from Eastern Ridge mining area.	Slight increase in salt loads due to excess dewatering discharged in Ophthalmia Dam, but salinity likely to remain within historical ranges – refer to Ethel Gorge Case Study. Whaleback mine has high AMD source potential with AMD from OSAs being currently managed via collection and treatment.	Environmental monitoring: • Groundwater levels at Ethel Gorge; • Groundwater quality at Ethel Gorge and in Ophthalmia Dam; and • The stygofauna assemblage at Ethel Gorge. Groundwater and surface water: • Maintenance of natural surface water flow into Ethel Gorge and further downstream within the Upper Fortescue River. Flows in Fortescue River are captured by Ophthalmia Dam during low flow events and provide recharge into the Ethel Gorge groundwater system. • Ophthalmia Dam and other existing MAR facilities provide for bulk and targeted replenishment of groundwater to minimise impacts in and near Ethel Gorge. AMD: • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	Water RMS: • Surplus water - Under the current Ophthalmia Dam Scheme, water availability is matched to operational needs where possible, and opportunities actively sought for optimising water balances within mining areas and potentially between mining areas. • Surplus water may be returned to the groundwater system where practicable and appropriate. The most likely surplus water management approach will be MAR via discharge into Ophthalmia Dam. The use of MAR minimises the spatial extent of groundwater drawdown, thereby contributing to the preservation of stygofauna habitat. • Borefield abstraction - Abstraction from the Ophthalmia borefield may potentially be used to control the groundwater level and groundwater quality. Abstraction serves to balance the aquifer where necessary. • Targeted creek discharge - Discharge into creek lines may be used to supplement natural surface water flow within a threshold range. Closure RMS: • Outcome-based closure objectives for Ethel Gorge. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects.	Targeted ecohydrological studies: • Validation and refinement of the current ecohydrological conceptualisation for Ethel Gorge; including the contribution of groundwater to vegetation water use and level of dependence of the vegetation of groundwater. • Quantitative analysis of recharge processes at Ethel Gorge, including consideration of the influence of Ophthalmia Dam and MAR on water levels and water quality (in terms of salt loads). • Ecosystem responses to modified hydrological regimes (i.e. groundwater salinity changes). • Validation of potential land surface modifications/catchment reduction on the hydrological regime at Ethel Gorge. Targeted surplus studies: • Improved accuracy of mining area level water balance forecasts. • Trials of surplus water management options including MAR and surface discharge to riparian areas. Ensure multiple options are available proportional to capacity uncertainty. • Assessment of the receiving capacity of the hydrogeological system. Targeted closure studies: • Optimal groundwater and surface water management designs in closure landforms.
	30% development	BHP Billiton Iron Ore Only	**High** at OB37, but change potential is offset by infiltration from Ophthalmia Dam. Consequently the residual change is **Low** – refer to Ethel Gorge Case Study	**Moderate** Catchment reduction associated with Eastern Ridge and Shovelanna mining areas.	Increase in salt loads due to discharge of excess dewatering in Ophthalmia Dam from various operations – refer to Ethel Gorge Case Study. Whaleback mine has high AMD source potential with AMD from OSAs being currently managed via collection and treatment.			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
	Full development	BHP Billiton Iron Ore Only	**High** at OB37, but change potential is offset by infiltration from Ophthalmia Dam. Modelling indicate residual change is **Low** – refer to Ethel Gorge Case Study	**High** Catchment reduction from Eastern Ridge, Shovelanna, Homestead, and East Ophthalmia mining areas.	Increase in salt loads due to discharge of excess dewatering in Ophthalmia Dam from various operations. Whaleback has high AMD source potential will likely form a groundwater sink after closure with no connection to Ethel Gorge.			
		Third party only	None	None	None			
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential			Management considerations		
			Drawdown	Surface water availability	Other	Normal business practices	Targeted management (RMS')	Knowledge improvement
Fortescue Marsh	2014	Cumulative	None Drawdown change potential from FMG's Christmas Creek and Cloudbreak operations managed by MAR.	None Low change potential restricted to local drainages north of the Marsh due to reduced catchment from FMG mining areas.	Excess dewatering from FMG's Christmas Creek and Cloudbreak mining areas is managed by MAR. The excess dewatering volumes include both fresh and hypersaline water.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	Targeted ecohydrological studies: • Validating, amending and improving the current ecohydrological conceptualisation of Fortescue Marsh. • Review the findings of ecohydrological studies undertaken by third parties (where available). • Implement studies targeting any knowledge gaps (as required). Seek to collaborate with third parties where opportunities for mutual benefit are identified.
	30% development	BHP Billiton Iron Ore Only	None Only AWT mining at Marillana.	None Moderate to high change potential in local drainages only, owing to reduced catchment from Marillana mining area.	None			
		Third party only	None Drawdown change potential from FMG's Christmas Creek and Cloudbreak operations managed by MAR.	None Low to moderate change potential in local drainages in the Marsh area owing to reduced catchment from third-party mining areas.	Excess dewatering (saline and fresh) from FMG's Christmas Creek and Cloudbreak mining areas managed by MAR. Other third-party operations (Brockman Resources' Marillana, FMG's Nyidinghu and Mindy Mindy, and HPPL's Roy Hill) are assumed to be conditioned to have no change potential on Fortescue Marsh from disposal of excess dewatering water.			
		Cumulative	None	None	Assumed to be conditioned to have no change potential on Fortescue Marsh from disposal of excess dewatering water.			
	Full development	BHP Billiton Iron Ore Only	**High** - within a small portion of southern fringe of Marsh related to Marillana mining area. **None** – remainder of Marsh	None. Moderate to high change potential in local drainages and a portion of Weeli Wolli Creek due to reduced catchment at Marillana mining area.	Excess dewatering water from Marillana, Mindy and Coondiner mining areas will require management to have no change potential on Fortescue Marsh. AMD potential (pit lakes and OSAs) is generally low but could be **high** if BHP Billiton Iron Ore targets deeper ore reserves at the Mindy mining area.	Environmental monitoring: • Prior to mine development in the vicinity of Fortescue Marsh, review and consider the groundwater and surface water monitoring data collected by the existing mine operators (where and if available). Based on this review, target multi-level monitoring networks and data will be developed to address any knowledge gaps. Surface water: • Diversion and flow dynamics in major drainages that contribute inflows to Fortescue Marsh. AMD: • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	Water RMS: • Surplus water management - Water availability to be matched with operational needs where possible, and opportunities actively sought for optimising water balances within mining areas and potentially between mining areas. • Management and mitigation of potential saline water ingress associated with orebody dewatering using options such as MAR. Closure RMS: • Outcome-based closure objectives for Fortescue Marsh. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects. Mitigating controls will be developed as required to address threatening processes.	Targeted ecohydrological studies: • Validating, amending and improving the current ecohydrological conceptualisation of Fortescue Marsh. • Review the findings of ecohydrological studies undertaken by third parties (where available). • Implement studies targeting any knowledge gaps (as required). Seek to collaborate with third parties where opportunities for mutual benefit are identified. Targeted surplus studies: • Improved accuracy of water balance forecasting. • Local to sub-regional trialling of surplus water management approaches to help understand hydrological controls and determine practicable mitigation options. Targeted closure studies: • Optimal groundwater and surface water management designs in closure landforms.
		Third party only	None	None Moderate to high change potential in local drainages and a portion of Weeli Wolli Creek due to reduced catchment at Brockman Resource's Marillana mining area.	Third-party operations (Brockman Resources' Marillana, FMG's Nyidinghu and Mindy Mindy, and HPPL's Roy Hill) are assumed to be conditioned to have no change potential on Fortescue Marsh from disposal of excess dewatering water.			
		Cumulative	**High** - within a small portion of southern fringe of Marsh related to Marillana mining area.None – remainder of Marsh	**Moderate** Cumulative reduction in catchment area >5% from multiple mining areas.	Excess dewatering water from BHP Billiton Iron Ore and third-party operations will require management to have no change potential on Fortescue Marsh. AMD potential is generally low but may increase if deeper ore reserves are targeted.			
Freshwater claypans of the Fortescue Valley	2014	Cumulative	None	None	None	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	Targeted ecohydrological studies: • Validating, amending and improving the current ecohydrological conceptualisation of the Freshwater Claypans of the Fortescue Valley. • Implement studies targeting any knowledge gaps (as required).
	30% development	BHP Billiton Iron Ore Only	None	None	None			
		Third party only	None	None	None			
		Cumulative	None	None	None			
	Full development	BHP Billiton Iron Ore Only	None	None Low to moderate change potentially confined to localised drainages in the vicinity of the Roy Hill mining area.	Potential for surplus water from BHP Billiton Iron Ore's Roy Hill mining area. It is possible that a proportion of excess dewatering water may be saline.	Environmental monitoring: • Groundwater levels at the Roy Hill mining area. • The need for other monitoring parameters to be determined. Surface water: • Diversion and flow dynamics in major drainages that contribute inflows to Fortescue Marsh.	Water RMS: • Surplus water management - Water availability to be matched with operational needs where possible • Management and mitigation of potential saline water ingress associated with orebody dewatering using options such as MAR.	Targeted ecohydrological studies: • Validating, amending and improving the current ecohydrological conceptualisation of the Freshwater Claypans of the Fortescue Valley. • Implement studies targeting any knowledge gaps (as required).

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential			Management considerations		
			Drawdown	Surface water availability	Other	Normal business practices	Targeted management (RMS')	Knowledge improvement
Freshwater claypans of the Fortescue Valley	Full development	Third party only	None	None	None	AMD: • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard	Closure RMS: • Outcome-based closure objectives for Freshwater Claypans of the Fortescue Valley and the Fortescue Marsh. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects. Mitigating controls will be developed as required to address threatening processes.	Targeted surplus studies: • Improved accuracy of water balance forecasting. • Local to sub-regional trialling of surplus water management approaches to help understand hydrological controls and determine practicable mitigation options. Targeted closure studies: • Optimal surface water management designs in closure landforms.
		Cumulative	n/a	n/a	Change potential is only related to BHP Billiton Iron Ore's operations.			
Weeli Wolli Spring	2014	Cumulative	None Substantial drawdown in area of Spring due to RTIO's Hope Downs operation, but ecohydrological change at Spring is managed through irrigation.	None Flow at Weeli Wolli Spring is being maintained through irrigation by Hope Down's operator.	Substantial discharge of excess dewatering water in Weeli Wolli Creek from Hope Downs, but water quality is fresh.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under the baseline scenario.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under the baseline scenario.	Targeted ecohydrological studies • Validating, amending and improving the current ecohydrological conceptualisation of Weeli Wolli Spring. • Review the findings of ecohydrological studies undertaken by Rio Tinto's Iron Ore business at Hope Downs (where available).
	30% development	BHP Billiton Iron Ore Only	**Low** - small drawdown from MAC mining area towards spring; however, to be managed as **High** in recognition of spring sensitivity and analysis uncertainty	**Moderate** Reduction in catchment due to combined effect of deposit MAC (A and C Deposits) and Jinidi mining areas.	If both MAC and Jinidi are considered may be water negative requiring water supply (e.g. borefield); otherwise, slightly surplus.	Environmental monitoring: • Groundwater levels at Weeli Wolli Spring and surrounding groundwater systems; • Surface water flow regime at Weeli Wolli Spring and relationship with recharge dynamics; • Recharge dynamics in the upper catchment, and throughflow effects relevant to Weeli Wolli Spring. • Ecological health condition • Stygofauna assemblage at Weeli Wolli Spring. • Riparian vegetation community health at Weeli Wolli Spring. • Aquatic biota of the river pools associated with Weeli Wolli Spring. Surface water: • Diversion and flow dynamics in major drainages that contribute inflows to Weeli Wolli Spring. • Surplus water management - Water availability to be matched with operational needs where possible, and opportunities actively sought for optimising water balances within mining areas and potentially between mining areas. There are a range of options available with some trials current underway at the MAC mining area. AMD: • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	Water RMS: • Appropriate interfacing with management program being implemented by RTIO, in consultation with RTIO • Surplus water - Surplus water may be returned to the groundwater system where practicable and appropriate. The use of MAR may minimise the spatial extent of groundwater drawdown. • Surface water diversion - Augmentation of natural surface water flow into Weeli Wolli Spring via targeted drainages, if required. • Vegetation health - Augmentation of soil moisture via irrigation, if required. Closure RMS: • Outcome-based closure objectives for Weeli Wolli Spring. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning. • Prediction of cumulative closure effects.	Targeted ecohydrological studies • Validating, amending and improving the current ecohydrological conceptualisation of Weeli Wolli Spring. • Quantitative analysis of surface water and groundwater interactions at Weeli Wolli Spring. • Ecosystem responses to modified groundwater levels and groundwater throughflow regime. • Contribution of groundwater to vegetation water use at Weeli Wolli Spring. • Characterisation of the effect of land surface modifications within the catchment on the hydrological regime at Weeli Wolli Spring. Targeted surplus studies: • Improved accuracy of water balance forecasting. • Local-scale trialling of additional surplus water management options considering the proposed activities and influence of third parties. Targeted closure studies: • Ongoing mineral waste characterisation during pre-development phases. • Source – pathway – receptor analysis for deposits with AMD source risk. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning.
		Third party only	**Moderate** Hope Downs closed by 2024, and residual drawdown dependent on closure strategy.	**Low** OSAs rehabilitated and pit backfilled.	RTIO's Hope Downs operation will be closed. Change potential depends on post-closure water level response.			
		Cumulative	**Moderate** Hope Downs closed by 2024, and residual drawdown dependent on closure strategy.	**Moderate** Combined catchment reduction from Hope Downs, MAC and Jinidi mining areas.	Change potential depends on the closure strategy of RTIO's Hope Downs operation.			
	Full development	BHP Billiton Iron Ore Only	**Low to moderate** - encroaching drawdown from MAC and Jinidi mining areas towards spring; however, proposed to be managed as **High** in accordance with a precautionary approach.	**High** Reduction in catchment due to combined effect of MAC (A and C Deposits) and Jinidi mining areas.	For most of the period, operations are water negative, which require water supply (e.g. borefield) with potential change potential on groundwater resource. There will be periods of dewatering surplus. OB 13 and 16 in Jinidi mining area has moderate potential for AMD.			
		Third party only	**High** Depends on closure outcomes from Hope Downs.	**Low** Assuming Hope Downs OSAs rehabilitated and pit backfilled.	Change potential at Weeli Wolli Spring will be dependent on the closure outcomes from Hope Downs.			
		Cumulative	**High** Depends on closure outcomes from BHP Billiton Iron Ore operations and Hope Downs.	**High** Cumulative reduction in catchment from BHP Billiton and third-party operations.	Aggregate change potential from BHP Billiton Iron Ore Operations and depends on closure outcomes from Hope Downs.			

Ecological asset	Scenario	Operations[1]	Ecohydrological change potential			Management considerations		
			Drawdown	Surface water availability	Other	Normal business practices	Targeted management (RMS')	Knowledge improvement
Karijini National Park	2014	Cumulative	None	None Minor (<5%) catchment reduction due to West Angelas mining area	RTIOs West Angelas mining area is licenced to discharge surplus water into local creek system. Existing borefield provides groundwater supply with potential change on groundwater resource.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	n/a - Negligible ecohydrological connectivity with existing and proposed operations in the Strategic Proposal under these scenarios.	Validation of postulated hydrological linkages and discontinuities between the Mudlark mining area and Karijini National Park (refer to Section 7.1).
	30% development	BHP Billiton Iron Ore Only	None	None	Water negative operations at Mudlark mining area that may require groundwater supply resulting in potential change on groundwater resource.			
		Third party only	None	**Low** (Turee Creek East) - Catchment reduction due to RTIO West Angelas mining area.	RTIOs West Angelas mining area is licenced to discharge surplus water into local creek system. Borefield provides groundwater supply with potential change on groundwater resource.			
		Cumulative	None	**Low** – as above	Combined effect of groundwater supply bores on groundwater resource.			
	Full development	BHP Billiton Iron Ore Only	**Low to moderate** Drawdown associated with Alligator South mine may extend to the national park; however the likelihood is low owing to hydrogeological complexity, geological structure, topographic differences and separation distance (Section 7.1.3). Further validation is necessary to confirm ecohydrological change potential.	**Low** Catchment reduction due to Alligator South mining area.	Mainly water negative operations which require potential groundwater supply with potential change on groundwater resource. Occasional water surplus which require management.	Environmental monitoring: • The need for groundwater, surface water and other monitoring parameters to be determined. AMD: • Managed in in accordance with BHP Billiton Iron Ore's risk based AMD Management Standard.	Water RMS: • Surplus water management - Water availability to be matched with operational needs where possible. • Surplus water to be managed in order to maintain the hydrological regime of Karijini National Park within a threshold range. Closure RMS: • Outcome-based closure objectives for Karijini National Park. • Pit lakes - assessment of backfill strategies; assessment of pit lakes in closure landforms. • Source – pathway – receptor analysis for the migration of saline pit lake water as part of mine closure planning.	Targeted ecohydrological studies • Validating, amending and improving the current ecohydrological conceptualisation of Karijini National Park.
		Third party only	None	**Low** (Turee Creek East)- Catchment reduction due to RTIO West Angelas mining area	West Angelas mining area is closed.			
		Cumulative	**Low to moderate** As above	**Low** Catchment reduction due to Alligator South and West Angelas mining area	Aggregate change potential depends on BHP Billiton Iron Ore groundwater supply option and closure strategy.			

[1] Change potential due to BHP Billiton activities is before mitigation is considered. Change potential due to third-party operations is after mitigating measures are applied (consistent with publicly-available information)

16. Ethel Gorge case study

The Ethel Gorge case study presents an example of the implementation of the Water Regional Management Strategy (Water RMS) for the purpose of applying an adaptive management approach when assessing and managing potential impacts on ecological receptors caused by mining-related changes to the groundwater and surface water regime at the Ethel Gorge study area. The case study is presented in Appendix G and includes supporting documentation.

The case study demonstrates the application of adaptive management techniques and outcome-based hydrological conditions to mitigate potential impacts within historical baseline trends. It includes the following components.

- An overview of the project domain and ecological assets, including the baseline, historical and hydrological conditions, identification of ecological receptors and an evaluation of receptor tolerances to hydrological change, providing the basis for setting early warning triggers and management thresholds;
- A change assessment examining potential hydrological changes caused by future BHP Billiton Iron Ore mining operations, hydrological indicators of change and potential impacts on ecological receptors. The change assessment also considers a range of mitigation and management measures to avoid, minimize and manage the potential impacts and
- Monitoring, review and corrective actions in support of the overall management approach. Corrective actions will be implemented in the event that thresholds are exceeded.

An adaptive management approach for the Ethel Gorge case study represents a summarised application of the Eastern Pilbara Water Management Plan. The approach prepares the business for various and changing dewatering and surplus water scenarios and where necessary manages the hydrological changes associated with activities including potential impacts to the Ethel Gorge community, water resource and riparian vegetation.

The approach demonstrates that BHP Billiton Iron Ore operations can undertake various pumping and discharge scenarios, whilst effectively achieving the necessary hydrological conditions to sustain the key receptors by using a range of feasible and scalable controls to prevent and mitigate impacts.

It is a staged and iterative process, which is responsive to the specific water requirements of the key receptors. Decision making is aligned to outcome-based objectives that reflect ecological values, baseline datasets, assessment of potential hydrological changes (predicted and actual), predicted impacts on receptors, monitoring of change, and the outcomes of management actions where applied. The management approach is therefore progressively developed and refined, by accumulated scientific knowledge and measured outcomes.

The adaptive strategy is underpinned by a risk-based approach that focuses on the assets of importance and considers scientific uncertainty and outcome-based objectives. Early warning triggers and thresholds are selected to ensure that monitoring is targeted to key hydrological change processes. In the early stages of the process, these triggers and thresholds are typically conservative and precautionary, reflecting incomplete scientific knowledge. As scientific understanding becomes more complete, the level of uncertainty reduces and management thresholds can be refined.

16.1. Project domain and ecological assets

Ethel Gorge is located on the Upper Fortescue River approximately 15 km northeast of Newman and directly downstream of the confluence of several creek systems. The Ophthalmia Dam is a purposely-designed managed aquifer recharge (MAR) structure, located about 3 km upstream of Ethel Gorge. The dam captures and retains flows in the Fortescue River before either infiltrating or being discharged through controlled release to infiltration basins to replenish aquifers beneath the dam.

The Ethel Gorge stygobiont community (Tier 2 in BHP Billiton’s ecological asset classification) occurs in the groundwater beneath Ethel Gorge and the Ophthalmia Floodplain, which is referred to as the Ophthalmia aquifer. The stygobiont community is listed as a Threatened Ecological Community (TEC) by the Department of Parks and Wildlife (DPaW) and classed as endangered (DPaW, 2014). The stygofauna assemblage includes about 78 species with half being restricted to the Ethel Gorge area and some species are only found in the Ophthalmia aquifer (Bennelongia, 2014).

There are two main threatening process to stygofauna associated with mining developments in the Ethel Gorge area. Firstly, groundwater drawdown has the potential to decrease the available habitat for stygofauna. The study area has experienced substantial changes in groundwater levels historically, in connection with groundwater abstraction, dewatering activities, recharge through the Dam, and climatic variation. However, to date, no measurable impacts on the stygofauna community have been observed during the monitoring period (BHP Billiton Iron Ore, 2014d). Secondly, the stygofauna community may be impacted by changes to groundwater quality associated with abstraction and/or discharge of excess dewatering water into Ophthalmia Dam. Historical monitoring suggests that groundwater salinity has increased in parts of the aquifer and decreased in others; however, no measureable impacts on the stygofauna community have been observed (BHP Billiton Iron Ore, 2014d).

As part of the existing ministerial conditions (Ministerial Statement 712), the implemented subterranean fauna survey plan sets out the procedures and measures for monitoring the distribution and abundance of species and/or communities of subterranean fauna. It also outlines remedial action should monitoring indicate that project operations compromise the long-term survival of subterranean fauna and/or communities.

The vegetation of the major drainage channels in the area (Tier 3in BHP Billiton's ecological asset classification) comprises about 3 650 ha of dense riparian and woodland vegetation. There are two main threatening processes on this riparian vegetation. Firstly, a reduction in the frequency of flooding events could contribute to the ecological water requirements of the vegetation by replenishing moisture stores in the vadose zone. It is unknown whether the riparian vegetation communities have a groundwater dependency, and therefore the potential impact of drawdown on vegetation health is subject to a high degree of uncertainty. Secondly, the riparian vegetation may be impacted through rising groundwater levels and saturation of the root zone (referred to as waterlogging) from increased infiltration caused by the increased discharge of surplus dewatering water to Ophthalmia Dam and the associated infrastructure.

As part of the existing ministerial conditions (Ministerial Statement 478), vegetation health is monitored adjacent to Orebody 25 to assess the potential impacts from groundwater drawdown around Orebody 25. However, to date, the drawdown extent has not extended to the riparian vegetation.

16.2. Change assessment – operational

16.2.1. Background

The Strategic Proposal includes development of ten orebodies in the Ethel Gorge area up to the 30% development stage, with dewatering required to facilitate below watertable mining. Four orebodies are currently approved for dewatering; whereas, six new deposits are proposed within the SEA. The Ophthalmia Borefield will continue to meet a portion of future water demand. Predictive modelling was carried out to estimate groundwater drawdown and its impact on the Ethel Gorge ecological receptors (RPS, 2014a). Additional groundwater modelling was also carried out after an assessment of the OB31 dewatering requirements indicated that it is possible that surplus dewatering rates from OB31 could be considerably higher than anticipated (RPS, 2015).

The change assessment assumes excess dewatering water is to be discharged from existing and proposed operations in the Eastern Pilbara region into Ophthalmia Dam and four recharge ponds. This dewatering discharge is expected to have a higher natural salinity concentration than the receiving groundwater. Consequently, groundwater salinity may increase due to the combined effects of salt loading in input waters, evaporative concentration in the Ophthalmia Dam and evapotranspiration from the Ethel Gorge area. Predictive modelling has been undertaken to estimate the increase in groundwater salinity and its impact on the ecological receptors (RPS, 2014b).

A regional numerical groundwater model was developed to evaluate the effect of groundwater drawdown associated with the SEA mining schedule on groundwater systems in the Ethel Gorge area (RPS, 2014a). The numerical model also evaluated the effect of rising groundwater levels caused by increased infiltration from the discharge of surplus dewatering water to Ophthalmia Dam and the associated infiltration infrastructure. The numerical groundwater model was calibrated to the historical groundwater conditions. A separate analytical water and salt balance was developed to evaluate the changes of salinity concentrations resulting from the discharge of excess dewatering water into the Ophthalmia Dam (RPS, 2014b).

A three-dimensional saturated thickness profile was developed based on available geological information. It demonstrated that portions of the existing Ethel Gorge stygobiont community TEC boundary are located in areas underlain by completely unsaturated alluvium or calcrete. In other parts of the Ethel Gorge study area, there is only a thin saturated thickness and these areas are prone to complete desaturation from natural groundwater fluctuations (BHP Billiton Iron Ore, 2014e). There are also areas with a significant saturation thickness which occur outside the TEC boundary.

Historically, groundwater levels in the Ethel Gorge area fluctuated by up to six metres owing to a combined effect of natural groundwater level variability, localised drawdown effects from operating production bores and controlled recharge. Groundwater levels are currently at historically high levels due to abnormally wet conditions experienced across the Pilbara Region since the late 1990s.

Groundwater drawdown is offset by leakage from the Ophthalmia Dam, four recharge ponds and two infiltration basins, which maintains higher groundwater levels in the Ophthalmia aquifer comprising Tertiary Detritals and calcrete (refer to Appendix G Map 1; showing its lateral extent). Significant drawdown is expected beneath the Homestead and Shovelanna tributaries owing to dewatering of orebodies situated on the flanks of these tributary palaeochannels, but the impacts of these drawdowns on the Ophthalmia aquifer are predicted to also be offset by leakage from the Ophthalmia Dam. Further investigations are required to validate the degree of hydraulic connection between the tributary palaeochannels and Ophthalmia aquifer.

Orebody 37 is situated directly adjacent to the Ophthalmia aquifer. The geological model suggests that the Ophthalmia aquifer is separated from the proposed mine workings at Orebody 37 by low permeability Jeerinah Formation and other low permeability lithologies. As such, drawdown is not predicted to extend to the Ophthalmia aquifer (BHP Billiton Iron Ore, 2014e). However, further investigations of the geological setting at Orebody 37 are required to validate this finding.

16.2.2. Findings

The numerical modelling suggests that groundwater levels can be sustained throughout the Ophthalmia aquifer, which implies no significant impacts on either the stygofauna community or riparian vegetation associated with groundwater drawdown resulting from the Strategic Proposal. The modelling demonstrates that drawdown in the Ophthalmia aquifer would be offset by leakage from the Ophthalmia Dam and infiltration along the recharge ponds. The findings are sensitive to the hydraulic connection uncertainties described in the preceding section, which require further assessment, which require validation. The numerical model also suggest that rising groundwater levels, caused by increased infiltration from the discharge of surplus water to Ophthalmia Dam and associated infiltration infrastructure will remain within the historical range. This finding is sensitive to the surplus dewatering discharge rate which requires validation.

The water and salt balance modelling shows that for the majority of the Ophthalmia aquifer and the majority of climatic and operating conditions, salinity concentrations will remain within the historical recorded ranges (between 1977 and 2014). However, salinity concentrations could increase to about 30% above historical maximum ranges for lower than normal rainfall conditions (RPS, 2014b). The operating strategy of the dam is predicted to exert a strong influence on groundwater salinity concentrations. In particular, salinity concentrations could be 70% above historical maximum ranges if water is released from the dam during non-flooding periods.

Available scientific knowledge suggests that many stygofauna species can tolerate a variable salinity regime (Halse *et. al.*, 2014). However, less resilient species may be vulnerable to salinity increases beyond the range of natural variability. Riparian vegetation communities are considered unlikely to be significantly affected by increases in groundwater salinity concentrations, as the vegetation principally relies on soil moisture in the vadose zone. Progressive technical studies are required to address these uncertainties within the framework of BHP Billiton Iron Ore’s adaptive management approach. A precautionary approach which considers historical ranges rather than species tolerance and adaptability has been adopted for this case study.

The increase in groundwater salinity is likely to be within the tolerance thresholds of the stygofauna community. There is also no significant risk of impacts on riparian vegetation communities associated with groundwater salinity increases associated with the implementation of the SEA mine schedule. This outcome is however dependent on the adoption of an appropriate operating strategy for the Ophthalmia Dam.

16.3. Change assessment – closure

16.3.1. Background

The numerical groundwater model was used to assess the hydrogeological changes that may result from the closure of the mining operations within the Strategic Proposal. It was assumed that after 2030, mining will stop and no further excess dewatering water will be discharged to Ophthalmia Dam. All groundwater abstraction will cease and groundwater levels around open pits will naturally recover. Ophthalmia Dam will remain in place and will continue to capture surface flows from the Fortescue River. It was also assumed that all pits will remain open and will not be backfilled. For Orebody 37, an alternative scenario was considered where Orebody 37 is partially backfilled to 5m above pre-mining groundwater levels.

16.3.2. Findings

Groundwater levels in the Ophthalmia aquifer are predicted to recover very rapidly (less than one year) following cessation of groundwater abstraction, after which time the groundwater levels will be sustained by the leakage from Ophthalmia Dam (RPS, 2014a). In contrast, the rate of groundwater level recovery around the open pits is predicted to be very slow. Groundwater conditions in the Ophthalmia aquifer will largely be unaffected by the groundwater conditions at the mined out orebodies (RPS, 2014a). Backfilling of Orebody 37 was assessed to make virtually no difference to the post-mining conditions of the Ophthalmia aquifer.

Consistent with the operational scenario, there is some uncertainty regarding the hydraulic connection between the tributary palaeochannels and the groundwater system supporting the Ethel Gorge stygobiont community TEC and further work is required to validate this finding..

The modelling suggests that groundwater levels in the Ophthalmia aquifer will recover within a couple of years after cessation of groundwater abstraction, which implies no significant impacts on the Ethel Gorge stygofauna community and riparian vegetation. The apparent hydraulic disconnection between the mine pits and the Ethel Gorge groundwater system suggests that the closure strategy of the open pits will have no significant effect on groundwater levels in the Ophthalmia aquifer. However, the degree of hydraulic disconnection will need to be validated.

16.4. Monitoring, review and corrective actions

BHP Billiton Iron Ore operates a groundwater and surface water monitoring program in the Ethel Gorge study area, and also monitors the health of the Ethel Gorge stygofauna community and riparian vegetation. Water monitoring observations are included in BHP Billiton Iron Ore's Annual Aquifer Reviews, and data on stygofauna and riparian vegetation monitoring are included in Annual Environmental Reviews.

BHP Billiton Iron Ore is in the process of modifying the monitoring and management strategy for the Ethel Gorge area to better align with the predicted changes caused by proposed future operations included in the SEA. It is proposed that the Ethel Gorge area will be divided into a number of management zones to better represent the hydrological conditions.

Based on the outcome of the technical studies, investigation triggers and mitigation triggers will be developed for these management zones. These will provide the basis for ongoing adaptive management of the Ethel Gorge ecological receptor. It is anticipated that the trigger values will be regularly reviewed and updated, as informed by ongoing monitoring and the outcomes of progressive technical studies addressing the hydrological regime and ecological responses to the regime.

Predictive modelling runs will be progressively validated and updated as more information becomes available from ongoing technical studies. Where predictive modelling findings indicate that defined trigger values could potentially be exceeded, appropriate mitigation measures will be identified.

Both preventative and corrective controls are currently in place to manage water levels and salinity concentrations. The preventative measures entail returning excess dewatering water back to the aquifer by means of discharge to the Ophthalmia Dam and recharge ponds. The corrective action controls comprise:

- Ophthalmia Dam with an infiltration capacity of about 30 to 80 ML/day and four overflow valves to allow controlled discharge to the infiltration basins and into Ethel Gorge;
- Two Infiltration basins with a combined infiltration capacity of about 60 ML/day;
- Four existing recharge ponds with a combined infiltration capacity of about 64 ML/day;
- Ophthalmia borefield with a capacity to pump 16 ML/d which can be used to mitigate elevated water levels and abstract higher salinity groundwater if required; and
- Options for storage and controlled release of water in the Ophthalmia dam to manage salinity concentrations in the Ophthalmia aquifer.

Further potential mitigation measures will be aligned with the feasible water options as outlined in the Water RMS. Where implemented, the effectiveness of mitigation measures will be evaluated and optimised using predictive modelling. This approach will ensure that residual risks to ecological receptors are minimised throughout the implementation of the Strategic Proposal.

Part VI – References

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