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Memo

To	Marc Morris	**Company**	BHP Billiton Nickel West Pty Ltd
From	Dan Huxtable / Duncan Storey	**Job No.**	175B
Date	12/03/2018	**Doc No.**	003a
Subject	Yakabindie Project - Risk Assessment of Riparian Vegetation Subject to Groundwater Drawdown		

1. INTRODUCTION

BHP Billiton Nickel West Pty Ltd (Nickel West) is proposing to mine the Mt Keith Satellite Deposits, located about 15 km south of the existing Mt Keith Mine on the Yakabindie Pastoral Lease. The project involves the development of two mine pits (Six Mile Well and Goliath), a waste rock landform, associated support infrastructure and a transport corridor to the existing mine.

The Six Mile Well and Goliath ore bodies include below-water-table (BWT) resource requiring dewatering prior to mining. The proposed mine pits are proximal to Jones Creek and groundwater drawdown is predicted to intersect a portion of the creek system. Jones Creek supports a riparian Eucalypt woodland community that is considered to have environmental and heritage significance.

AQ2 Pty Ltd (AQ2) and Equinox Environmental Pty Ltd (Equinox) were commissioned by Nickel West to complete an ecohydrological risk assessment of the potential impact of groundwater drawdown on the riparian vegetation of Jones Creek. This report describes the findings of the assessment.

2. SCOPE OF WORK

The scope of work for the ecohydrological risk assessment included the following items:

1. Review the environmental context of the subject area (climate, hydrogeology, hydrology, vegetation),
2. Review groundwater drawdown projections relating to the development of the Mt Keith Satellite Deposits,
3. Review scientific knowledge and operational experience relating to the effect of groundwater drawdown on vegetation, and
4. Based on the outcomes of (1), (2) and (3) evaluate the risk of groundwater drawdown associated with the proposal affecting the riparian vegetation of Jones Creek.

Each of these items are addressed as follows.

3. YAKABINDIE ENVIRONMENTAL CONTEXT

The Mt Keith Satellite Deposits are located in the north-eastern Goldfields of Western Australia, approximately 50 km NNW of Leinster, around 25 km south of the Mount Keith Mine, and 3 km east of the Goldfields Highway.

3.1 Climate

The climate is described as desert: hot (persistently dry) under the modified Köppen classification system (Stern et al. 2000). It is characterised by hot summers, with mean monthly temperatures typically exceeding 35^{0}C, and milder winters. The long term mean annual rainfall is about 220 mm, but since the 1990s this has increased to about 280 mm. Rainfall is highly variable within and between years; however, typically greater rainfall is received in the summer months associated with seasonal thunderstorms and occasional cyclonic events. Mean annual potential evaporation (ETo)[1] is approximately 1,800 mm with a pronounced seasonal pattern (i.e. summer ≈ 2 × winter). Monthly ETo almost invariably exceeds monthly rainfall. Monthly data for key climate parameters in the period 2000 to 2017 is shown in Figure 1; based on Data Drill gridded data at 0.05° resolution obtained from the SILO dataset[2].

As a consequence of the prevailing climate, vegetation in the locality regularly experiences drought conditions. Drought severity can be characterised by sequences of time that separate rainfall events of sufficient magnitude to replenish soil moisture (approximated as >25 mm events). In the subject area, the amount of time between such events is typically 1 – 2 years (Figure 2).

Terrestrial plants respond to drought in two broad ways (Ludlow 1989):

- Tolerance – physical and physiological adaptations that enable the plant to maintain key functions under dry soil conditions (e.g. increased stomatal resistance, leaf and wood anatomy that protects against hydraulic failure, leaf orientation to reduce exposure to solar irradiance etc). Many arid zone shrubs such as Acacia species exhibit these traits.
- Avoidance – subclassified as:
  - Ephemerality – where plants complete their reproductive life-cycle during favourable conditions. Persistence is enabled by seeds that remain dormant until favourable conditions return.
  - Perennial (typically long-lived species) restricted to habitats with more persistent moisture. This may include habitats with deeps soils that are capable of capturing and storing large volumes of plant available water, or areas with a shallow water table accessible to plant roots.

3.2 Physiography

Within a regional context, the subject area is located at the northern end of the Yilgarn Craton, comprising large areas of granitic lithology and relatively narrow, linear belts of greenstone. The Mt Keith Satellite Deposits occur in the Mount Keith–Perseverance greenstone belt, a NNW trending greenstone lineament of volcanic origin that extends for 150 km and is associated with undulating topography (Liu et al. 2014).

The proposed Six Mile Well and Goliath pits are located in greenstone hills within the Upper Jones Creek catchment. They are bisected by Jones Creek which drains to the SSW (Figure 3). The local area topography is undulating, with a vertical height difference of up to 100 m between the hills and surrounding plains. Jones Creek ultimately drains into a clay pan about 20 km further to the southwest (MWES 2016).

Soils of the upland areas have formed from in-situ weathering of the parent rocks (predominantly limonite or basalt). They are typically shallow or skeletal and medium textured (loam-clay loam) with a proportion of quartz and ironstone gravel. Soils of the lower slopes comprise gravelly red earths overlying weathered parent materials or hardpans[3], with a gravelly surface. These areas support open shrubland vegetation dominated by *Acacia* species (Western Botanical 2017).

[1] Calculated using the FAO Penman-Monteith formula as per Allen et al. 1998

[2] The SILO dataset is a comprehensive archive of Australian rainfall and climate data constructed from ground-based observational data (Jeffrey et al. 2001). Refer to (http://www.longpaddock.qld.gov.au/silo/).

[3] Regolith materials impregnated and cemented by iron oxides and hydroxides, and amorphous silica.

The Upper Jones Creek is a 5th order stream under the Strahler classification (Strahler 1952); which is fed by a series of small dendritic drainage networks emanating from the surrounding hills. These sub-catchments range in size from tens to hundreds of hectares. The major drainage line is a 5 to 15 m wide channel with well-defined banks, forming an incision into the surround plains with a longitudinal gradient of less than 0.5%. Runoff modelling reported by MWES (2016) indicates a flow frequency of 76 per 100 years, with flows occurring in roughly 50% of years. Flows are initiated by 20 – 30 mm rainfall events.

The bed of Jones Creek consists of coarse (sandy) sediments of variable depth overlying the weathered basement. Soil water in the alluvium is replenished by transient flow events. Although the depth of the alluvium has not been characterised, drilling logs suggest it is no more than a few meters deep (MWES 2017); which is consistent with the geological context of the area. This is further supported by observations of basement outcropping in the creek bed (Appendix 1).

The creek line vegetation includes scattered *Eucalyptus camaldulensis* var. *obtusa* trees, up to 12 m tall and with a projected foliar cover of 5 - 20% (Western Botanical 2017). Examination of aerial photography (Figure 4) indicates a mature tree density of about 30 - 80 trees/km of flow line, equating to about 10 - 30 mature trees/hectare. Localised patches of trees are likely to be associated with deeper alluvium and /or flow constrictions, for example in association with in-filled scour pockets. The creek bed is otherwise non-vegetated and probably subject to episodic scouring and bed load movement that prevents vegetation colonisation. The banks and narrow floodplain include a mid-story of shrubs including *Acacia burkittii*, *A. tetragonophylla*, *A. aptaneura* and *Pimelea microcephala* subsp. *microcephala*, over a patchy grass understorey dominated by *Themeda triandra*, *Cymbopogon ambiguous* and *Aristida contorta* (Western Botanical 2017).

3.3 Groundwater

The local area stratigraphy comprises a thin or non-existent veneer of soil overlying (MWES 2016):

- Oxide ferruginous – clay altered, local hard pan and nodular iron up to 10 m deep; over
- Oxide silica-carbonate – complete oxidation, serpentinite, irregular silicification and carbonate alteration. Tens of meters deep; over
- Supergene – partial oxidation towards top, serpentine bleached and porous.

The parent rocks have low permeability. Groundwater is relatively scarce and is associated with secondary porosity formed by structural features such as faults and associated fracturing/contact zones. There is no laterally continuous regolith horizon aquifer due to elevation, depth to water table and erosional denudation (MWES 2016). It can therefore be described as a compartmentalised, fractured rock type aquifer.

Proximal to the proposed mine pits, the water table depth is at least 12 m beneath Jones Creek; whilst outside of the creek bed the depth to the water table is typically > 25 m as dictated by topography (MWES 2016; 2017). Water salinity is typically in the range 3,000 – 8,000 mg/L.

4. GROUNDWATER DRAWDOWN PROJECTIONS

According to MWES (2016; 2018), groundwater levels will be maintained at the base of the pit throughout mining operations with dewatering resulting in a cone of drawdown around the pit. After mining is complete, water levels will then gradually rise to equilibrium levels. The Six Mile Well pit will be completely backfilled such that the long-term equilibrium water levels will return close to the baseline condition. The post-closure Goliath pit will remain a permanent void.

In the case of the Six Mile Well pit, it is anticipated that dewatering will be progressed over a 4-year period with a relatively uniform rate of drawdown over this period (MWES 2016; 2018). A numerical model was developed by MWES to evaluate the extent of drawdown during mining. The model was calibrated against water level change data generated from a 10-day pump test. Based on the modelling outputs, the maximum depth of drawdown beneath Jones Creek is estimated to be about 12 to 16 m below the baseline (pre-dewatering) condition, affecting about 1.0 km of the creek line southeast of the pit. The full extent of drawdown (defined by the 2 m drawdown contour) will be about 2 – 3 km (Figure 3).

In the case of the Goliath pit, MWES predicted that drawdown will be of very limited extent due to the absence of permeability (i.e. will not intersect Jones Creek). This prediction is based on knowledge of the local area geology rather than a numerical model.

These predictions appear to be reasonable based on the available hydrogeological information.

5. KNOWLEDGE REVIEW - THE EFFECT OF GROUNDWATER DRAWDOWN ON VEGETATION

5.1 Vegetation water sources

Plants release considerable amounts of water to the atmosphere through their leaves, in order to support atmospheric carbon dioxide uptake and carbon fixation via the process of photosynthesis. This water transfer process is referred to as transpiration. The availability of water to plant roots therefore has a major impact on plant photosynthesis, growth and health (Couvreur et al. 2014).

Soil water extraction by plants is a function of the soil volume accessible to roots and the gradient of water potentials in soil, roots, stems and leaves that drives water transport into the atmosphere. This is sometimes referred to as the ‘plant water use envelope’ (Sperry et al. 2002); which varies between species and for the same species under different growing conditions. Important parameters include the root system depth and lateral extent, water conductivity of soil and plant tissues, and the threshold matric potential above which soil water can be extracted by the plant. Species capable of accessing groundwater, either directly or from the capillary fringe, are referred to as phreatophytes (Thomas 2014).

The key species of interest in the Jones Creek vegetation community is *Eucalyptus camaldulensis.* commonly referred to as River Red Gum. It is Australia’s most widespread eucalypt species, occurring across the majority of the continent, but is generally confined to narrow riparian corridors and classifiable as a ‘drought avoider’. It is recognised as a water source opportunist, which can access shallow and deep soil water and also groundwater when available (Colloff 2014). A key adaptation is a dimorphic root system, consisting of expansive shallow lateral roots that may extend well beyond the projected canopy area and a large taproot capable of penetrating to considerable soil depth. It can withstand predawn leaf water potentials of -1.5 to -2.0 MPa (Braimbridge and Loomes 2013; Utsugi et al. 2009; Thorburn and Walker 1994); which allows it to extract water from relatively dry soil (i.e. well below field capacity).

5.2 Transpiration rates

Multiple studies across a broad range of tree species have demonstrated that trees of similar size transpire similar amounts of water under equivalent growing conditions; commonly referred to as the ‘theory of functional convergence’ (Zeppel 2013). The theory is particularly well supported for *Eucalyptus* species.

Data collated by Zeppel (2013) for *Eucalyptus camaldulensis* was used to develop a general relationship between stem size and daily water use for this species across a broad spectrum of growing conditions (Figure 5). This shows that trees with a diameter at breast height (DBH) of 30 – 40 cm can be expected to use in the range of 30 to 100 L/day.

5.3 Groundwater dependent vegetation

Groundwater dependent vegetation is defined as vegetation that is reliant on presence of groundwater within the rooting depth of the ecosystem (usually via the capillary fringe) (Eamus et al. 2006a;b). Groundwater may be accessed by phreatophytes continuously, seasonally or transiently. Notwithstanding, invariably only a fraction of total tree transpiration comes from groundwater. For reasons of energetic and ecologically efficiency, plants tend to preferentially use shallow soil water when it is available (David et al. 2016; O’Grady et al. 2011; Thomas 2014 and references therein). Given that vadose zone storage increases as depth to groundwater increases, in general terms the relative importance of groundwater diminishes with increasing depth to water table (Eamus et al. 2015; Zolfaghar et al. 2017). Unless the water table is very close to the surface and thereby constitutes the primary water source, maintaining access to groundwater typically becomes important for phreatophytes during prolonged dry phases.

In many situations, *Eucalyptus camaldulensis* is considered to be a facultative phreatophyte, meaning that groundwater is used when it is available but its absence does not cause the loss of this vegetation element from that site (O'Grady et al. 2006). Less commonly, *Eucalyptus camaldulensis* can develop an obligate dependence on groundwater if a permanent, shallow source is available and the trees develop a root architecture and stand density that is strongly configured to this source. In such situations, the tree density/stand basal area is typically much higher than the surrounding landscape. Based on consideration of stand level water use (i.e. where this exceeds rainfall inputs), and practical experience from ecosystems in the Pilbara and elsewhere in Western Australia, communities of *Eucalyptus camaldulensis* with potential obligate groundwater dependence typically occur in forest formations[4] with stand basal areas greater than 10 m^2/ha. Assuming a mean tree DBH of 35 cm, this equates to >100 trees per hectare.

6. RISK ASSESSMENT

6.1 Ecohydrological conceptual model

Based on the available information as reviewed in Section 3 to 5, a conceptual ecohydrological model for Jones Creek in the vicinity of the Mt Keith Satellite Deposits has been formulated. This incorporates a high-level water balance based on the major water inputs and outputs. A schematic depiction is shown in Figure 6.

Summarily, the conceptual ecohydrological model of Jones Creek comprises:

- A 5 – 15 m wide creek bed incised into the weathered basement materials. The plains adjacent to the channel comprise shallow colluvial soils overlying the basement materials.
- The creek bed alluvium consists of predominantly course grained sediments of variable depth (up to several meters). In places the basement is exposed in the creek bed and banks.
- Scattered *Eucalyptus camaldulensis* var. *obtusa* trees in the channel and on the banks. This species has laterally extensive root system and is able to access the full extent of the alluvium. Root depth is constrained by the basement.
- Xerophytic vegetation on the banks and surrounding plains is shallow rooted and drought tolerant.
- A fractured rock aquifer in weathered basement rocks underlying the creek bed. There is a significant vertical separation between the water table and the base of the creek bed alluvium (>10 m).

The high-level water balance is summarised as follows:

- Annual rainfall is typically in the range 150 – 350 mm/year. Given the low tree cover, rainfall interception and loss via canopy evaporation is considered to be negligible.
- Plant available water storage in the alluvium is estimated to be about 40 - 80 mm per meter of vertical alluvium depth (i.e. 4 – 8% v:v); based on the Saxton and Rawls (2006) soil water equations and conservatively assuming predominantly coarse grained sediments with a gravel content of about 50% (w:w). Assuming the alluvium is 1 – 2 m deep this equates to a total storage of 40 – 160 mm. Water storage in the alluvium is fully replenished by flow events, which occur roughly every 2 years on average.
- In addition to replenishment from flood events, there will partial replenishment more frequently resulting from that component of the rainfall during smaller events that is not lost to direct evaporation from the creek bed.
- The mature tree density of about 30 – 80 trees/ha. Assuming that mature trees use approximately 30 to 100 L/tree/day (Figure 5), corresponding with the typical tree size in the creek system, the annual tree transpiration flux is estimated to be about 20 -100 mm/year.

[4] Projected foliar cover >50%.

- Direct evaporation from the largely unvegetated creek bed. Published ecohydrological studies in arid/semi-arid environments that are broadly comparable to the subject area suggest that the ratio of transpiration to evapotranspiration[5] is likely to be in the order of 30 to 50% assuming the contribution of groundwater to total evapotranspiration is negligible (Parolari et al. 2015; Shanafield et al. 2015; Zhu et al. 2014; Wang et al. 2014; Gwenzi et al. 2013). This suggests that a plausible annual evaporation flux from the creek bed, derived from the bulk of incident rainfall that does replenish the deeper vadose zone, in Jones Creek is about 100 to 200 mm/year.
- There is minimal leakage of water from the transiently saturated alluvium into the underlying fractured rock aquifer. Based on commonly used estimates from similar arid environments (e.g. McFarlane et al. 2015), this is assumed to be 1 – 3% of mean annual rainfall (i.e. about 2 - 10 mm/year).

6.2 System response to groundwater drawdown

Consistent with the conceptual ecohydrological model, it appears that the *Eucalyptus camaldulensis* var. *obtusa* trees along Jones Creek are sustained by surface water inputs and do not interact with the groundwater system, by virtue of:

- The ability of *Eucalyptus camaldulensis* root systems to explore and occupy the full extent of the creek bed alluvium;
- Sufficient storage in the creek bed alluvium to sustain the modest density of mature, riparian trees in between flow events; and
- Physical separation between tree root systems and the water table by basement rocks (>10 m).

Groundwater drawdown associated with orebody dewatering at Six Mile Well and Goliath pits, regardless of the extent and duration, will not significantly impact mechanisms of water removal and replenishment in the creek bed alluvium that sustain the riparian woodland community. Accordingly, the risk of impacts to tree health caused by drawdown in the vicinity of the proposed mine pits is negligible.

7. CONCLUDING REMARKS

Information provided by Nickel West was suitable for the development of an ecohydrological conceptual model for Jones Creek in the upper catchment proximal to the propose Six Mile Well and Goliath pits. Based on this conceptual model, taking into account a high-level system water balance, the risk of impacts to tree health caused by drawdown in the vicinity of the proposed mine pits is negligible. It is considered that the *Eucalyptus camaldulensis* var. *obtusa* trees growing along the creek subsist on water stored in the unsaturated alluvium that is periodically replenished by creek flows.

In contrast with groundwater drawdown, mining related disturbances that effect the surface flow regime of Jones Creek (in particular by causing a significant reduction in the frequency and magnitude of flows) could potentially impact on tree water availability and tree health. To ensure the values of the Jones Creek riparian vegetation community are preserved, it is recommended that Nickel West adopts measures to ensure that the flow regime of the creek is maintained during the development of the Mt Keith Satellite Deposits.

[5] The sum of transpiration and direct evaporation from the land surface.

Regards,

Dan

Consulting Ecologist
Equinox

Duncan

Consulting Hydrogeologist
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Author: DH (11/03/18)
Checked: DGS (12/03/18)
Reviewed: DGS (12/03/18)

Attachments:
- Appendix 1: Photographs of Jones Creek

8. REFERENCES

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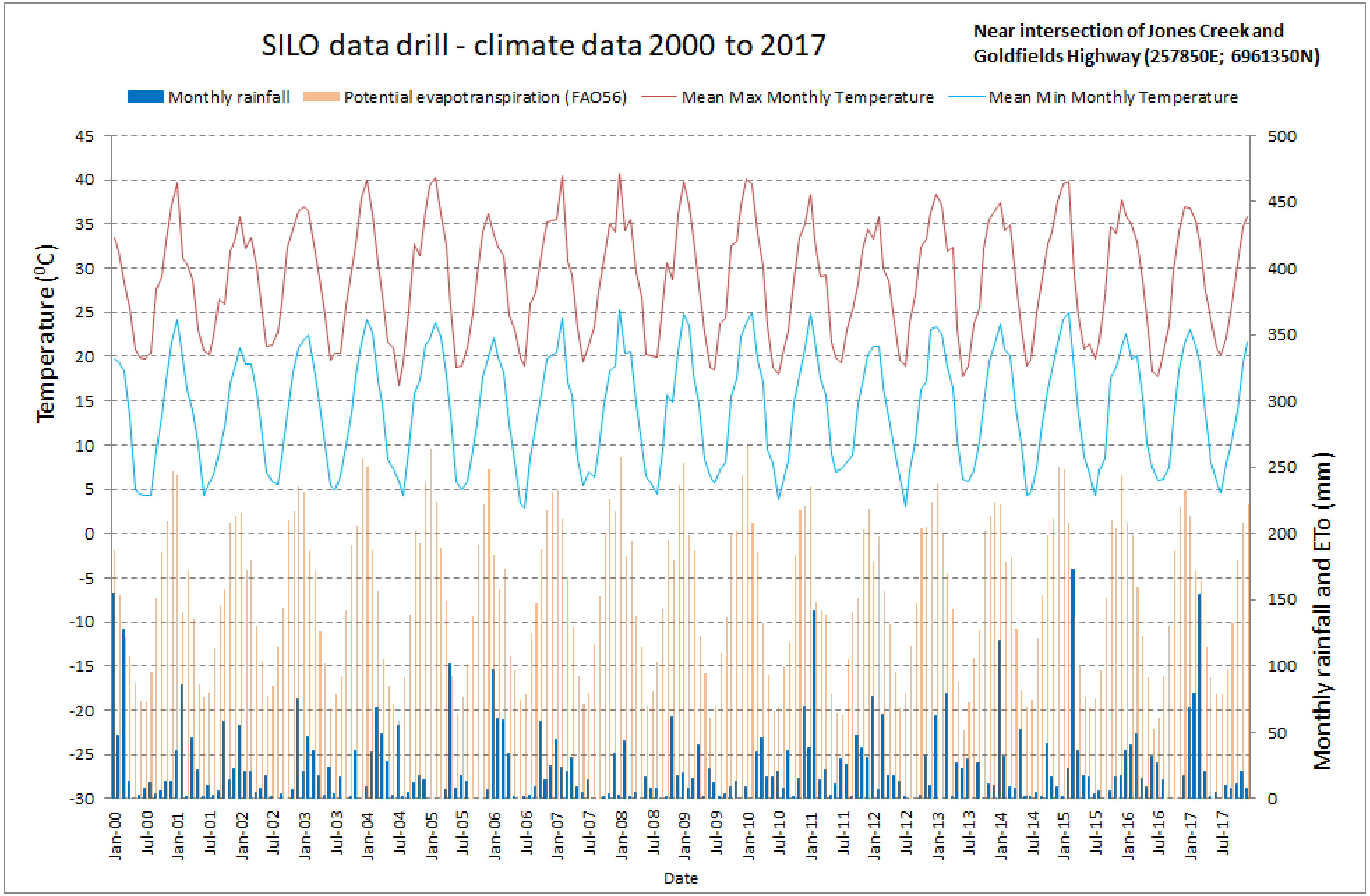


Figure 1 Key climate metrics for the Mt Keith Satellite Deposits area in the period 2000 to 2017

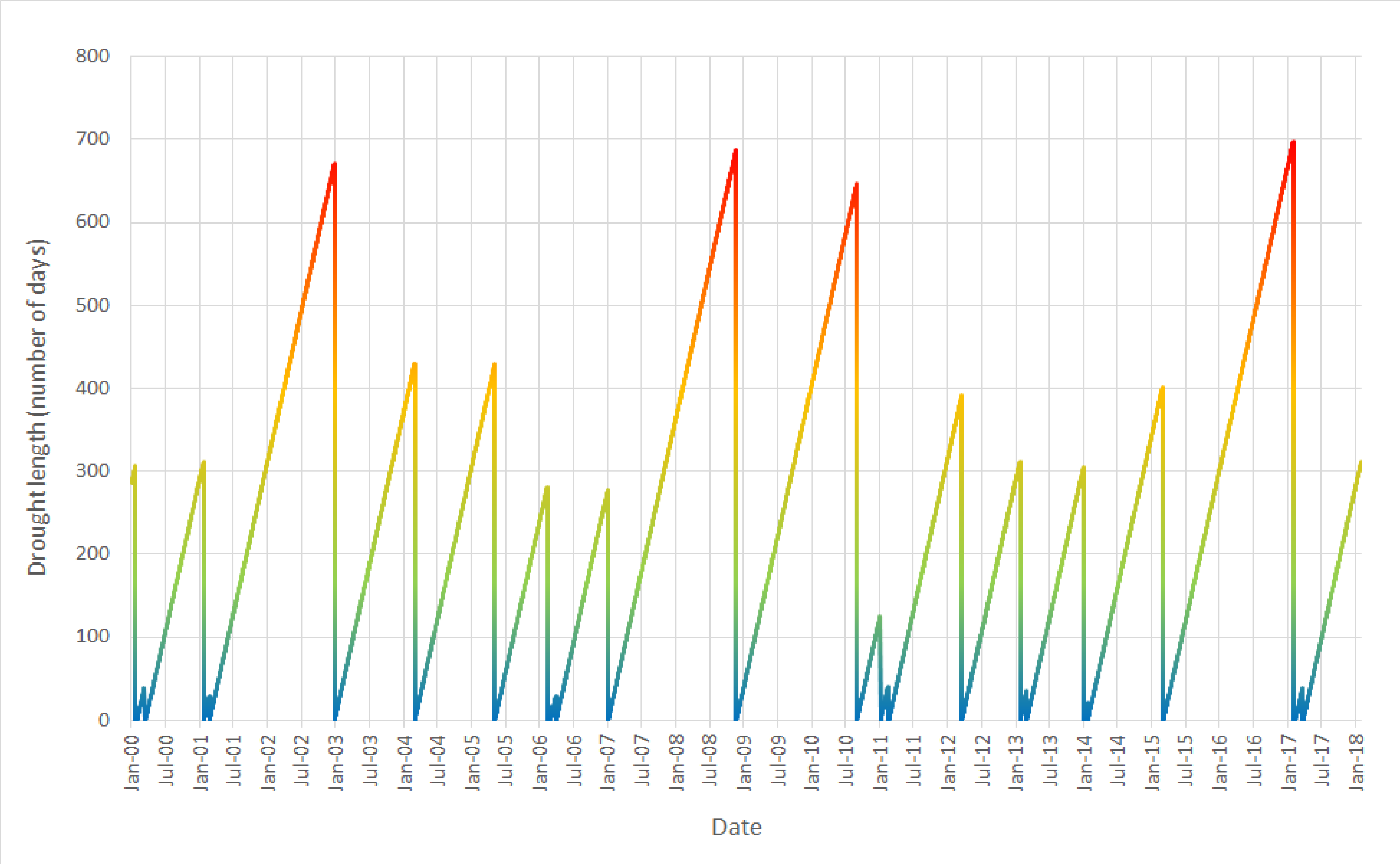
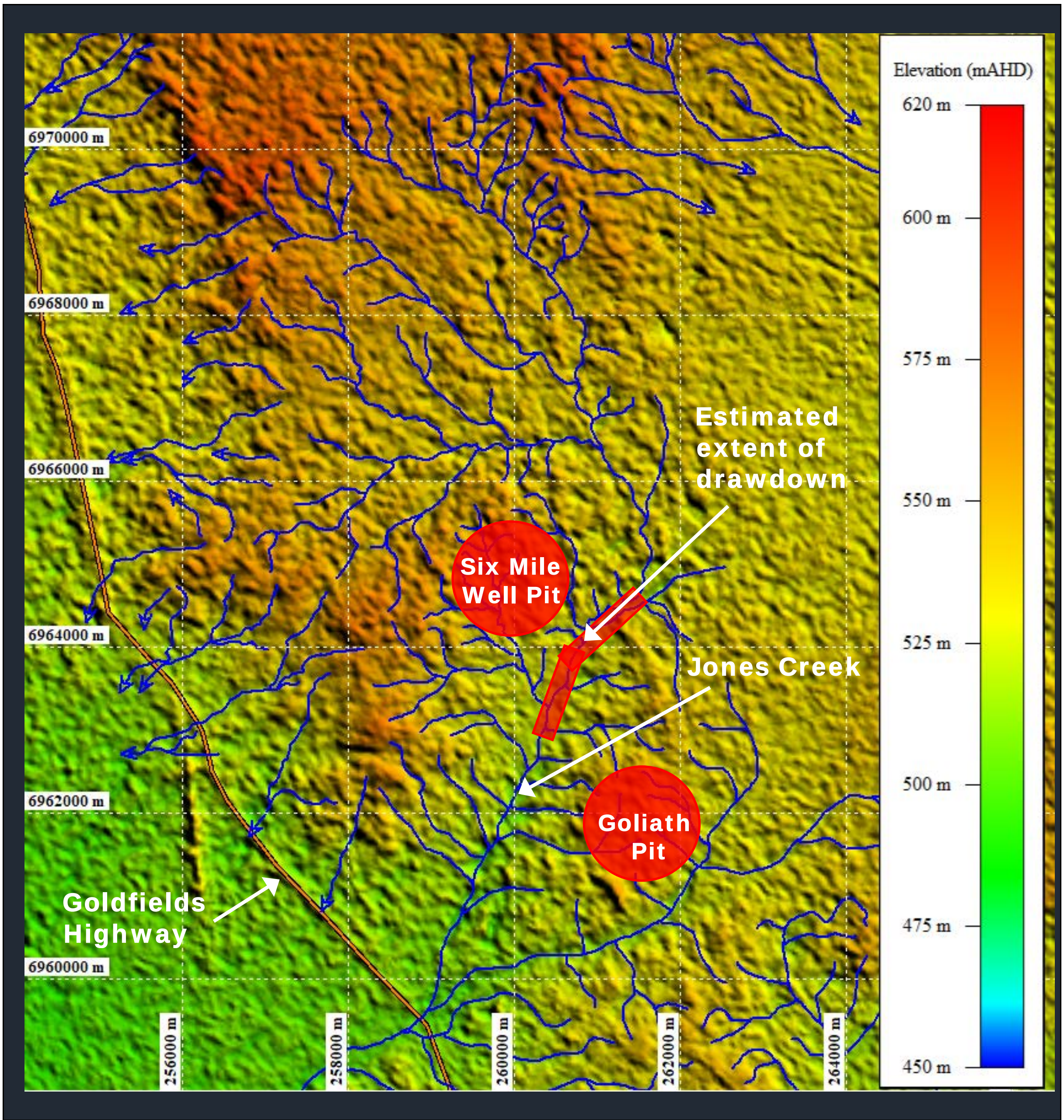
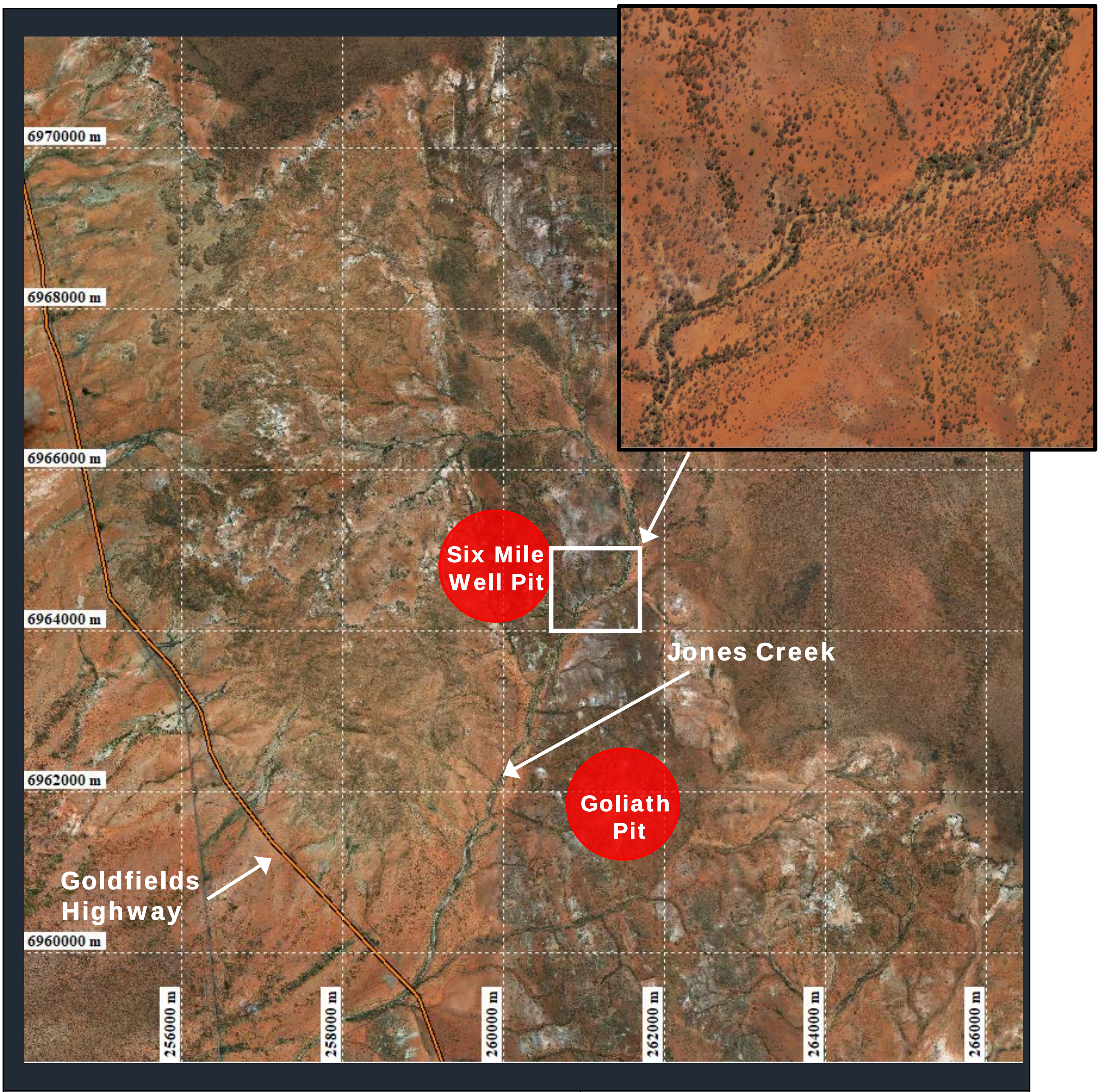


Figure 2 Mt Keith Satellite Deposits area – number of day since a significant (>25 mm) daily rainfall event in the period 2000 to 2017 Data sourced from SILO data drill (UTM Zone 51; 257850E 6961350N)



Data sources: Department of Water WA Hydrography Basemap: Global Mapper ASTER GDEM v2 Worldwide Elevation Data	Prepared by: D. Huxtable Date: 09/03/18 Coordinate System: GDA 1994 MGA Zone 51 Doc. Ref. A326f3

Figure 3 Mt Keith Satellite Deposits area – topography, drainage and the estimated extent of groundwater drawdown (>2 m below pre-dewatering baseline)



Data sources: Inset Landgate Orthomosaic (April 2011) Basemap: Global Mapper World Imagery	Prepared by: D. Huxtable Date: 09/03/18 Coordinate System: GDA 1994 MGA Zone 51 Doc. Ref. A326f4

Figure 4 Mt Keith Satellite Deposits area – aerial photography

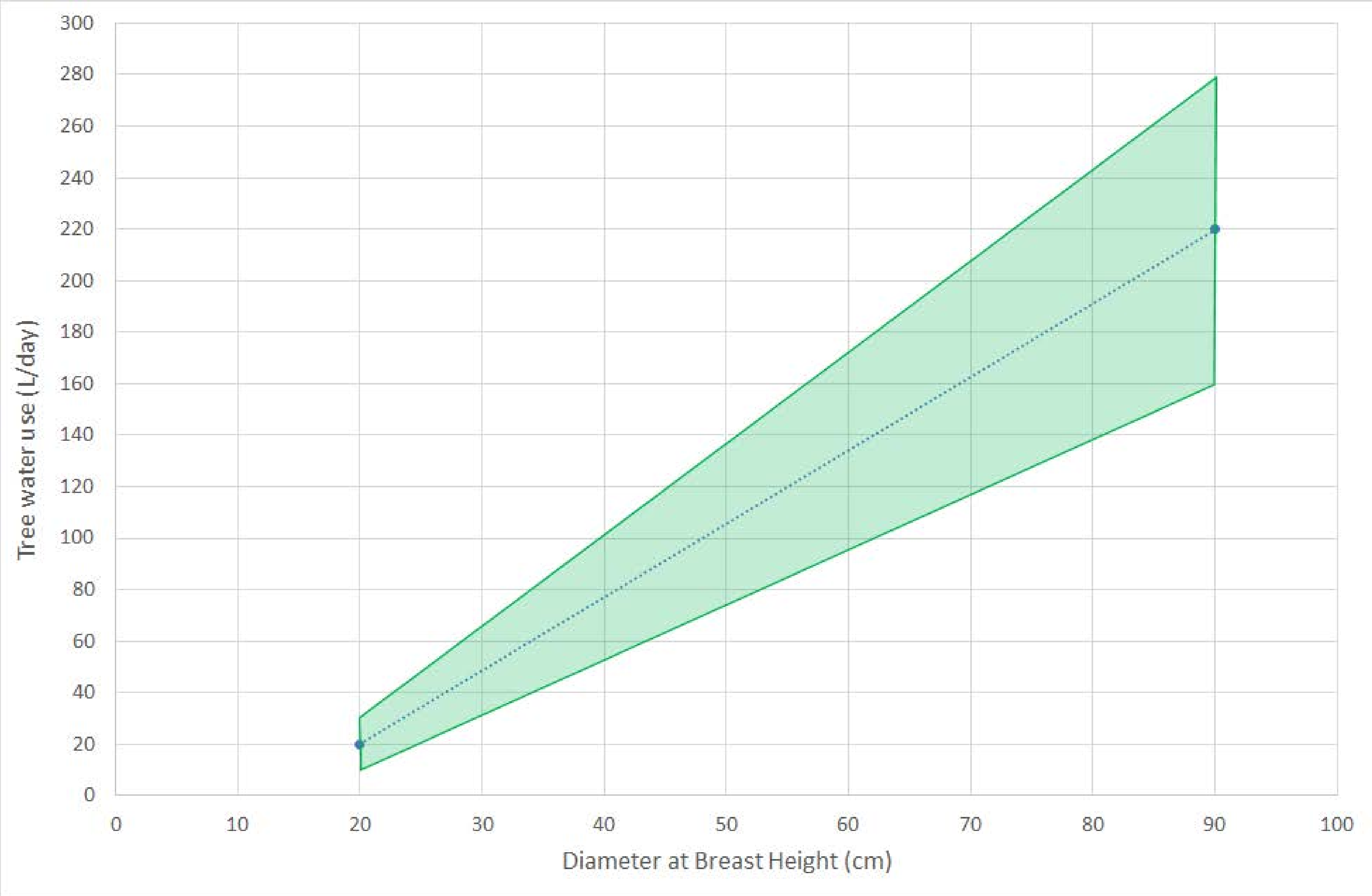


Figure 5 Relationship between *Eucalyptus camaldulensis* stem size and daily water use (derived from data presented in Zeppel 2013)

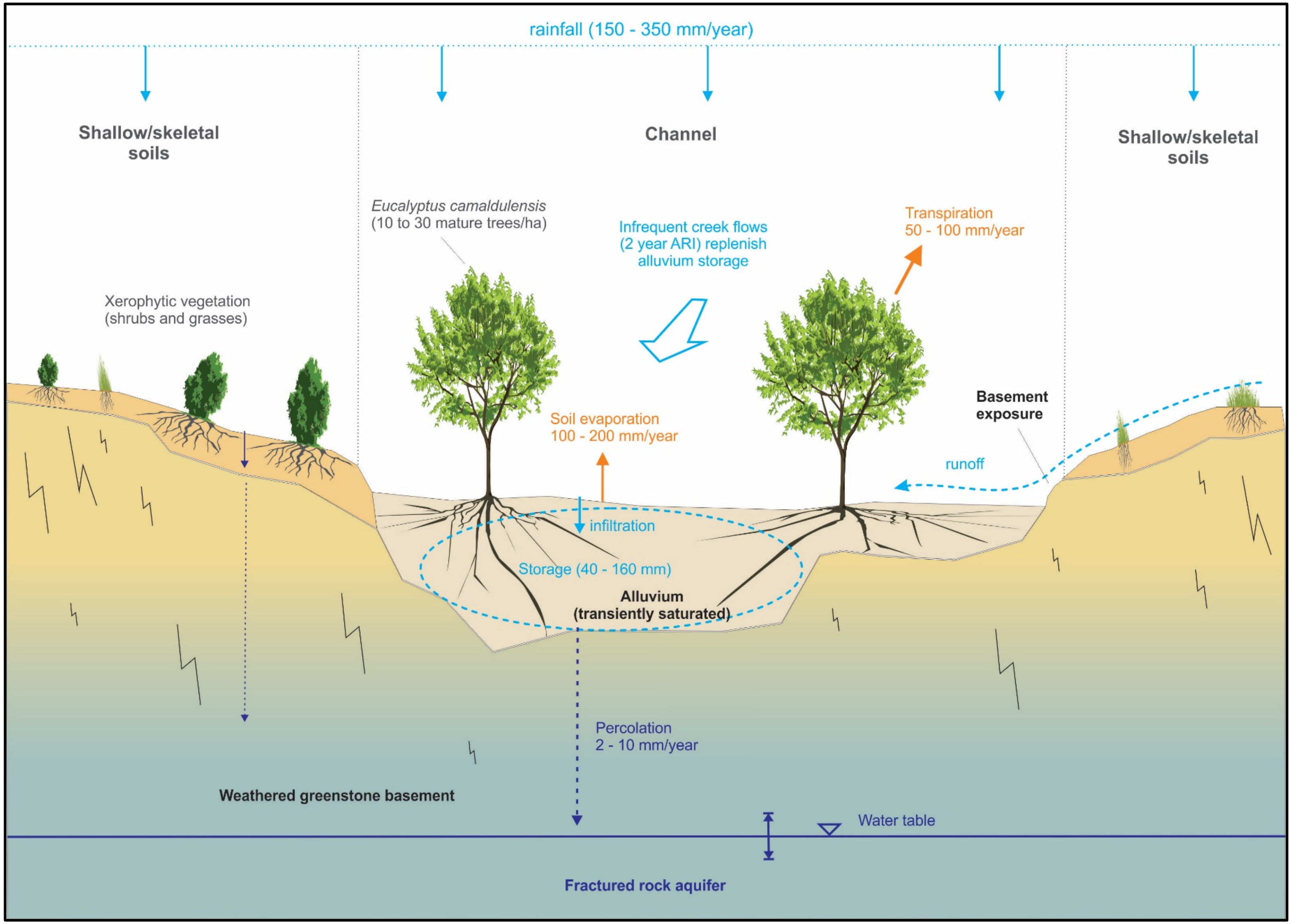


Figure 6 Mt Keith Satellite Deposits area – conceptual model of the ecohydrology of Jones Creek

APPENDIX 1

Photographs of Jones Creek

(provided by G. Cockerton, Western Botanical)

Examples of the Jones Creek channel and
***Eucalyptus camaldulensis* var. *obtusa* trees**

Saturation of the creek bed alluvium following a flow event

An example of basement exposure in the creek bank