Resource Development – Water Resource Evaluation

Surplus water discharge extent assessment – Warramboo BWT

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1. Issue

The Mesa A/Warramboo deposits are located in the Robe Valley area of the Pilbara region of Western Australia. The deposit is approximately 38 km northwest of the existing Mesa J operations, 43 km west of Pannawonica town and 245 km by rail from the Cape Lambert port facilities (Figure 1).

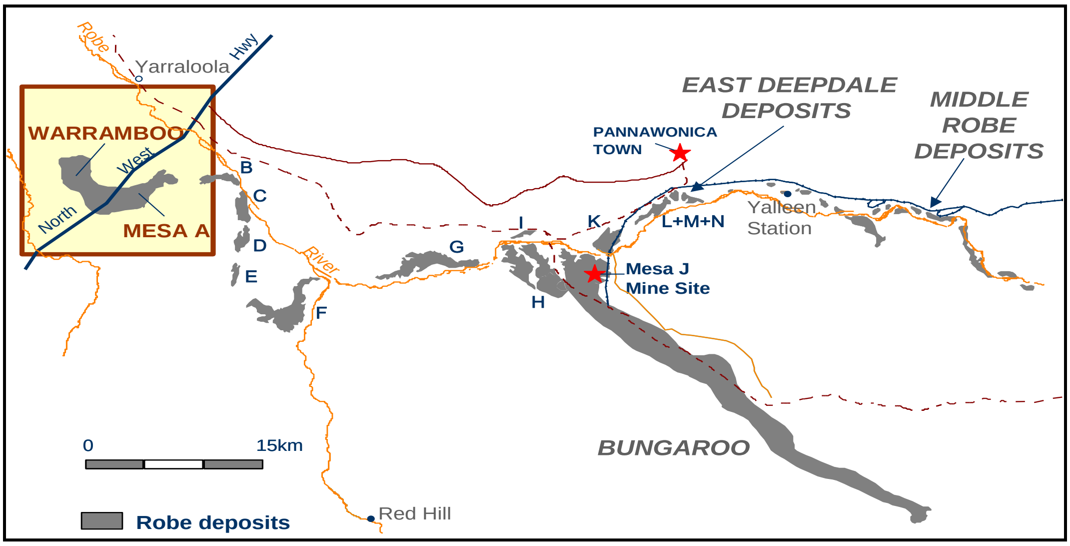

Figure 1: Location of Mesa A / Warramboo deposit

Management of water on Rio Tinto sites follows strict environmental and water use standards (refer to Rio Tinto Environmental Standards). These standards align with the "Pilbara Water in Mining Guideline" (DoW, 2009) which identifies options for use and/or release of dewatering discharge:

- Efficient on-site use, including mitigation of any impacts.
- Used for fit-for-purpose activities (such as processing and dust suppression). The proponent needs to demonstrate that the water is of suitable quality for the end use.
- Transferred to meet other demand including other proponents in the area and public water supply, as approved by the Department of Water. Where it is proposed to use the water for public supply, a drinking water source protection plan should be developed and approved by the Department of Water and the Department of Health.
- Injection back into the aquifer at designated sites determined by the proponent and agreed by the Department of Water.
- Controlled release to the environment where the dewater release is allowed to flow (either through a pipe or overland) into a designated water course or wetland and determined by the proponent and agreed by the Department of Water.

It is understood that the Warramboo deposit currently has environmental approvals in place to allow above water table mining activities under Ministerial Statement 756, as part of the Mesa A / Warramboo Iron Ore Project. The below water table (BWT) component is a new environmental factor and, therefore, normally requires a referral to the EPA under Section 38 of the *EP Act*. Section 38 referral may require additional environmental surveys of the discharge location and potential surface water discharge extent in order to assess environmental impacts.

2. Objectives

Management of surplus water at Warramboo BWT may include the controlled discharge of surplus water into the Warramboo Creek, southwest of the proposed operations (Figure 1). Therefore, the objective of this study was to estimate the extent of impact of surplus water discharge along the Warramboo Creek. The methodology to achieve this objective is outlined below:

- Develop a two-dimensional (2D) hydraulic model of the creek system downstream of the proposed discharge location.
- Determine the hydraulic characteristics that are not inherently accounted for by the 2D hydraulic model, i.e. saturated hydraulic conductivity of the soils.
- Estimate the maximum possible extent that surplus water discharge will flow under steady-state conditions.
- Investigate multiple steady-state scenarios, namely a continuous discharge rate of 5, 10, 15 and 20 ML/day.

3. Catchment characteristics

Regionally, the Warramboo deposit is located within the Onslow Coast River Region within the Pilbara-Gascoyne Topographic Drainage Division (Figure 2). The recommended surplus water discharge location is the Warramboo Creek between the old and new North West Coastal Highway. The main watercourse of this drainage system, from the hydraulically most remote point on the edge of the catchment to the proposed discharge location measures approximately 70 km in length with an equivalent uniform slope of 1.4 m/km, and drains a catchment approximately 685 km^2 in area. For the most part, the Warramboo Creek is well-defined (Figure 3) before discharging into the poorly defined scrubland in the coastal plain. It is likely that during large floods the poorly defined lower reaches of the Warramboo Creek in the coastal plain merge with the Robe River floodplain (Aquaterra, 2005).

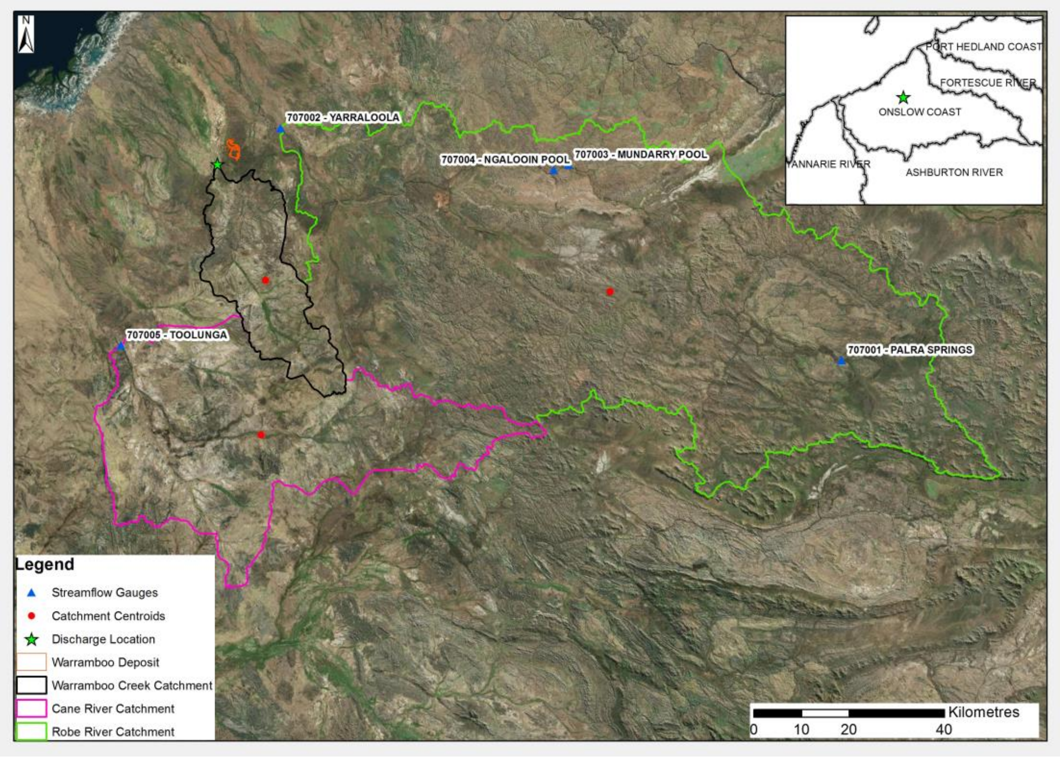

Figure 2: Catchment plan

4. Climate

According to the Köppen classification, the climate of the area is classified as hot (summer drought) grassland. Figure 4, based on gridded rainfall and evapotranspiration data from the Bureau of Meteorology, demonstrates strong seasonality in the regional climate with the area receiving approximately 60% of the 359 mm mean annual precipitation (MAP) between January and March, and 85% between January and June. The rainfall is typically associated with tropical low pressure systems and thunderstorm activity from the monsoonal trough that develops over northern Australia during summer and to lesser extent convective thunderstorms, from which extensive flooding is likely to occur.

The mean monthly distribution of potential evapotranspiration (Figure 4) indicates that the mean atmospheric demand exceeds the mean rainfall throughout the year. The ratio of annual rainfall to evapotranspiration, i.e. the Aridity Index, as defined by the United Nations Environmental Programme (1992), is 0.22, resulting in the area being classified as “semi-arid”, bordering on “arid”. Not only is the climate of the site water limited, it is also exposed to significant inter-annual variations in rainfall. The coefficient of variation of annual rainfall (CV) is 0.43 which when classified using the Bureau of Meteorology’s index of variability is rated as “moderate to high”.

Figure 3: Well-defined Warramboo Creek

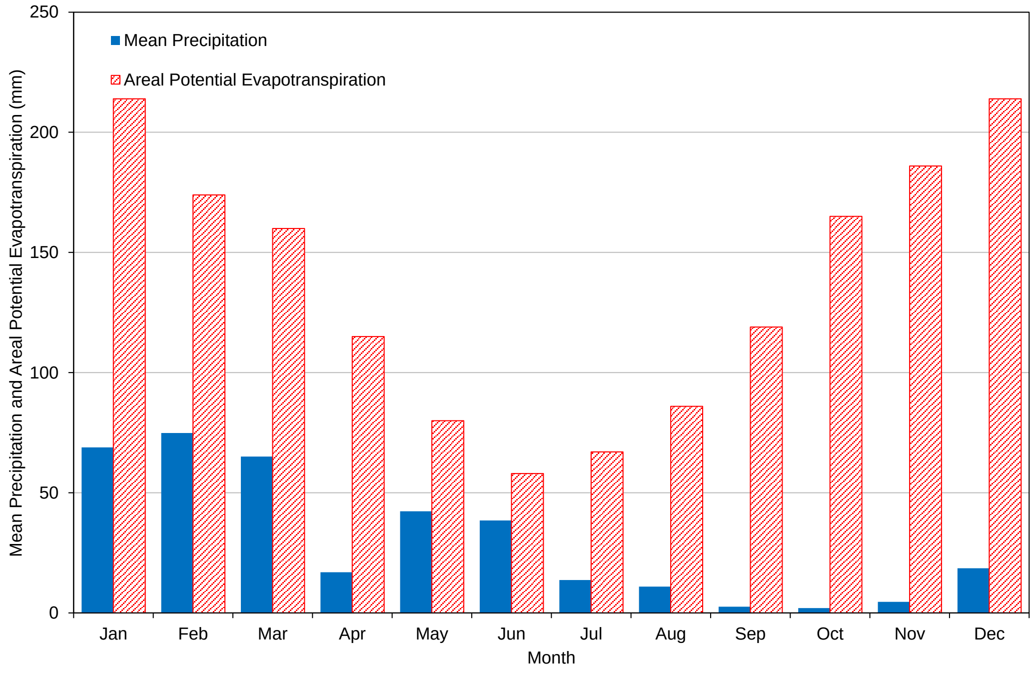

Figure 4: Average monthly climate statistics[1] for the Warramboo Creek catchment

5. Hydrology

Ruprecht and Ivanescu (2000) describe the hydrology of the Pilbara as being one of extremes, ranging from severe droughts to major floods. Streamflow in the Pilbara is mostly in direct response to rainfall, hence the similar seasonality and variability. In contrast to the south of the State, surface water runoff generation in the Pilbara region typically results from infiltration excess as opposed to saturation excess, which is typical in arid and semi-arid climates. Infiltration excess occurs when the rate of rainfall exceeds the infiltration capacity of the soil and is commonly associated with high intensity cyclonic and monsoonal rainfall and impervious catchments, whereas conditions satisfying saturation excess runoff generation occur during prolonged rainfalls influenced by cyclones and tropical depressions. With the low rainfall in the region and general lack of groundwater contribution to surface water flow, extended periods of low flow or even zero flow are common.

Typically, the paucity of streamflow gauges in the Pilbara region means that historical streamflow data are not available; as is the case for the Warramboo Creek catchment. Consequently, regional information is needed to describe the hydrologic regime. The nearest streamflow gauging station is Yarraloola (707002), located on the Robe River adjacent to the North West Coastal Highway (Figure 2). Despite having a respectable record (active since January 1972) the catchment area of 7100 km^2 is an order of magnitude greater than the Warramboo Creek catchment and is thus unlikely to adequately represent the hydrologic regime of the study area. The next closest streamflow gauging station is Toolunga (707005), located on Cane River (Figure 2). With a contributing catchment area of 2330 km^2 and catchment centroid located 32 km from the Warramboo Creek catchment centroid (less than half the distance when compared to that of the Robe River catchment – 72 km – cf. Figure 2), the Cane River catchment contributing to Toolunga is believed to be more representative of the Warramboo Creek catchment, both physiographically and climatically.

[1] Obtained for the centroid of the study area from gridded data provided by the Bureau of Meteorology for the standard climate period 1961-1990

The annual time series for the Toolunga streamflow gauge is presented in Figure 5. This time series demonstrates the high inter-annual variability of streamflow, where flow is typically in response to infiltration excess due to high intensity rainfall and as such exhibits a non-linear relationship between rainfall and runoff. Such complexities introduced by the natural hydrological regime are further demonstrated by the amplification of the inter-annual variability from rainfall to runoff, with a CV of annual runoff at Toolunga of 0.8. This indicates that streamflow is approximately two times more variable than rainfall in the catchment. Furthermore, the mean annual runoff of 84 GL equates to a mean runoff depth of 36 mm; approximately 10% of the mean annual precipitation.

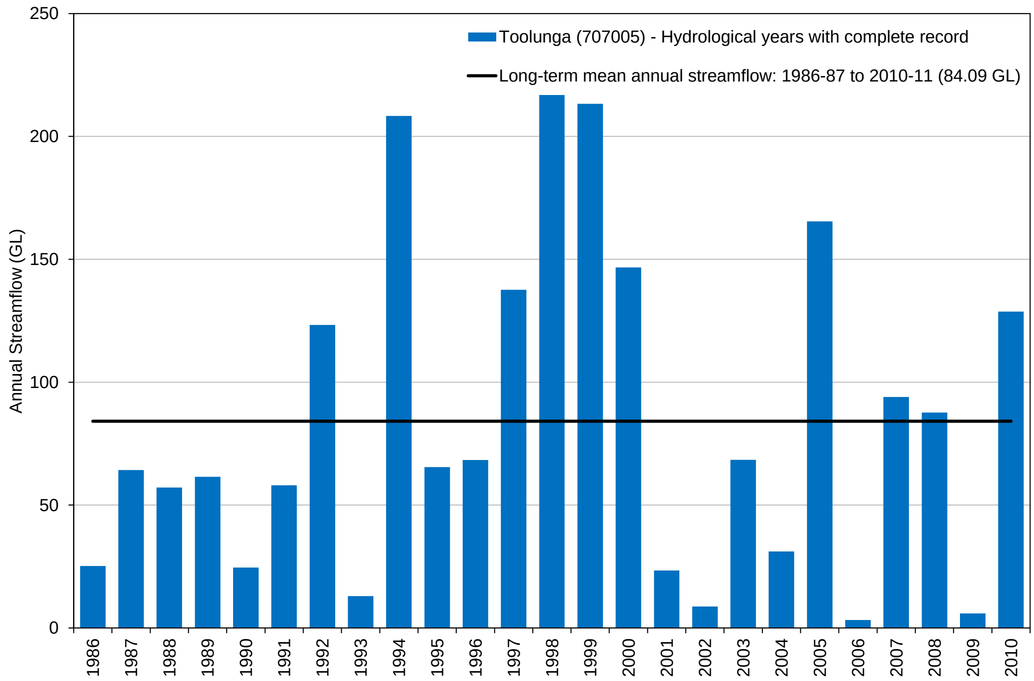

Figure 5: Annual streamflow recorded at Toolunga streamflow gauge (707005) on Cane River

The monthly streamflow distribution is presented in Figure 6, which demonstrate a monthly streamflow regime typical of the Pilbara. It is evident that the bulk of the streamflow occurs during the high rainfall months of January to March, with the highest streamflow generally occurring in February. High streamflow variability at the monthly scale is evident through comparisons of the monthly averages with their respective quartiles. Except for those months where the mean is zero, the mean flow is consistently closer to the 75th percentile than to the median. This highlights how mean monthly streamflow values in the Pilbara are often biased by infrequent, large events and suggests that monthly averages alone may not adequately describe the hydrological regime.

A further example of the non-linear relationship between rainfall and runoff is demonstrated through comparisons of the monthly rainfall and streamflow distributions. Despite the similar mean monthly rainfall totals, as well as number of rain days, for the months of January and February, the mean monthly flow for the Cane River in February is almost three times the January flow (cf. Figure 6 and Figure 7). Although the distribution of the number of larger rainfall events likely to result in infiltration excess (i.e. events greater than 10 mm and 25 mm) shows a better correlation with the streamflow distribution, the lower January flow appears to be the result of the six preceding drier months. This highlights the importance of antecedent catchment conditions with regards to runoff generation in the Pilbara, despite the region being regarded as being dominated by infiltration excess runoff mechanisms.

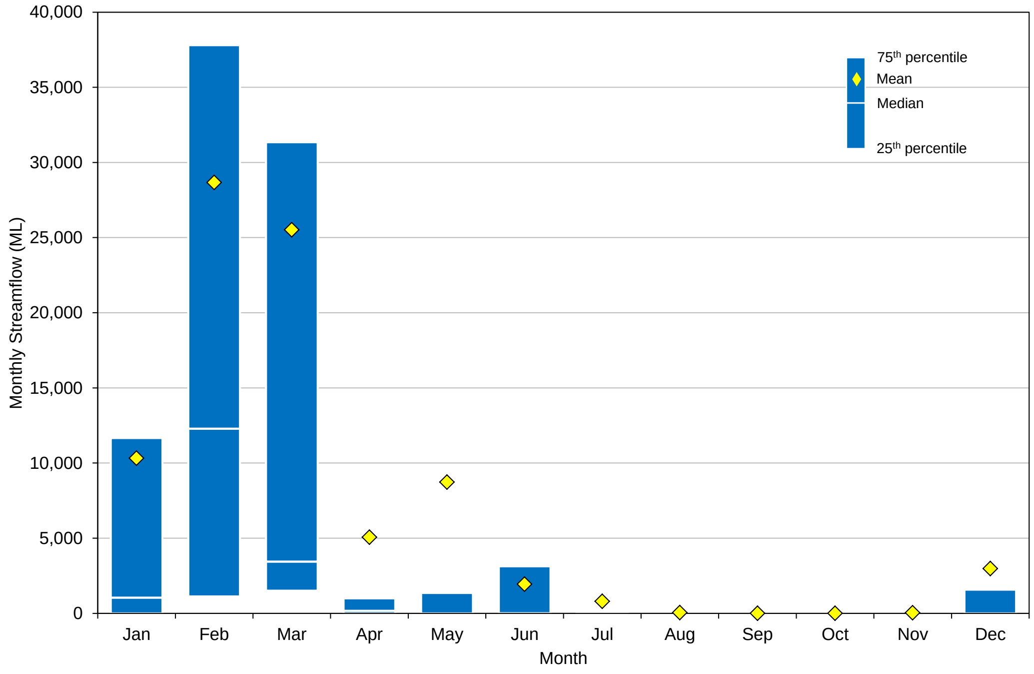

Figure 6: Monthly streamflow distribution at Toolunga streamflow gauge (707005) on Cane River

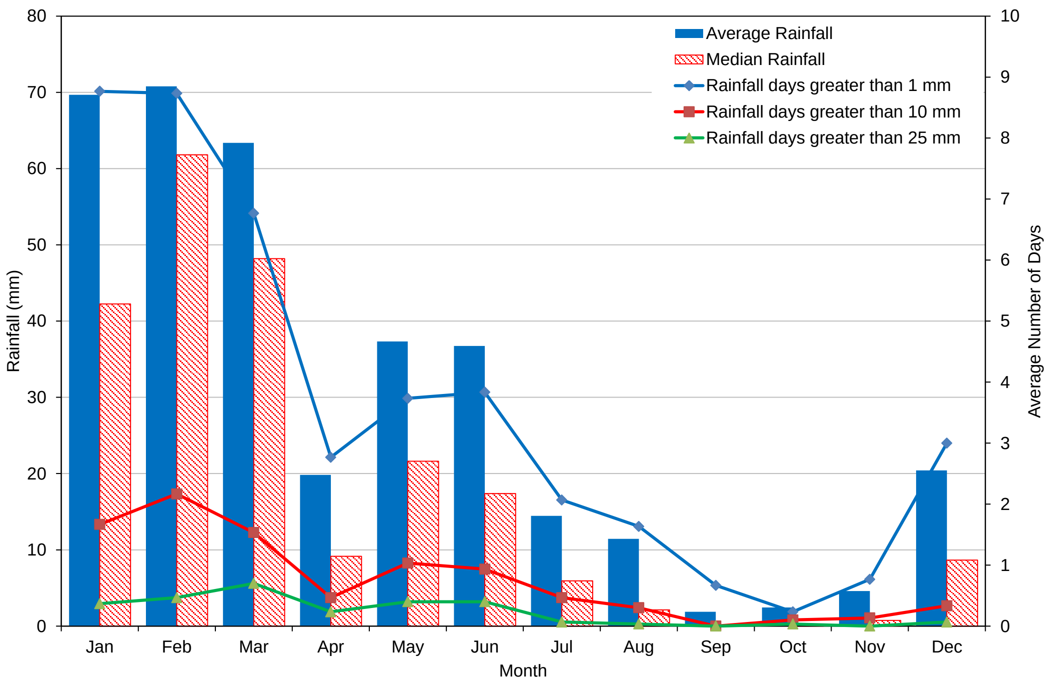

Figure 7: Average monthly rainfall statistics[2] for the Cane River catchment

Flow duration curves (FDC) were produced for the Toolunga streamflow gauge for each complete water year on record in order to further describe the hydrologic regime (Figure

[2] Obtained for the catchment centroid from gridded data provided by the Bureau of Meteorology for the standard climate period 1961-1990

8). The grey lines represent the FDCs for individual water years, while the thicker black line describes the flow regime for the entire length of record.

The ephemeral nature of the river is captured by the daily FDCs in Figure 8 where, on average, it is shown that the river is dry approximately 80% of the time. Furthermore, the inter-annual variability alluded to previously is demonstrated graphically by the spread of individual annual FDCs where the wettest year, in terms of sustained flows (not annual volume), on record at Toolunga was 1999, where flow was recorded nearly 70% of the time, while in the driest year flow was only recorded 5% of the time.

Perhaps unsurprisingly, the water years that had flow recorded for the most number of days of the year were also the two water years that recorded the highest annual totals (Figure 5 and Figure 8). However, the third wettest year in terms of sustained flows (2000 - Figure 8) saw the creek flowing for nearly twice as many days as the third wettest year by volume (1994 – highlighted in red in Figure 8 for clarity), despite the 1994 annual flow being approximately 40% greater than that in 2000 (Figure 5). This again highlights the importance of antecedent catchment conditions as 1994 followed the third driest year on record, whereas 2000 followed the two wettest years (Figure 5).

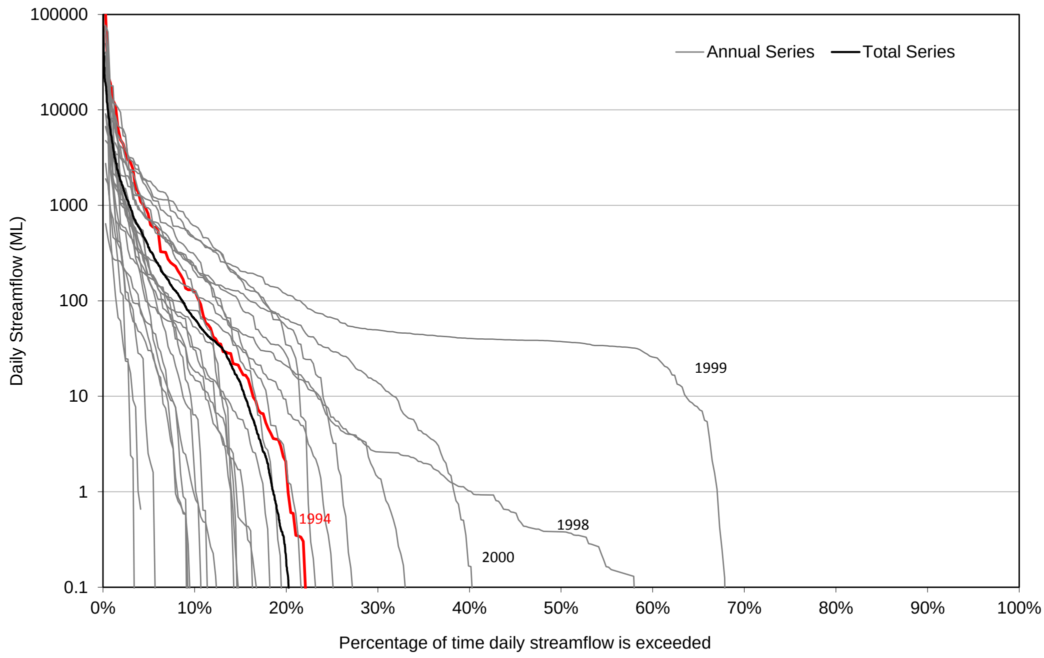

Figure 8: Flow duration curves at Toolunga streamflow gauge (707005) on Cane River

6. Hydrogeology

The groundwater at Warramboo is stored within an unconfined aquifer that comprises the Robe Pisolite and the Yarraloola Conglomerate (RTIO, 2013b). The aquifer is particularly transmissive where the conglomerate underlies the pisolite within the Robe Valley palaeochannel.

The water table in the area of Warramboo is between 12 and 30 metres below ground level. Recharge to the main aquifers is predominantly via direct infiltration from rainfall and indirectly during periods of high streamflow. Groundwater flow is inferred to be east to west with a gradient of 0.01 m/m and discharges via outflow to the ocean approximately 60 km down gradient (RTIO, 2013a).

There are no known groundwater dependent ecosystems in the immediate area of Warramboo (RTIO, 2013a).

7. Modelling approach

Water flowing in a watercourse is removed from the surface via two mechanisms, namely: evaporation and infiltration. However, these hydrologic processes are inextricably intertwined with the flow characteristics, and hence the hydraulics, of the river system. The braided nature of typical Pilbara watercourses creates a complex hydrodynamic environment where the flow behaviour is essentially 2D in nature, which may be poorly represented using a 1D model.

Recent developments to the **T**wo-dimensional **U**nsteady **Flow** (TUFLOW) model have effectively transformed TUFLOW into a 2D coupled hydrologic-hydraulic modelling system, with the ability to model soil infiltration in both unsaturated and saturated conditions. This makes the TUFLOW model a useful tool for surplus water discharge extent estimation.

This section documents the process and assumptions made in developing the 2D hydraulic model for the Warramboo Creek.

7.1 TUFLOW hydraulic model

For this study, TUFLOW's GPU Module was adopted. This is a powerful new solver built into the TUFLOW software, which utilises the substantial parallel computing ability of modern Graphics Processor Units, or GPUs (TUFLOW, 2014). TUFLOW GPU is an explicit solver for the full 2D Shallow Water Equations, including a sub-grid scale eddy viscosity model. The scheme is both volume and momentum conserving. Owing to the power of modern GPUs very large models (>100 million cells) with fine grids can now be run within a sensible timeframe (TUFLOW, 2014). This allowed for a high resolution 1 m DEM, derived from surveyed spot heights and breaklines, to be used to describe the topography of the creek system. The model configuration is shown in Figure 9.

7.2 Surface roughness

Surface roughness is defined using Manning's roughness coefficient – 'n'. The roughness coefficient adopted for the Warramboo Creek was determined according to Chow (1959), which takes into consideration channel irregularities, variation in cross section, obstructions, vegetation density and meandering of the reach. These factors were assessed using aerial photography and confirmed during a site visit. The adopted Manning's 'n' roughness coefficient for the Warramboo Creek was 0.045, which describes a clean, winding channel with pools and shoals, as well as weeds and stones. This value was applied to all active cells in the model, which was limited to the creek channel, as can been seen in Figure 9.

7.3 Model inflows

Multiple steady-state scenarios were assessed, namely a continuous discharge of 5, 10, 15 and 20 ML/day.

7.4 Model outflows

The maximum discharge extent is achieved when equilibrium is reached between the inflows to and the outflows from the system. Water flowing in a watercourse is removed from the surface through evaporation and/or infiltration.

7.4.1 Evaporation

Annual and monthly potential evaporation rates (Class A pan) are available from the Bureau of Meteorology (BoM) website. However, evaporation from open water bodies can be significantly less than A-pan estimates owing to a variety of climatic factors. As such, correction factors are often required to relate A-pan evaporation to evaporation from open water bodies. From Figure 10 it can be seen that evaporation from open water bodies for most of the Pilbara region of Western Australia is between 60-70% of the A-pan evaporation rates.

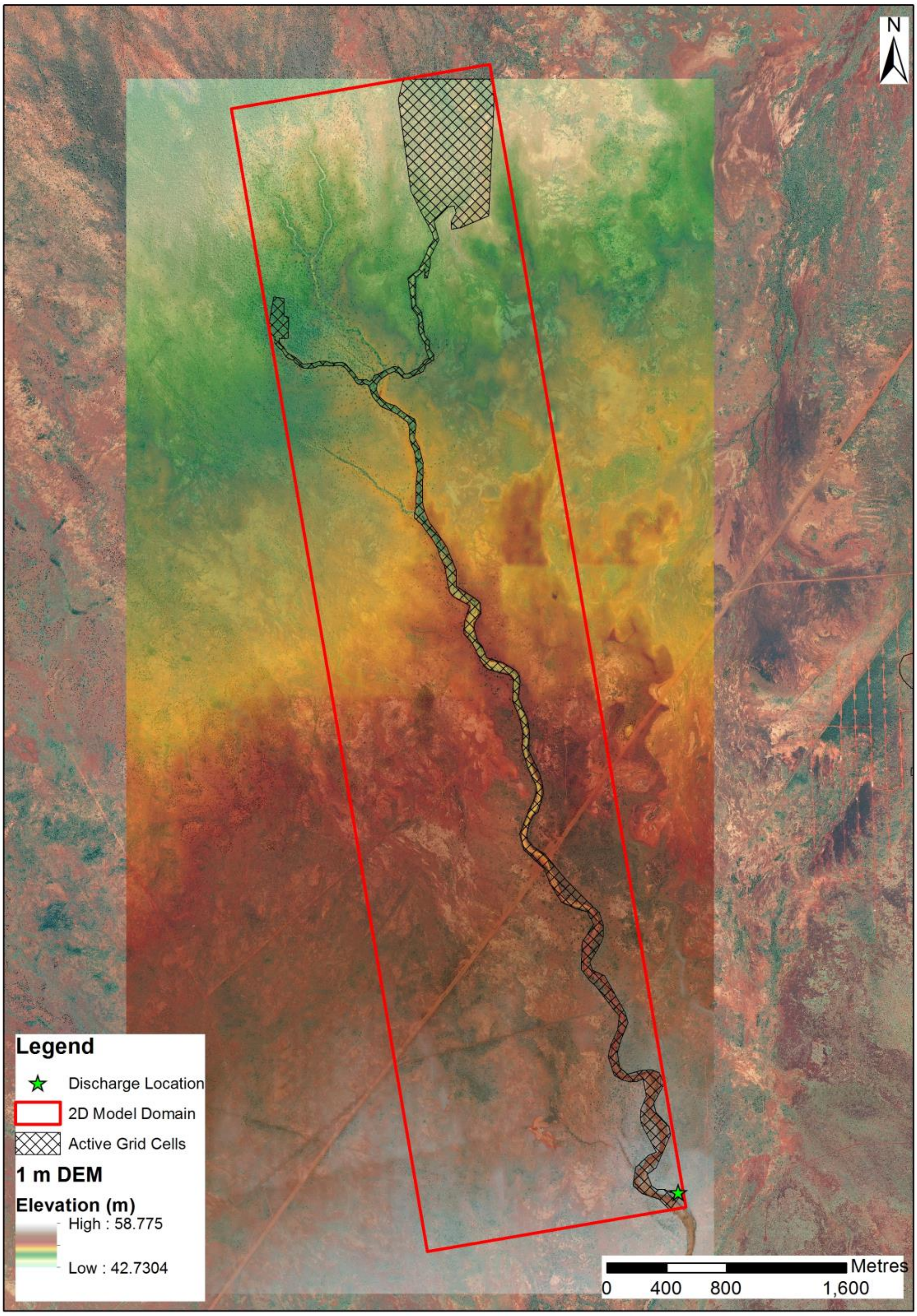

Figure 9: TUFLOW model configuration

From Figure 10, the A-pan evaporation rate for the Warramboo Creek downstream of the discharge location was determined to be 3340 mm per year. According to Luke et al. (1987) evaporation from open water bodies for the Warramboo Creek is between 65-70% of the A-pan evaporation rate. Conservatively, an A-pan correction factor of 0.65 has been adopted. The adopted evaporation rate was, therefore, 2171 mm per year, which translates to an average rate of 0.25 mm/h.

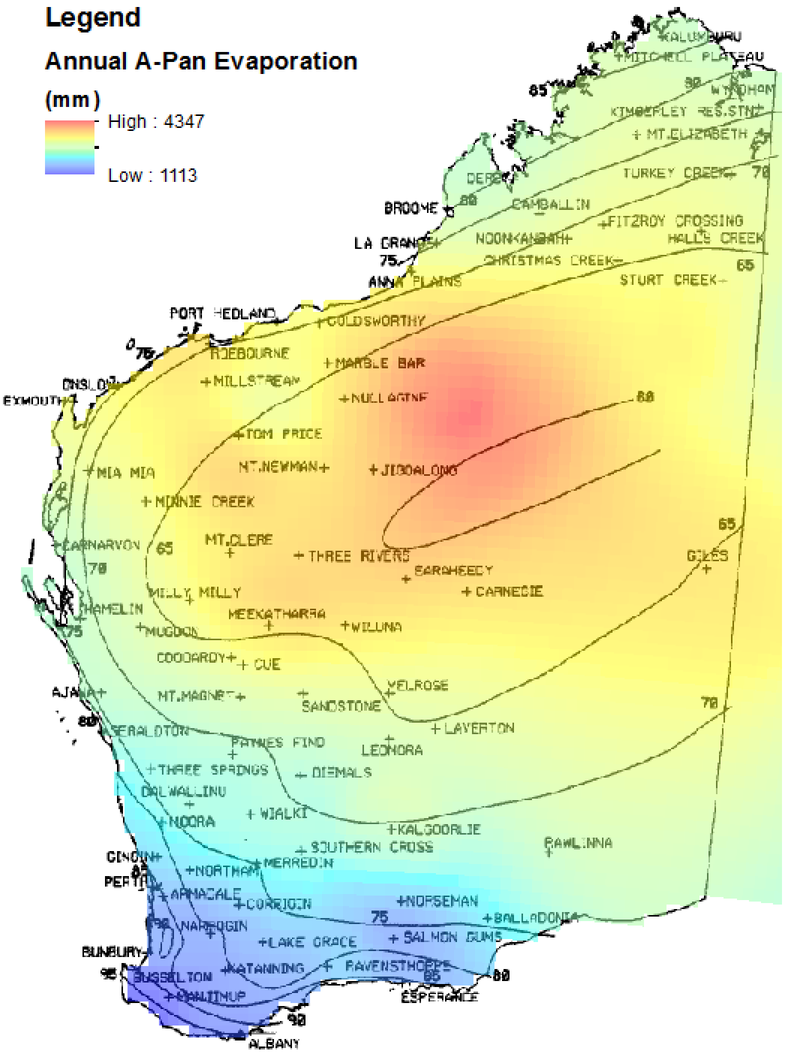

Figure 10: Gridded annual A-pan evaporation and A-pan correction factors (contours) for Western Australia (from BoM and Luke et al., 1987)

7.4.2 Infiltration

The maximum discharge extent is achieved when equilibrium is reached between the inflows to and the outflows from the system. As the soil moisture content increases so the infiltration rate of the soil decreases until the saturated hydraulic conductivity (K_{sat}) of the soil is reached. Consequently, equilibrium between the inflows and outflows, and hence the maximum discharge extent, can only be achieved once the soils have reached saturation. As such, when the aim of the discharge extent modelling is to determine the maximum discharge extent for long-term discharge there is no need to simulate losses in unsaturated conditions, and a continuing loss rate equal to K_{sat} may be adopted.

Although the Soil Hydrological Properties for Australia – SHPA – (Western and McKenzie, 2006) provides K_{sat} values for the whole of Australia, experience has shown that these values can be up to three orders of magnitude too high (*cf.* discussion on soil water holding capacity in SKM, 2013), thereby overestimating losses from the system and drastically underestimating the maximum discharge extent. As a result, a texture-based approach to estimate K_{sat} in the absence of measured data has been applied. This approach derives a weighted clay content for each Map Unit in the Atlas of Australian Soils (Northcote et al., 1960-1968), which places the Map Unit into one of six Texture Groups documented by McKenzie et al. (2000), shown in Table 1.

Table 1: Texture groups according to clay content - adapted from McKenzie et al. (2000)

Weighted Clay Content (%)	**Texture Group**	**Texture Grade**
0 – 8	Sands	Sand Clayey Sand Loamy Sand
8 – 17.5	Sandy Loams	Sandy Loam Fine Sandy Loam Light Sandy Loam
17.5 – 25	Loams	Loam Loam, Fine Sandy Silt Loam Sandy Clay Loam
25 – 35	Clay Loams	Clay Loam Silty Clay Loam Fine Sandy Clay Loam
35 – 47.5	Light Clays	Sandy Clay Silty Clay Light Clay Light Medium Clay
47.5 – 100	Clays	Medium Clay Heavy Clay

The least permeable texture grade is adopted as the representative texture for each Texture Group, and is therefore considered to be a conservative estimate of K_{sat}. The adopted K_{sat} values for each Texture Group are presented in Table 2.

A site visit was conducted on 20/21 August 2014 to assess soil conditions within the Warramboo Creek. Investigations suggest that the alluvial material at the surface ranged from fine sands to coarse gravels (Figure 11). The Atlas of Australian Soils (Northcote et al., 1960-1968) shows that Warramboo Creek downstream of the discharge location crosses two different soil Map Units, namely, My53 and Oc72. Using the approach outlined above the *Texture Group* and K_{sat} for each Map Unit was derived, and is presented in Table 3

Figure 11: Fine sandy (left) and course gravelly (right) textures of alluvial material in Warramboo Creek

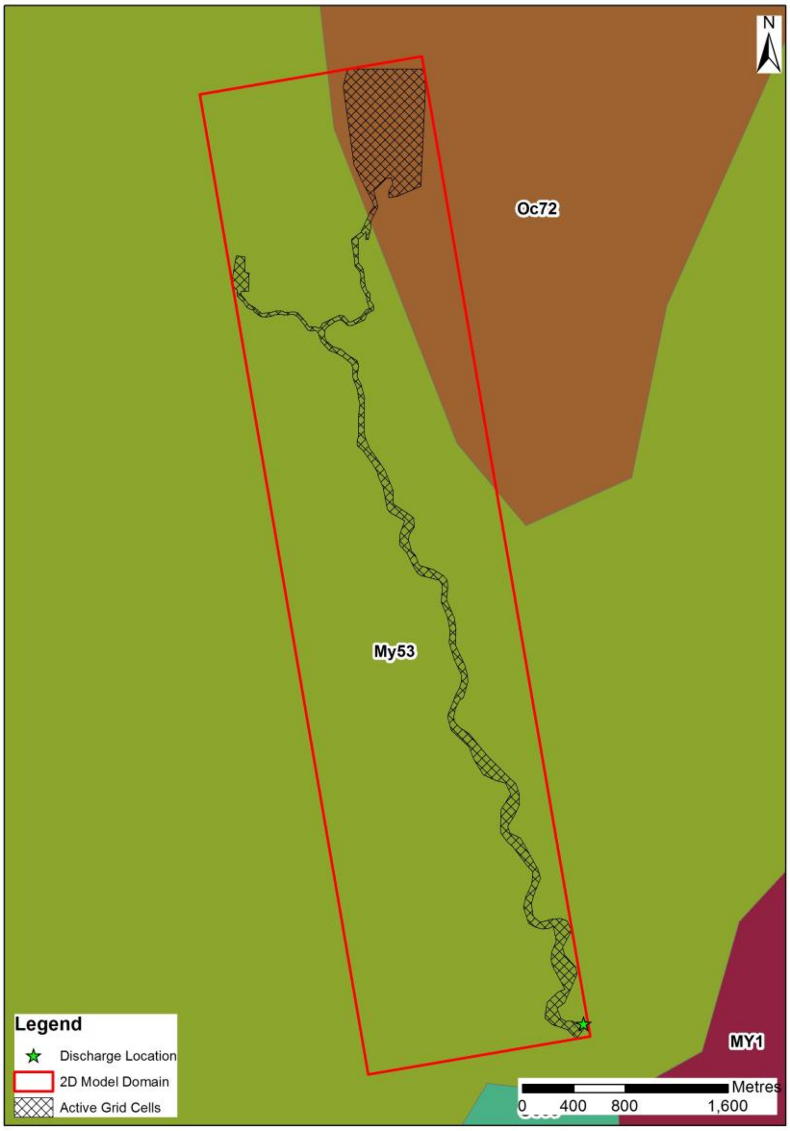

Figure 12: Soil Map Units intersected by the Warramboo Creek downstream of the proposed surplus water discharge location

Table 2: Saturated hydraulic conductivities for different texture groups – adapted from Clapp and Hornberger (1978), Cosby et al. (1984) and van Gool et al., (2005)

Texture Group	**Adopted K_{sat} (mm/h)**
Sands	50.6
Sandy Loams	18.8
Loams	10.1
Clay Loams	6.1
Light Clays	3.7
Clays	3.0

Table 3: Soil Map Units in study area and adopted saturated hydraulic conductivities

Soil Map Unit	**Weighted Clay Content of Limiting Soil Horizon (%)**	**Texture Group**	**Adopted K_{sat} (mm/h)**	**Median K_{sat} from Soil Hydrological Properties for Australia (mm/h)**
My53	34.5	Clay Loams	6.1	100
Oc72	46.8	Light Clays	3.7	10

Soil map unit My53, which covers most of the modelled area, is described by Northcote et al. (1960-1968) as "Extensive plains dominated by neutral red earths (Gn2. 12) with areas of acid and alkaline red earths (Gn2. 11, Gn2.13). There is frequently a cover of surface gravels. There are minor areas of (KS-Gn2.11) soils adjacent to Robe River iron deposits and some hard red soils (Dr2.32) along creek lines". This corresponds with what was observed on site (*cf*. Figure 3 and Figure 11).

It is evident from Table 3 that the adopted infiltration rates for the discharge extent modelling are considerably lower than those suggested in the Soil Hydrological Properties for Australia (Western and McKenzie, 2006). It is believed that the adopted values for K_{sat} presented in Table 3 are more reflective of the creek conditions.

8. Results

Results for the various discharge modelling scenarios are presented in Table 4 and Figure 13. It is estimated that the surplus water discharge extent will range from 2.2 km to

7.6 km down gradient of the proposed discharge location, depending on the discharge rate, before completely infiltrating/evaporating.

Table 4: Estimated discharge extent from discharge location for various discharge rates

Scenario	Maximum Velocity (m/s)	Maximum Distance Travelled (km)
5 ML/d	0.4	2.2
10 ML/d	0.5	4.4
15 ML/d	0.6	6.0
20 ML/d	0.7	7.6

The surplus water discharge volume would be significantly smaller than the volume generated by the catchment during flood events. Based on model results, discharged water would be contained within the low flow channel/s, hence overtopping of the creek banks in dry conditions is not anticipated. As a result, local ecological cycles triggered by flood events would be unlikely to be activated or impacted. Furthermore, maximum surface water velocities from modelled discharge rates are less than 1 m/s and unlikely to result in channel erosion.

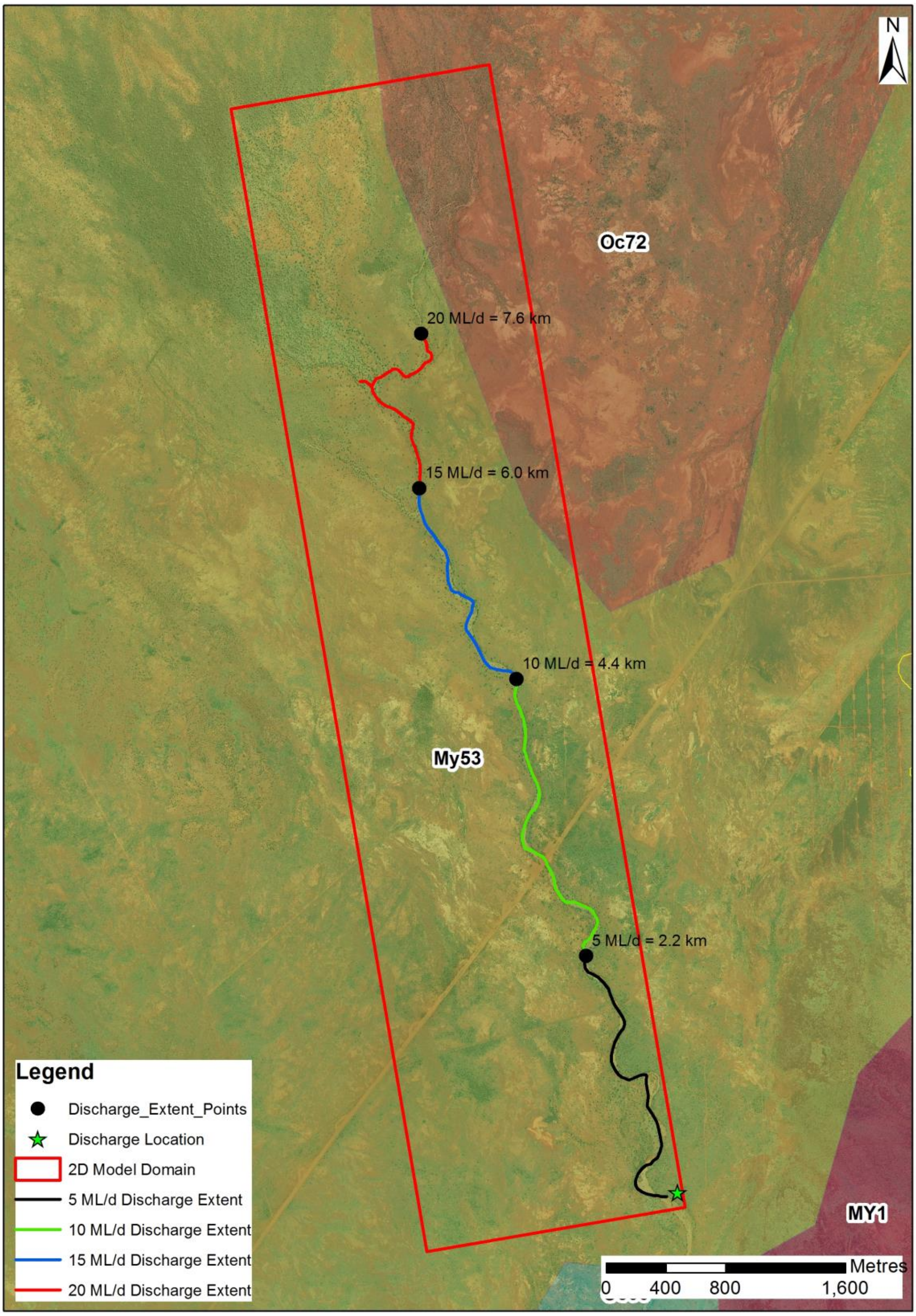

Figure 13: Modelled maximum discharge extents for various discharge rates

9. Conclusion

A 2D hydraulic model of the Warramboo Creek has been developed to estimate the extent of potential future surplus water discharge from the Warramboo BWT operations. The key advantage of the approach is the ability to hydraulically simulate the complex hydrodynamic environment while simultaneously accounting for hydrologic processes such as infiltration and evaporation.

The maximum surface water extents from four discharge scenarios were modelled: namely a continuous rate of 5, 10, 15 and 20 ML/day. It is estimated that the surplus water discharge extent will range from 2.2 km to 7.6 km down gradient of the proposed discharge location, depending on the discharge rate, before completely infiltrating/evaporating.

The surplus water discharge volume would be significantly smaller than the volume generated by the catchment during flood events. Based on model results, discharged water would be contained within the low flow channel/s, hence overtopping of the creek banks in dry conditions is not anticipated. As a result, local ecological cycles triggered by flood events would be unlikely to be activated or impacted. Furthermore, maximum surface water velocities from modelled discharge rates are less than 1 m/s and unlikely to result in channel erosion.

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