Water Balance Assessment

Wattle Grove South MRS Amendment

Project No: EP22-002(03)

Prepared for Hesperia Pty Ltd
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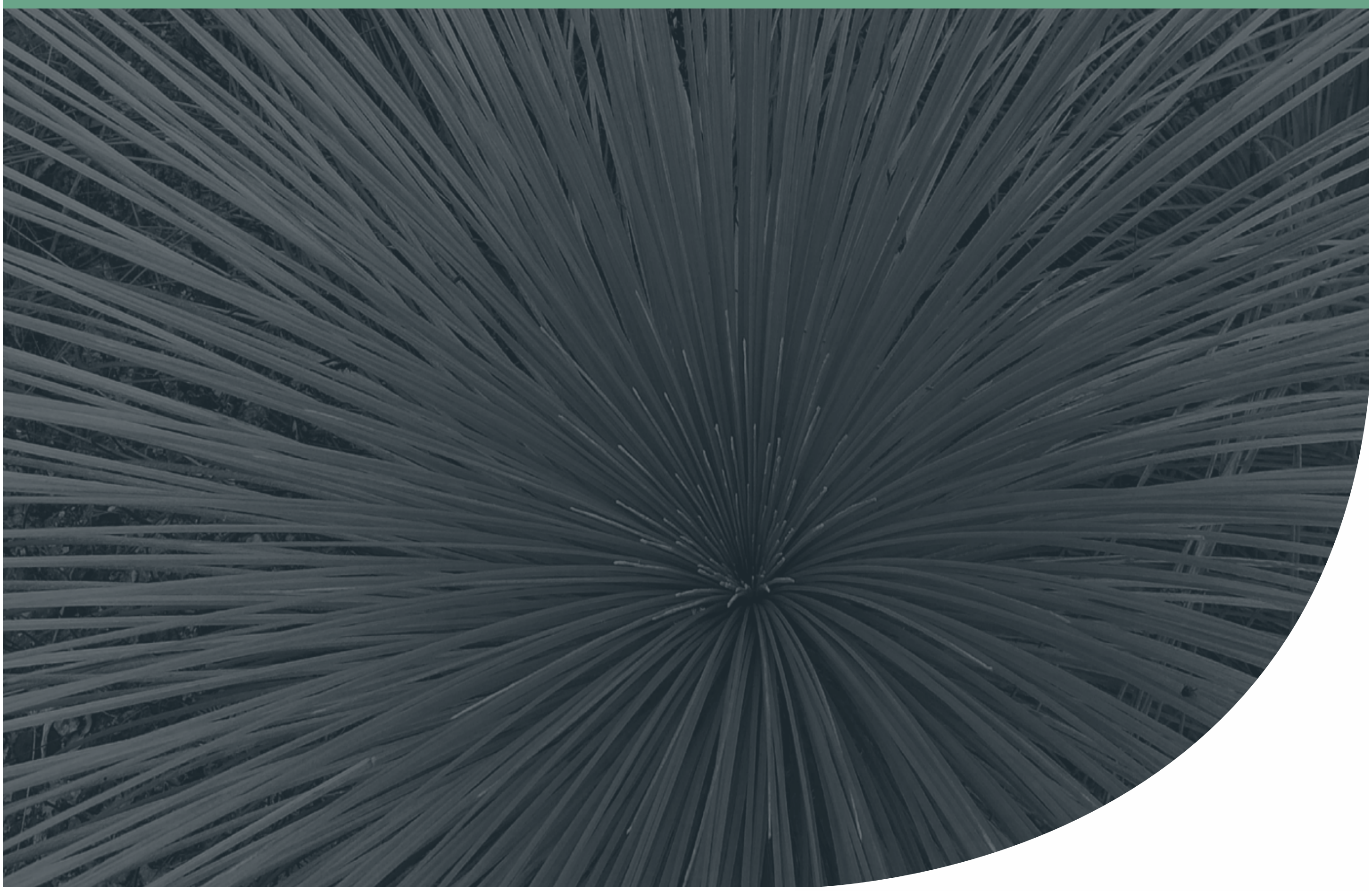

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		Benjamin Brash	BPB		
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Executive Summary

This document outlines a water balance assessment (WBA) that has been prepared to support the environmental review document (ERD) prepared to support Metropolitan Region Scheme (MRS) Amendment 1388/57.

The overall WBA is outlined and described within the body of this report. A number of appendices (technical assessments) have also been prepared to detail the specifics of the individual components of the WBA and are intended to be read in conjunction with and supplementary to the WBA.

The hydrological regime of the WBA areas is complex in some regards, is interrelated and highly seasonal. The drivers and features of the hydrological cycle within the MRS amendment area are:

- Seasonally varied annual rainfall
- Rainfall interception due to vegetation, landform and soils
- Surface water runoff (including from upstream catchments)
- Majority of the MRS amendment area is underlain by permeable sand with significant depth to groundwater
- Horizontal groundwater throughflow within the superficial aquifer beneath the MRS amendment area
- Evapotranspiration which varies across different vegetation types and land uses
- Recharge to the underlying superficial aquifer
- Seasonal perched groundwater due to underlying soil profiles in minor parts of the MRS amendment area along the north west boundary.

A conceptual understanding of the water cycle within the MRS amendment area has been developed based on detailed investigations into the existing environment. The conceptual understanding is strongly influenced by the generally sandy and permeable nature of the majority of soils, underlain by irregular and interspersed sandy clay/clay of varying extent and depth. The site is located in an area of transition between the low permeability steeper slopes of the Darling Scarp, and the flatter landform beneath the Greater Brixton Street Wetland (GBSW) which is consistently underlain by thin layers of sand over clay/sandy clay. The MRS amendment area is also close to the top of catchment for groundwater, with modest amounts of aquifer recharge occurring upstream and entering the site via shallow groundwater throughflow. The higher permeability sands of the site facilitate infiltration at source, resulting in the majority of water inputs to the site either taken up by vegetation (i.e. via evapotranspiration) or recharged to groundwater.

A conceptual water balance has been developed which considers the pre-development and post-development environments of the MRS amendment area and of the Urban Expansion (UE) and Urban Investigation (UI) areas. The pre-development environment WBA has quantified each component of the assessment and has provided a basis for assessing the impacts of the proposed development. The key components of the water balance are:

- Rainfall
- Irrigation inputs from aquifers and domestic application of scheme water
- Rainfall and irrigation water interception
- Surface water runoff and drainage

- Upstream catchment inflows
- Groundwater throughflow
- Seasonal perched groundwater
- Evapotranspiration
- Recharge.

The WBA covers an annual time scale and provides a linked assessment of the key components listed above. The surface water and evapotranspiration processes represent the average of the 2010-2019 (inclusive) period. Use of an average for these components accounts for the annual variability of these values and provides for a more robust assessment. The groundwater throughflow components are based on measured (level) data from 2022. While the assessment period is a year and most of the data and results are presented as an annual figure (as summations or averages), each component is calculated with varying timesteps, typically daily but as small as hourly intervals (e.g. for the surface water runoff component).

The WBA takes a before/after comparison approach, in that it first assesses the water balance that currently exists for the pre-development environment and then applies the same assessment methodology to the post-development environment(s). Two scenarios are evaluated; one where the UE and UI are fully developed, and one where no development occurs in the UE and UI areas. The post-development water balance scenarios follow the same methodology as the pre-development water balance. It assumes that rainfall remains the same i.e. they assume that future rainfall and climate conditions are reflective of the period assessed in the WBA. The primary factors which influence changes in the post-development water balance are the increased impervious area resulting from the urban development proposed for the MRS amendment area and the development condition of the upstream catchments (i.e. whether it remains rural residential or becomes urbanised).

A key influence for the post-development scenarios is the reduction to evapotranspiration for the MRS amendment area (due to vegetation loss), infiltration within stormwater management infrastructure and increase in recharge. Surface water outflows for the MRS amendment area increase by approximately 11% to 24% (depending on the scenario). Of this, the increase in surface water outflows directed towards GBSW is up to 5,192 kL, and while this is a 16.4% increase in the volume of water, this only represents 0.4% of the overall water balance. Evapotranspiration reduces by approximately 26% (for rainfall) to 43% (for irrigation water). Both of these influences can be attributed to the increase in urbanisation, reduction of vegetation across the WBA area and reduction in irrigation water application.

Given the permeable sandy profile beneath most of the MRS amendment area and proposed adoption of infiltration-based water management, the increase in (or residual) water volume will result in an increase in groundwater recharge (to the superficial aquifer). The annual amount of water that will become recharge to the superficial aquifer in the pre-development scenario is 313,871 kL and this will increase in the post-development scenarios to 379,011 kL. In addition, a conservative assumption is that the UE and UI area (upstream catchments) will also see a similar increase to groundwater recharge attributed to urbanisation. Estimation of groundwater recharge for the upstream catchments has been based on the same proportions of recharge determined for the MRS amendment area. The estimated groundwater recharge generated by the upstream catchments is 198,981 kL.

Whilst the MRS amendment area will experience increased recharge to superficial groundwater from urban development groundwater flows are unlikely to change due to the stormwater management approach seeking to maintain the groundwater mound at this location (Hyd2O 2024). Given the radial direction of flows exiting the MRS amendment area there is the potential for impacts to occur to GBSW and the MKSEA area. However, as the superficial aquifer is several metres below the shallow perched conditions experienced along the western boundary of the site and the portion of GBSW near the site, the MRS amendment area will not affect localised perched conditions beneath GBSW.

While there will continue to be groundwater outflows from the MRS amendment area there are no drivers for change to the shallow/perched groundwater leaving the site towards the GBSW. The portion of the MRS amendment area underlain by shallow clay are upgradient of the GBSW and will not be developed. Further, the location of Tonkin Highway along the western boundary of the MRS amendment area is assumed act as an impermeable flow boundary for shallow/perched groundwater flows, as the construction of Tonkin Highway would have removed the shallow permeable soil profile beneath the highway to facilitate construction. Further, the perched groundwater conditions in this part of the site coincide with the Dampier to Bunbury Natural Gas Pipeline (DBNGP) corridor and the *Dampier to Bunbury Pipeline Act 1997* prohibits development within this corridor. The nature of construction of the DBNGP will also have disrupted the pre-development groundwater flow pathway and is expected to act as a preferential drainage pathway directing shallow/perched groundwater flows either downwards to the more permeable sands or away from GBSW and the MRS amendment area.

The WBA initially represents the recent average meteorological conditions and therefore inherently does not account for any potential future climate change impacts, which would likely amount to a warmer, drier climate with more intense rainfall events. The effect of climate change has therefore been incorporated into the water balance model as a separate process through assessment of climate change on the post-development scenario which assumes that the upstream UE and UI areas are developed as per the MRS amendment area.

To account for climate change factors, a future rainfall dataset was obtained from DWER to assess changes to key water balance inputs due to climate change (rainfall and evapotranspiration) (DWER 2021). The dataset from DWER is based on the climatic scenario projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset (associated with the Intergovernmental Panel on Climate Change’s (IPCC) 4th assessment report) (IPCC 2007). The DWER dataset uses the climate scenario projections to predict future climate data extrapolated from an observed climate baseline obtained from the Australian climate database named ‘SILO’ (Queensland Government 2021). The DWER climate prediction dataset provides predicted future rainfall data in daily intervals for three climate change scenarios (Wet, Median, Dry) at a time horizon of 2050 and 2100. The predictions are geographically based and as such the dataset obtained for this assessment has been calculated specifically for location of the assessment. The 2050 and 2100 ‘Dry’ scenarios were selected for the climate change assessment as a conservative prediction.

Rainfall, associated runoff and evapotranspiration are the most significant components of the water balance by magnitude and future climate prediction data is available for rainfall, making assessment of climate response possible. While there will likely also be a direct effect on the other smaller-magnitude water balance components, future climatic predictions (specifically relevant to the MRS amendment area) for these components are not readily available. However, these components are altered indirectly due to flow on effects from changes in other components due to changes in water availability, which has been considered as part of the climate change sensitivity analysis. The rainfall climate change factor was applied to the following water balance components:

- Rainfall
- Upstream catchment flows
- Rainfall interception
- Surface water runoff from the MRS amendment area
- Evapotranspiration.

The flow-on impacts of these changes also effect groundwater driven processes (throughflow and recharge).

The outcomes of the climate change sensitivity showed that in the Dry 2050 scenario the impact of the assessed climate changes was relatively small, being similar to the post-development (urbanised) water balance. Surface water flows reduced by approximately 10% when compared to the base case post-development scenario, but were still greater than the pre-development environment. Evapotranspiration and rainfall decreased further from the pre-development scenario as a direct result of the reduction in rainfall associated with climate change. Reduction to the other water balance components were also noted as a results of the reduction in rainfall.

The Dry 2100 scenario indicates more significant reductions in surface water runoff will occur with a reduction of approximately 63% when compared to the base case post-development scenario, or approximately 50% lower than pre-development levels. Evapotranspiration and interception also reduce significantly, being a portion of rainfall and irrigation. Increases to recharge to the superficial aquifer system beneath the MRS amendment area under this scenario are minimal with recharge to the superficial aquifer approximating the pre-development environment.

The impacts to surface water flows specifically to GBSW from climate change (not just overall from the MRS amendment area) have also been considered as part of this WBA. For the Dry 2050 scenario with fully urbanised upstream catchments the surface water runoff exported from the MRS amendment area to GBSW reduces from a 16.4% increase (in the post-development scenario without climate change factors) to a 5.1% increase in surface runoff towards GBSW, which represents 0.1% of the overall water balance. For the Dry 2100 scenario with fully urbanised upstream catchments the surface water runoff exported from the MRS amendment area reduces by 57.3% compared to the post-development scenario without climate change.

The key findings from the WBA are summarised below:

- The proposed development will change the water balance of the MRS amendment area by reducing evapotranspiration, increasing recharge and, to a lesser degree, surface runoff.
- The increase in surface water runoff can be managed through the logical placement of stormwater infrastructure within the site, to ensure any additional surface water generated due to the development is captured, treated and infiltrated on site. This in turn will ensure that changes to surface water runoff towards the GBSW can be mitigated.

- The predicted increase in recharge has the potential to increase groundwater depth, however this will not have a significant impact on any of the water balance components, as the superficial aquifer lies several metres below the natural surface level of the MRS amendment area. The (northerly) localised flow direction of superficial aquifer in this area does not grade towards GBSW. Further, GBSW is predominantly fed by direct rainfall. Therefore, the urbanisation of the MRS amendment area will not adversely impact the existing hydrological regime in the GBSW.
- Tonkin Highway (situation along the western boundary of the MRS amendment area) will act as an impermeable flow boundary, excluding shallow perched groundwater flows in a westerly direction (given likely removal of the shallow soil profile during construction). The presence of the DBNGP at this boundary is also expected to facilitate downward infiltration of shallow perched groundwater to the deeper sandy layer.
- There are no drivers that will trigger a change to the conditions supporting shallow perched groundwater levels and flow along the northern boundary of the MRS amendment area that is upstream of the GBSW.
- Assessment of climate change indicates a likely impact on the water balance due to reduced rainfall volumes. This will reduce the overall available water within the MRS amendment area in the future, with the likely outcome being a reduction in evapotranspiration but comparable recharge to the superficial aquifer and surface runoff as occurs in the pre-development scenario.

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Environmental Review Instructions (excerpt)

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1 Introduction

1.1 Background

The Western Australian Planning Commission (WAPC) have initiated amendment 1388/57 to the Metropolitan Region Scheme (MRS). The amendment proposes to rezone approximately 126 ha of land within Wattle Grove from 'Rural' to 'Urban' situated within the Urban Expansion (UE) and Urban Investigation (UI) areas designated in the North-East Sub-Regional Planning Framework (DPLH 2018). The amendment is subject to environmental assessment by the Environmental Protection Authority (EPA) under the *Environmental Protection Act 1986* (the EP Act). Hesperia Pty Ltd (the proponent) is completing the Environmental Review (ER) required by the environmental assessment on behalf of WAPC.

For the purposes of this water balance assessment (WBA), 'the MRS amendment area' refers to the land bound by Tonkin Highway (west), Welshpool Road East (north), Crystal Brook Road (north), Victoria Road and Easterbrook Road (east) and the rear boundaries of lots fronting Victoria Road (south). The location of the MRS amendment area, UE and UI areas, and current aerial photography are shown in **Figure 1**. While the WBA has been prepared in support of rezoning of the MRS amendment area, the wider UE and UI areas in Wattle Grove have been considered in the WBA where relevant to the amendment. The location and extents of the MRS amendment area and wider UE and UI areas are shown on **Figure 1**.

The WBA is outlined and described within the body of this report. A number of detailed technical assessments have also been prepared to document the specifics of the individual components of the WBA and are intended to be read in conjunction with and supplementary to the WBA, and these are appended to this report.

1.2 Purpose of this report

As a part of the environmental assessment process for the proposed amendment, the EPA has requested an ER be undertaken and documented within an Environmental Review Document (ERD) to support the amendment in accordance with the instructions provided by the EPA. Specifically regarding the ER (see **Appendix A**), this WBA seeks to assist in addressing address points 6, 7, 8 and 12 from Table 3 (Inland Waters). A breakdown of how these are addressed by the WBA are summarised in **Table 1**. The instructions outline the key objectives, potential impacts and risks as well as the work required to ensure the objectives are achieved. Of greatest relevance to the WBA is the Inland Water environmental factors, however by association can directly or indirectly influence all the outlined environmental factors. The EPA objective for the Inland Water environmental factor is:

"To maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected"

Table 1: Excerpt of ER document requirements

ER item number	ER required work summary	WBA section which addresses ER required work
6	Using a pre and post development water balance model, characterise the existing hydrology of the site and existing sub surface flow contribution to the GBSW; and assess the potential impacts (direct and indirect) of the proposed change in land use associated with the amendment, and urban expansion and investigation areas, on water quantity and quality of surface and ground waters and subsurface flow contribution in relation to nearby significant wetlands and waterways	Section 3, Section 4.1, Appendix B, Appendix C, Appendix D
7	Calculate the additional recharge from proposed change in land use associated with the amendment, and the resultant impact to the groundwater flow velocity and direction toward the GBSW. This should also include identification of the additional recharge from the urban expansion and investigation areas.	Section 4.1, Appendix B, Appendix C, Appendix D
8	Demonstrate that predevelopment surface water and groundwater flows to the Yule Brook and GBSW are maintained post development as a result of the proposed change in land use associated with this amendment, and urban expansion and investigation areas.	Section 4.1.3, Appendix B, C
12	Items 6, 8 and 11 should model existing conditions of, and potential changes to, groundwater and surface water chemistry, particularly in relation to salinity and soil sodicity, that will result from the proposed change in land use associated with this amendment, and urban expansion and investigation areas.	Appendix E

1.3 Previous and relevant studies

Previous studies of relevance to this water balance assessment have been undertaken within the MRS amendment area and surrounding land. These studies include nearby water balance investigations and water management reports which have been used to inform the WBA presented in this document. These include:

- *Wattle Grove District Water Management Strategy* (Hyd2O 2024)
- *Geophysical Subsurface Investigation for MRS Amendment 1388/57, Wattle Grove Western Australia* (GBG 2023)
- *Maddington Kenwick Strategic Employment Area Water Balance Assessment* (Emerge Associates 2022)
- *Wetland Water Balance – Lot 414 Grove Road, Maddington Kenwick Strategic Employment Area* (Emerge Associates 2020)
- *Environmental values and pressures for the Greater Brixton Street Wetland on the Swan Coastal Plain* (EPA 2022)
- *Surface nuclear magnetic resonance sounding in the Greater Brixton Street Wetlands* (DBCA 2018)
- *A Jewel in the Crown of a Global Biodiversity Hotspot* (Lambers 2019)
- *Perth Regional Aquifer Modelling System (PRAMS) model development: Hydrogeology and groundwater modelling (Report HG20)* (DoW 2008)
- *Perth Regional Aquifer Modelling System (PRAMS) model development: A vertical flux model for the Perth groundwater region. Report HG33* (DoW 2009a)

- *Perth Regional Aquifer Modelling System (PRAMS) model development: Application of the Vertical Flux Model. Report HG27* (DoW 2009b)
- *Perth Regional Aquifer Modelling System (PRAMS) model development: Review of the Coupled Perth Regional Aquifer Modelling System. Report no. HG 30* (DoW 2009c)
- *Perth Regional Aquifer Modelling System (PRAMS) model development: Review of the Vertical Flux Component of the Perth Regional Aquifer Modelling System. Report no. HG 29* (DoW 2009d).

2 Existing Environment

2.1 Climate and rainfall

An annual median long-term average of 819.6 mm of rainfall has been recorded at the nearby Jandakot Aero weather station (number 9172) over a period of 10 years from 2010 to 2019 (inclusive / BoM 2020a). Rainfall gauging at the Gosnells station (number 9106) has been undertaken since 1961, with an average annual rainfall of 804.3 mm to date. The majority of this rainfall is received between the months of May and August. Further analysis of recent rainfall years indicates that the 30 year average rainfall at the Gosnells station (1991 to 2020) is 736.9 mm.

High resolution rainfall data from the Jandakot Aero station has been obtained for the purposes of this WBA (BoM 2020). This station was used as the greater temporal resolution (half hourly intervals) enables a detailed analysis of rainfall. Similar data was not available for the Gosnells station. The rainfall data covers a period of 10 years from 2010 – 2019 (inclusive) and consists of rainfall measurements in half hourly intervals. The average rainfall over this period is 734.9 mm. Both the Gosnells and Jandakot rainfall datasets indicate a downtrend in rainfall magnitude and as such the more recent (i.e. 10 year) observations are considered more relevant for application in the WBA. Rainfall is discussed further and in relation to the WBA inputs, in **Section 4.1.1**.

2.2 Topography

The MRS amendment area has a low relief with a gradual fall from east to west. Natural surface elevations vary from 37 m Australian height datum (AHD) at the east to 21 m AHD along the western boundary. The topographic contours of the MRS amendment area and immediate surrounds are shown on **Figure 2**.

2.3 Existing land use

Currently the MRS amendment area is comprised of a mix of commercial sites, rural residential land holdings and a turf farm with narrow un-kerbed local access roads. A decommissioned poultry farm is located along the southeastern boundary.

Pockets of vegetation are present across the MRS amendment area with increasing density from the western to eastern boundaries. The vegetation communities comprise a mixture of open woodlands which generally consist of a variety of *Corymbia* (Marri), *Eucalyptus*, *Melaleuca*, *Allocasuarina* (Sheoaks) and *Banksia* or equivalent species. Non-native vegetation is also expected to be found within the MRS amendment area. Current aerial imagery is shown in **Figure 1**.

2.4 Wetlands

The MRS amendment area contains two resource enhancement wetlands (REW / UFI 8037 and 15257) situated along the western boundary adjacent to Tonkin Highway. Additionally, two conservation category wetlands (CCW / UFI 8026 and 8027) are located at the north west corner of the proposed development adjacent to the intersection of Tonkin Hwy and Welshpool Road East.

Located to the west of Tonkin Hwy is the CCW recognised as the Greater Brixton Street Wetlands (GBSW). The condition of GBSW, from mapping performed by the Department of Biodiversity, Conservation and Attractions (DBCA), varies from excellent to completely degraded. For the area of GBSW closest to the MRS amendment area, the condition is listed as good to completely degraded.

The extent of mapped geomorphic wetlands within the vicinity of the MRS amendment area is shown on **Figure 3**.

2.5 Bush Forever

No Bush Forever (BF) sites are located within the MRS amendment area. Several BF sites are situated to the west and are associated with the GBSW and Maddington Kenwick Strategic Employment Area (MKSEA). Mapped BF locations are shown on **Figure 3**.

2.6 Soils and geology

Review of regional soil geology has identified that the MRS amendment area is situated within a transitional area between the Piedmont Zone of the Darling Scarp and the Pinjarra Plain. As such the soil profile of the MRS amendment area is expected to be complex and heterogeneous. Guildford and Yoganup formation soils are likely to be present along with greatly varying concentrations of Bassendean sands, increasing towards the east. Fine grained soils are indicated to occur predominantly to the west of the MRS amendment area increasing in frequency with depth but also to the north and, to a lesser extent, centrally (likely sporadically).

Regional soil information detailed in the *1:50,000 Geological Map Series – Armadale 2133 IV* (DMIRS 2018) for surface soils in the vicinity of the MRS amendment area are described in **Table 2.** Regional geology and the broader physiographic regions are shown on **Figure 4**.

Table 2: Summary of geological map units within the vicinity of the MRS amendment area

Map Unit	Description	Equivalent unit on geological maps
S_8	Sand – white to pale grey at surface, yellow at depth, fine to medium-grained, moderately sorted, subangular to subrounded, minor heavy minerals, of eolian origin.	Bassendean Sand (Qpb)
S_{10}	Sand – as S8 over sandy clay to clayey sand of the Guildford Formation, of eolian origin.	Thin Bassendean Sand over Guildford Formation (Qpb/Qpa)
S_{12}	Sand – structureless, yellow, fine-grained, subangular and medium to coarse-grained subrounded to rounded quartz, feldspar and heavy minerals common, minor silt and clay, of colluvial origin	Yoganup Formation (Qpr)
Mgs_2	Gravelly silt – strong brown, tough, common pebbles of fine to coarse-grained, sub-rounded granite, some dolerite and rare sandstone (SS), variable sand content	Colluvium (Qc)
Ms_4	Sandy silt – cream to pale brown, angular to rounded sand, low cohesion, of alluvial origin	Alluvium (Qha)
Cs	Sandy clay – white-grey to brown, fine to coarse-grained, subangular to rounded sand, clay of moderate plasticity gravel and silt layers near scarp	Guildford Formation (Qpa)

2.6.1 MRS amendment area investigations

A series of bores were installed during previous investigations in the vicinity of the MRS amendment area (GW1, GW5, WG1, WG3, Mba and Mbb). Recent information from these bores has assisted groundwater investigations within the WBA area. An initial on-site investigation was undertaken by Douglas Partners in October 2020. This investigation included 15 test pits (TP), Perth Sand Penetrometers (PSP) and the installation of two groundwater monitoring bores and infiltration tests (IT) (TP1 - TP15). The results of this investigation generally aligned with the regional mapping with no groundwater observed in any of the TP locations. Infiltration testing performed during this investigation (conducted 0.5 m to 1.0 m below ground level (BGL)) obtained values of 6 m/day to 34 m/day with higher infiltration rates associated with the S_8 and S_{12} soil units (see **Table 2**). An additional investigation was undertaken by Douglas Partner in November 2022. This investigation included 12 TP and three IT conducted in the southern region of the MRS amendment area (TP101 - 112). The results of this investigation generally aligned with the regional mapping with no groundwater observed in any of the TP locations.

Further investigations were conducted by Douglas Partners in October 2023 via two boreholes installed to a depth of 15 m BGL west of Tonkin Hwy adjacent to Boundary Road. Soil samples were logged as per AS1726 with specimens collected for Atterberg limit (AL), particle size distribution (PSD) and falling head (FH) permeability testing. These specimens were collected at approximately 9.5 m BGL, 12.0 m BGL and 14.0 m BGL. The results of this investigation indicated a layer of sandy clay soil up to 2.9 mBGL underlain by silty sands to depth. Atterberg and PSD test results aligned the deeper silty sands described in the borelogs. Results of the FH permeability testing are summarised in **Table 3**.

Table 3: Falling head permeability testing results

Depth (mBGL)	FH permeability result (m/day)	
	BH01	BH02
9.50 - 9.95	0.27	0.19
12.00 – 12.45	0.84*	0.35
14.00 – 14.45	0.14	0.23

** Result from BH01 (12.00 - 12.45 mBGL) elevated due to reduced silty soil found at this depth.*

The FH permeability tests indicated that the average vertical permeability of the deeper sandy soils (where the superficial aquifer was assumed to flow) was between 0.26 and 0.42 m/day. These results were converted to horizontal permeability values (using a conversion factor of 10) which determined the horizontal permeability at this location was 2.6 m/day and 4.2 m/day.

Additional groundwater monitoring bores were installed by Hyd2O in November 2020 (WG1, WG2, WG3), July 2022 (WG2S, WG4S/D, WG5S/D, WG6, WG7S/D, GW5D, GW8S/D, GW9S/D) and October 2022 (WG8, WG9, WG10S/D, MW202S/D). These bores were installed to assess the sub-soil and groundwater conditions (both shallow and deep) beneath the MRS amendment area. Assessment of the bore logs show that the local soils generally align with the regional soil mapping and support the previous soil investigation. In-situ permeability testing was performed through the use of borehole permeability tests to assess the conductivities of the soil profiles (HTS1 – bore WG1, HTS2 – bore

WG3, HTS3 – bore WG10) with conductivity values ranging from 12.3 to 28.8 m/day in the northern region of the proposed development area across the S_8, S_{10} and S_{12} soil units. These permeability ratings were used in preference to test pit rates for assessment of groundwater throughflow as they are considered to be a more accurate representation of horizontal permeability of the deeper underlying soil profile. The results of permeability testing are provided in **Table 4**. The location of the various MRS amendment area investigations is shown on **Figure 4** and **Figure 5**.

Table 4: Permeability testing results

Location	TP3	TP4	TP11	TP34	HTS1 (WG1)	HT2 (WG3)	HTS3 (WG10)
Permeability (m/day)	25	6	7	34	12.3	28.2	21.1

GBG Group undertook a geophysical investigations to assess the soil profile (to a depth of 50 m BGL) beneath the MRS amendment area in December 2022 and October of 2023 (GBG 2023). This investigation made use of Electrical Resistivity Tomography (ERT) to assess the deeper soil profile to interpret the porosity and permeability and to identify soils that could behave as an aquifer or aquitard. A total of 6,910 lineal metres across 16 transects was profiled as part of this investigation. The locations of these transects were guided by previous site soil and groundwater investigations with a view to providing additional information for the interpretation of groundwater flow direction and perching in the vicinity of GBSW.

The results of this investigation found that the soils beneath the MRS amendment area were generally non-uniform and complex. The soil profile obtained from this investigation was found to contain a mixture of soils which broadly aligns with previous geotechnical investigations.

Several regions of high resistivity soil were identified in the region of turf farm, Brentwood Road, Boundary Road and Victoria Rd (western boundary) starting at approximately 10 m AHD (15 m BGL) which extended to the depth of the geophysical investigation. Areas of lower resistivity soil were identified along Crystal Brook Road (northern boundary) and Johnson Place (outside of MRS amendment area to the north) extending from the natural surface to depth.

For soil below measured groundwater, low resistivity soils were interpreted to represent saturated, more permeable material. These low resistivity soils generally align with near surface geotechnical investigations and represent soils found along Crystal Brook Road and a portion of Johnson Road. Large masses of high resistivity soil below measured groundwater have been interpretated as very low permeability material. These high resistivity soils are found along Tonkin Highway, the southern end of Brentwood Road and Boundary Road.

2.6.2 Summary of soil profile and conditions

From a comparison between the regional soil mapping and the MRS amendment area investigations the soil conditions can be summarised as follows:

- Regional soil mapping found soil conditions beneath the MRS amendment area as highly variable consisting of a duplex soil along the western regions of the MRS amendment area with increasing sandy soils and greater depth of sand found in the central and eastern regions of the MRS amendment area.

- Soil in the western regions adjacent to Tonkin Highway consists of more fine grained soils (clay and silt) in the shallower soil profile which are interfingered with pockets of clayey sands/sandy clays to depth.
- Soils in the central and eastern regions of the MRS amendment area are generally found to have sand to the deeper soil profile with pockets of clay and silt found in both the shallow and deeper soil profiles.
- On-site soil investigations for the MRS amendment area are consistent with the regional soil mapping and previous investigations. indicated the presence of fine grained soils in the western region of the site which increases with depth. Increasing presence of sand with depth is noted towards the east.
- Geophysical investigation interprets the soils found across the MRS amendment area as being variable and complex. Lower permeability soils were found along the western boundary at approximately 15 mBGL with higher permeability soils located along the northern boundary close to the existing surface.
- Permeability for the MRS amendment area is variable with measured permeability rates ranging from 12.3 m/day up to 28.8 m/day in borehole tests and from 6 m/day to 34 m/day in test pits. Deeper soil profile adjacent to the western boundary at Boundary Road was found to have permeability rates ranging from 2.4 m/day to 4.2 m/day.

2.7 Groundwater

2.7.1 Aquifers

The *Water Register* (DWER 2024b) indicates that groundwater beneath the MRS amendment area is a multi-layered system comprised of the following:

- Perth – Superficial Swan unconfined aquifer
- Perth – Leederville confined aquifer
- Perth – Yarragadee North confined aquifer.

2.7.2 Groundwater levels

A review of the *Gnangara Jandakot Water Table Elevations* (DWER 2021a) provided the regional maximum groundwater contours for the MRS amendment area. These range from approximately 14.0 m AHD in the east to 12.0 m AHD along the western boundary adjacent to Tonkin Highway.

Additional groundwater level investigations have been undertake by Endemic (2012) for the purpose of gathering suitable data for baseline datasets (groundwater levels/quality, wetland water levels, surface water flow/quality) for the greater MKSEA and GBSW. This baseline data was collected over a period of 18 months during 2012 to 2013. While this investigation does not directly cover the MRS amendment area it does provide information for the lands to the west adjacent to Tonkin Highway.

Hyd2O have recently undertaken a groundwater investigation for the MRS amendment area to obtain as much data as reasonably possible to support the ERD. The measured depths in a number of groundwater monitoring bores within the MRS amendment area for both the regional superficial unconfined aquifer and a perched system have occurred on three occasions in the second half of 2022 (2022/08/26; 2022/10/10 and 2022/10/27).

Average annual maximum groundwater level (AAMGL) contours for the superficial aquifer have been derived from groundwater levels measured by Hyd2O and additional information obtained from DWER bores, Main Roads Western Australia (MRWA) bores located along Tonkin Highway, bores located to the west of the site within the MKSEA site, DBCA bores located within GBSW and Douglas Partners bores within the MRS amendment area. Additional data from the Canning River (located to the south west of the MRS amendment area) was incorporated to assist with the generation of the AAMGL contours. The complete extent of the groundwater monitoring bore dataset and the associated AAMGL contour dataset are presented in the District Water Management Strategy (DWMS). AAMGL contours for the MRS amendment area range from 16 m AHD at the north eastern region to 19 m AHD approximately at the western boundary. Groundwater contours and local bore locations for the MRS amendment area are shown on **Figure 5.** Groundwater flows were found to occur radially away from a mound evident along the western boundary adjacent to Tonkin Highway. Further discussion of seasonal variation within groundwater levels for the MRS amendment area and comparison to DWER regional mapping are presented in the DWMS (Hyd2O 2024).

Groundwater is highest beneath the existing turf farm adjacent to bore WG9 which is consistent the local low permeability geological conditions at this location and the application of groundwater extracted from the deeper aquifer at this location of the MRS amendment area.

Higher groundwater levels have been observed in bores GW5S, GW8S and GW9S, located to the west adjacent to Tonkin Highway, and in WG4S and WG10S to the north of the MRS amendment area, and these are concluded to represent localised perching. Measured depth within the shallow bores were used to derive maximum groundwater level (MGL) contours for the perched/shallow groundwater locations in the north western part of the MRS amendment area (WG4S, GW5S, GW9S and WG10S) as well as for the south western region of the MRS amendment area (GW8S) shown on **Figure 5**. The extent of perching beneath the MRS amendment area is relatively minor and limited to the fringes of the WBA area. The nature of construction of the DBNGP will also have disrupted the pre-development groundwater flow pathway and is expected to act as a preferential drainage pathway directing shallow/perched groundwater flows either downwards to the more permeable sands or away from GBSW to the south of the MRS amendment area.

2.8 Surface water

2.8.1 Existing hydrological features

Current drainage infrastructure found within the MRS amendment area is largely informal with a series of minor roadside swales installed alongside unkerbed roads. These informal structures are assumed to both convey and infiltrate the surface runoff generated by the local roads from rainfall events. Due to the existing soils found within the MRS amendment area (see **Section 2.6**) more formal drainage structures are likely not required given the current low density of development. Furthermore, the small portion of impervious areas present within the proposed development (roof, pavement and road asphalt) are not connected impervious areas given the absence of formal road drainage (i.e. pit and pipe network) and minimal extent of kerbed roads. Based on this, it is expected that runoff contributions from the MRS amendment area and upstream catchments are likely to be relatively minor, including runoff from impervious areas.

There are however some surface water features outside of the MRS amendment area or at the boundaries which are of relevance. An incised road-side swale to the north of Crystal Brook Road along the length of the MRS amendment area and upstream catchments acts a flow barrier for frequent and minor flows (which are of most consequence to a continuous annual water balance assessment – i.e. non-event based assessments). Runoff within this swale is conveyed to a drain that is located within open space adjacent to the north-western most corner of the proposed development area, which flows through a culvert under Tonkin Highway ('Discharge 1'). Flows from this culvert continue westward into GBSW through a degraded but natural streamline. The streamline is intercepted by access tracks however is well defined for approximately 450 m, at which point a portion of the streamline has been historically cleared for pasture and local track access, and recently (2017) filled which has effectively resulted in the removal of the natural streamline function. Infiltration and ponding of flows within the natural streamline due to the access track crossings and the imported fill/cleared section is expected to occur at this location. Connection to the downstream Yule Brook may be established during significantly larger rainfall events however this would require significant yet broad and shallow sheet flow across the MRS amendment area.

During an MRS amendment area inspection by Emerge Hydrologists in September 2022 to the culvert at Discharge 1 (located beneath Tonkin Highway, see **Plate 1**) no flow was observed and some ponding below the downstream invert elevation was noted. Based on the observed lack of baseflow during MRS amendment area visits and comparison of nearby groundwater level observations with topography, it is expected that the culvert at Discharge 1 flows predominantly in response to local rainfall events as opposed to interception of perched or superficial groundwater.

The runoff from north of Crystal Brook Road has not been considered in this WBA as a roadside swale located along Crystal Brook Road (northern boundary of the MRS amendment area) inhibits surface runoff from entering the MRS amendment area i.e. it is outside the WBA. Surface runoff from the UE and UI areas has been considered in the WBA (i.e. that which occurs as sheet flow from upstream areas into the WBA area). Runoff from the northern portion from the MRS amendment area and the northern upstream catchment is however also directed to the drain to the north-west and eventually discharged to the GBSW via the same pathway (which is external to the WBA area).

Runoff from the majority of the MRS amendment area and upstream catchments are expected to sheet flow (during sufficiently large rainfall events) generally towards Tonkin Highway, where a number of culverts are located which allow discharge under the highway into the adjacent MKSEA site. The main outlet locations discharge to Brentwood Road and Victoria Street. Ultimately runoff discharged to the MKSEA will be conveyed by the system of roadsides swales to Yule Brook.

A small portion of the MRS amendment area located to the south discharges southward towards a roadside swale on the eastern side of Tonkin Highway.

Hydrological features including the catchments, culverts and flowpaths are shown on **Figure 6**.

Plate 1: Discharge 1 culvert (Sept 12, 2022)

2.9 Conceptual understanding of the site

Based on the detailed investigations undertaken, information presented in this section of the report, and the information provided in the DWMS, the MRS amendment area is a superficial aquifer recharge area. It is located at or close to the top of a groundwater catchment area; groundwater inflows to the site are anticipated to follow existing surface channels/streamlines which act as a natural outlets for groundwater flows, resulting in overall flow directions towards Yule Brook to the North and Bickley Brook to the South. Shallow groundwater inflow to the site is therefore only a minor portion of the overall water balance.

The MRS amendment area is underlain by generally sandy soils with moderate to high permeability which results in rainfall/applied water being able to infiltrate downwards to the superficial aquifer. Shallow/perched groundwater (caused by localised fine grained/clayey soils near the surface) potentially occurs in the north western region of the MRS amendment area. These shallow/perched groundwater systems have the potential to direct shallow groundwater flows towards the west of the site (towards Tonkin Highway) which historically could have interacted with the GBSW (located to the west of Tonkin Highway). However, these flows are assumed to be intercepted by the DBNGP or unable to flow in this direction due to the impermeable boundary caused by the construction of Tonkin Highway. This results in shallow/perched groundwater to either become localised rechange to the deeper soil profile or leave the site in a northerly direction (via existing sandy soil pathways).

Deeper groundwater flows are found to be influenced by the existing groundwater mound that is found beneath the MRS amendment area (in the vicinity of the existing turf farm). The effects of this mound cause the deeper groundwater to flow radially away from the MRS amendment area. Reduced groundwater flows are noted in the north western regions of the MRS amendment area due to the presence of deep, low permeability soils at this location.

Based on the above, the majority of the water entering the site (surface water, groundwater inflow, rainfall etc.) is noted to either become recharge for the MRS amendment area which will result in higher groundwater outflows, or to be taken up by vegetation via evapotranspiration.

3 Conceptual Water Balance

The hydrological regime of the MRS amendment area along with the methodology used to quantify the key components is described conceptually within the following section of this document. It is complex in some regards due to the observed subsurface conditions in a western portion of the MRS amendment area where soils transition heterogeneously from near surface Bassendean sands to Guildford and Yonganup formation finer grained soils. The key features of the hydrological cycle identified within the MRS amendment area are:

- Rainfall
- Irrigation by various sources (superficial and confined groundwater).
- Rainfall and irrigation water interception
- Surface water runoff and drainage
- Upstream catchment inflows
- Groundwater throughflow
- Seasonal perched groundwater
- Evapotranspiration
- Recharge.

The individual components of the WBA have been outlined and discussed conceptually. Each element is quantified and discussed in greater detail in this section of the document and within the technical assessments provided in **Appendices B**, **C**, **D** and **E**. In order to conceptualise the overall water balance, the major fluxes attributable to the MRS amendment area are illustrated in a visual context in **Plate 2**.

As the MRS amendment area boundary is somewhat irregular with regards to lateral throughflow, for the purposes of the throughflow assessment the boundary has been slightly simplified to more succinctly account for throughflow fluxes.

3.1 Water balance key components

This section describes the key components of the WBA, and **Section 3.2** describes the methodology that has been used to quantify the key components of the WBA. The assessment of the final water balance is provided in **Section 4** under both pre-development and post-development scenarios.

The WBA covers an annual time scale. The surface water and evapotranspiration processes represent the average of the 2010-2019 (inclusive) period. Use of an average for these components accounts for the annual variability of these values and provides for a more robust assessment. The groundwater throughflow components are based on measured (level) data from 2022. Data from 2022 was selected as it was considered to represent the best spatial coverage for the MRS amendment area. While the assessment period is a year and most of the data and results are presented as an annual figure (as summations or averages), each component is calculated with varying timesteps, typically daily but as small as hourly intervals (e.g. for the surface water runoff component). The details of adopted timesteps are provided in the technical assessment covering each component (see **Appendices B**, **C** and **D**).

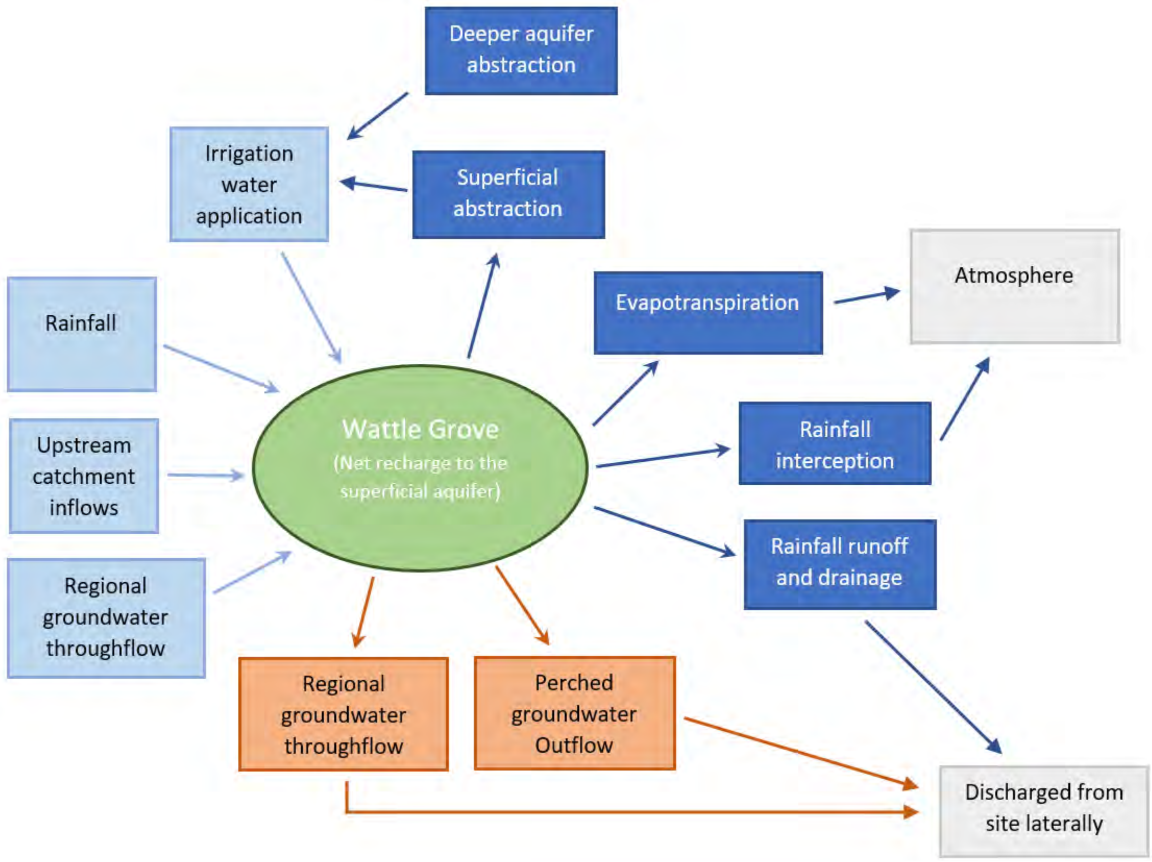

Plate 2: Conceptual water balance showing major water balance assessment factors (Pre-development)

3.1.1 Rainfall

Rainfall is a significant component of the hydrological regime and a key component of the water balance. Rainfall patterns are recorded for Australia by BoM at various weather stations located through the country. For the WBA an assessment of the weather stations in the vicinity of the MRS amendment area has been undertaken to determine the closest station to the MRS amendment area with the most robust rainfall dataset available. This may result in a weather station that is not the closest to the MRS amendment area being chosen for the WBA due to the quality of rainfall data available.

For this WBA rainfall data with a high temporal resolution is required to quantify several components, such as surface runoff and evapotranspiration. The time period for the data was over a 10 year period with rainfall data recorded in half hourly intervals. This allows for components that are sensitive to rapid rainfall generation to be adequately assessed while also minimising the effects of highly variable rainfall temporal patterns. This resulted in the use of rainfall from the Jandakot Aero station (ID: 009172) and not the Gosnells station (ID: 009106) which is located closer to the MRS amendment area.

3.1.2 Irrigation (abstracted groundwater application)

Within the MRS amendment area there are 14 groundwater licences issued by DWER for abstraction of groundwater from the superficial aquifer. For the purposes of this WBA it is assumed that the full allocation of each of these licences is being extracted from groundwater resources beneath the MRS amendment area. This abstracted groundwater is then assumed to be fully utilised for the irrigation of vegetation within the MRS amendment area. This is assumed for both the pre and post-development scenarios. In the post-development scenario use of groundwater will be specifically for the irrigation of public open spaces (POS) within the proposed development.

The MRS amendment area will be connected to the Water Corporation (WC) Integrated Water Supply System (IWSS) to supply potable water to the proposed development. Use of this potable water will be for internal house use and it is anticipated that there will be some minor irrigation of private lots, assumed to be applied to 10% of the residential lot area.

3.1.3 Rainfall interception and irrigation interception

A portion of incidental rainfall will be physically intercepted and stored on the leaves and branches of vegetation and litter. The water that is retained within the vegetation and/or litter which does not eventually reach the ground surface (i.e. via stemflow) will eventually evaporate and hence constitutes a loss of water from the MRS amendment area (i.e. rainfall interception). The extent of rainfall interception is one of the factors determined from the vertical flux model (VFM) component of the PRAMS assessment for various representative recharge units (RRUs). The VFM represents the vertical movement (or flux) of water with the soil profile, which determines recharge to the underlying aquifer system. The RRU represents an area of land which shares similar characteristics (for the application of a VFM), such as watertable depth, soil type or landuse. This assessment is linked to the calculation of evapotranspiration losses, which utilises the same approach and is discussed further in **Section 3.2.5**, as well as other vertical water balance components. The interception of rainfall has been based on published values within the *PRAMS model development: Application of vertical flux model (Report No. HG27)* (DoW 2009b) for various corresponding and analogous land uses within the MRS amendment area. These same principles and methodology have been applied with respect to the interception of irrigation water.

A detailed description of the methodology used to determine interception is provided in **Appendix D**.

3.1.4 Surface runoff and drainage

The surface water runoff is generated from rain falling on the MRS amendment area in the same way as the runoff that is generated from upstream catchments. The surface water runoff assessment for the MRS amendment area has been largely based on the assessment previously undertaken in the DWMS, but also expands on this to consider the urbanisation of the UE and UI areas that surround the MRS amendment area. With respect to land use characterisations, the surface water runoff assessment has been based on a typical urban subdivision outcome that is representative of the north-east corridor of Perth. The assumptions that have informed this outcome are discussed further in **Appendix B**. This assessment also comprised of a catchment and land use analysis which included assigning loss rates to various land uses within the MRS amendment area and upstream catchment for both the pre-development and post-development environments. The loss rates from the DWMS were adopted for this assessment, with some additional consideration to represent infiltration within stormwater management structures.

Using the above approach (which is detailed further in **Appendix B**), an annual mean runoff coefficient from each land use (in both the pre and post-development scenarios) was calculated. The runoff coefficient is then applied to the land use areas to determine annual runoff volumes.

3.1.5 Upstream catchment inflow

Surface water runoff from upstream catchment areas is accounted for as an inflow to the MRS amendment area. The method for calculating the upstream runoff values is the same as that for runoff from rain falling directly onto the MRS amendment area (which is covered in **Section 3.1.3**).

The surface water runoff assessment for upstream catchments is based on the existing land uses (for pre-development) and a typical urban subdivision outcome (for post development scenarios) and as per the method described above and **Appendix B**. The UE and UI areas upstream of the proposed development may or may not be developed for urban uses, and therefore two post-development scenarios have been considered: one which assumes the upstream UE and UI areas are urbanised and one which assumes that the upstream UE and UI areas are not urbanised.

3.1.6 Groundwater throughflow

Groundwater throughflow is the lateral flow of water through a soil profile. Groundwater throughflow occurs where there is a groundwater gradient, a permeable soil profile and a pathway for groundwater to travel through.

On-site soil investigations and review of regional soil geology has identified that the underlying soil profile of the MRS amendment area is complex and heterogeneous with shallow clayey soils occurring in minor portions to the west and north of the MRS amendment area near to the surface (but not consistently) and increasingly with depth (see **Section 2.6**). While noting the heterogeneity of the soil, the observations to date indicate that near-surface groundwater (i.e. above the underlying Leederville Aquifer) within the MRS amendment area can be delineated into a regional superficial unconfined aquifer beneath the entire MRS amendment area and small areas of a perched system located along Tonkin Highway. The variability of soils and the locations of their perched systems have been taken into account in the WBA.

3.1.7 Perched groundwater flow

From previous investigations undertaken by Hyd2O (see **Section 2.7.2**) for the MRS amendment area a seasonal perched groundwater system has been identified. The perched groundwater flow is driven by rainfall and is assumed to be seasonal, only occurring during the five months of higher rainfall (May – September) with flow assumed to be occurring at maximum measured depth of groundwater obtained by Hyd2O.

The seasonal perched system is at shallower depths in comparison to the permanent superficial groundwater system also found beneath the MRS amendment area (by several metres) while also being limited to a small area in the north western region of the site.

3.1.8 Evapotranspiration

Evapotranspiration for the MRS amendment area has been determined through the quantification of all other components of the water balance. This has considered the RRUs delineated for the MRS amendment area (see **Section 3.4**), regional soil mapping, land uses and groundwater levels. Documentation published for the development of PRAMS (DoW 2008, 2009a, b, c, d) details the associated range of values that have been shown to be suitable for the estimation of these components which allow for the determination of:

- Percentage of rainfall which has the potential of becoming recharge to groundwater, often simply referred to as recharge (and sometimes referred to in PRAMS documentation as 'drainage') and
- Likely amount of interception, of both rainfall and irrigation, before it reaches the ground.

Estimation of evapotranspiration has been achieved through the quantification of recharge, interception and taking the difference between all inputs and outputs for the WBA area, and then verified by calibrating the outcome to evapotranspiration rates adopted in other studies contained in the suite of PRAMS documentation listed above.

3.1.9 Recharge

An assessment of the degree of connectivity between the Superficial Swan and Leederville aquifers systems beneath the MRS amendment area has been undertaken to determine the degree of vertical groundwater movement from the Superficial Swan aquifer to the Leederville aquifer. The aquifer systems for the greater Perth region as presented in *Studying Perth's deep aquifers to improve groundwater management* (DWER 2021b) indicate that there is no connection between the Superficial Swan aquifer and the deeper Leederville aquifer in the vicinity of the MRS amendment area. The difference in total dissolved solids (TDS) values between the rainfall occurring on MRS amendment area (< 500mg/L) and the TDS values for the Leederville aquifer beneath the MRS amendment area ('> 2000 mg/l') suggests that rainfall does not reach the Leederville aquifer. This is likely due to the presence of an aquitard, which effectively reduces the TDS value within the superficial aquifer without having a similar effect on the Leederville aquifer, confirming the assumption of no/limited connectivity between the superficial and Leederville aquifers.

The lack of connection between the aquifer systems beneath the MRS amendment area means that there is likely to be minimal recharge to the deep Leederville aquifer that is presumed to also be located beneath the MRS amendment area (see **Section 2.7.1**). Therefore, this WBA assumes that no recharge to this deep aquifer system occurs. However, based on the MRS amendment area investigations undertaken, it can be assumed that there is a degree of connectivity between the shallow soil profiles/perched groundwater system and the superficial aquifer system beneath the MRS amendment area. For the purposes of this WBA the recharge volume that remains after all other components of the WBA are quantified and removed from rainfall represents the vertical movement ('recharge') of water downwards into the superficial aquifer. The groundwater inflow and outflow from the MRS amendment area predominantly occurs within the superficial aquifer, with the method as to how this is quantified discussed in **Section 3.2.4**.

3.2 Quantification of key components

3.2.1 Rainfall

Rainfall magnitude at the Gosnells station has a recent 30-year average (1991-2021) of 736.9 mm, which corresponds closely to the 2010-2019 average from the Jandakot Aero station (735 mm). Based on this, the data from the two nearby but separate stations are approximately analogous for the quantification of rainfall in the WBA. Jandakot Aero station data (BoM 2020) was used for the surface water runoff component as it provided the nearest station with high temporal resolution rainfall data that enabled detailed (hourly) surface runoff calculations to be determined. For consistency the same rainfall period was considered for the evapotranspiration component. Jandakot Aero rainfall for the years 2010-2019 (inclusive) at half hourly intervals was sourced for analysis, these were consolidated to provide hourly intervals. The 10 year interval was used for the surface water runoff component as runoff is generated as a rapid response to rainfall events and is sensitive to the rainfall event temporal patterns, which are highly variable. This becomes less significant when averaged over a longer time period, hence a 10 year period was chosen.

For consideration of climate change on the WBA (see **Section 4.2**) rainfall from the closest geological location found within the Australian climate database named 'SILO' (Queensland Government 2021) is required. This location is the suburb of Gosnells where rainfall data is available from the BoM is from Gosnells station. A separate consideration for rainfall and the effects of climate change on the WBA is presented in **Section 4.2**.

3.2.2 Surface water runoff

Surface water runoff is dependent largely on the land cover type and superficial soil profile (as well as rainfall), which effects how readily rainfall is converted into runoff. The surface water runoff land uses have been based on a typical urban subdivision outcome that is characteristic of the north-east corridor of Perth. This land use composition is considered to be highly representative of the likely future development of the MRS amendment area. The other surface water assumptions, including loss rates and catchment boundaries have been largely derived from the surface water assessment undertaken to support the DWMS by (Hyd2O 2024).

The calculation of the surface water runoff is based on the initial loss (IL) and continuing loss (CL) loss rate method which is routinely used in runoff magnitude calculations and modelling. The IL (in mm) and CL (in mm/hr) loss method is applied to the rainfall (in mm) on an hourly timestep basis for a period of 10 years (2010-2019 inclusive) and then averaged to provide an average annual runoff value. For runoff to occur both the IL and CL values must be exceeded in any given time step. This assessment was undertaken separately for each land use (i.e. once for every IL and CL combination) and in each development scenario. By multiplying the average annual runoff for each land use (IL, CL combination) by the area of each respective land use within each catchment, and then summing throughout, the total annual runoff volume is determined.

The upstream catchments and their land types/uses (pre-development and post-development) are shown on **Figure 6** and **Figure 7**. The catchment areas, land type areas and the IL and CL for each land type are detailed in Tables B1, B2, B3 and B4 of **Appendix B** for both the pre-development and the post-development scenarios.

3.2.2.1 Pre-development

As discussed in **Section 2.8**, there are no defined natural or man-made surface water conveyance features within the MRS amendment area. Any runoff that is generated is conveyed as overland flows to either MKSEA, to Crystal Brook Road and then to GBSW, or southward along the east of Tonkin Highway. Runoff is expected to follow topography and be conveyed as sheet flow generally to the west towards Tonkin Highway. Catchments within and upstream of the MRS amendment area have been digitised based on the publicly available 1 m topographical contours, aerial photography and informed by MRS amendment area visits from Emerge hydrologists.

Runoff from Catchments 1 and 1US is conveyed to Discharge 1 (the culvert crossing under Tonkin Highway for the drain to the north of the MRS amendment area). Flows from Discharge 1 will be conveyed within the natural (but degraded) streamline through the GBSW where flows will pond and infiltrate due to the interception of the streamline by access tracks, cleared land and imported fill. This degradation of the streamline will likely mean that the majority of Discharge 1 surface water flows are not expected to reach the downstream Yule Brook (as surface water).

Runoff from Catchments 2 and 3 (i.e. the majority of the MRS amendment area) and an upstream catchment 2US is expected to sheet flow (during sufficiently large rainfall events) generally towards Tonkin Highway, where a number of culverts are located to allow discharge under the highway into the adjacent MKSEA site. The main outlet locations discharge to Brentwood Road and Victoria Road. Runoff is currently discharged to the MKSEA located on the western side of Tonkin Highway. This is expected to continue to occur in the future prior to the development of the site. A small amount of runoff from Catchment 4, located to the south of the proposed development area, is conveyed to Discharge 4 which is conveyed southward towards a roadside swale on the eastern side of Tonkin Highway.

3.2.2.2 Post-development

The surface water regime is expected to change slightly in some regards in the post-development scenario. The overall flow regime and contributing catchment areas are generally consistent with the existing environment and the key discharge locations are maintained. The proposed future land use (see **Figure 7**) are anticipated to incorporate greater impervious areas which, unlike the existing impervious areas, are likely to be connected via kerbed roads and pit and pipe networks. The change in land use (from rural vegetation/pasture to urban) has the potential to increase flow volumes and flow rates leaving the MRS amendment area. This is however expected to be offset by the use of formalised drainage and infiltration infrastructure within the proposed development. These are designed to retain runoff from the first 15 mm of rainfall and maintain pre-development discharge rates. The stormwater management approach for the MRS amendment area is discussed in the DWMS (Hyd2O 2024).

It is noted that the DWMS does not account for ongoing infiltration within drainage structures (such as BRAs, soakwells and detention basins) which is very conservative however typical for assessments at the re-zoning stage. Infiltration has however been accounted for in the WBA by increasing the IL values to better represent the behavior of infiltration based drainage structures in the urbanised environment as all water quality treatment and flood detention structures will be logically placed into permeable areas. The infiltration achieved within the MRS amendment area by this approach will inform the future design approach for water management infrastructure.

3.2.3 Groundwater abstraction and irrigation

There are 14 groundwater licences issued by DWER for abstraction of groundwater from the superficial aquifer beneath the MRS amendment area. The groundwater allocations range from 2,400 kL/year up to 176,000 kL/year (which is associated with the existing turf farm). Combined, there is a total abstraction allocation of 260,655 kL of water from beneath the MRS amendment area each year.

The abstraction and irrigation of 176,000 kL is expected to result in a considerable net extraction from the relevant aquifer due to the additional exposure to evapotranspiration and interception losses. There is however a groundwater mound observed within the vicinity of the turf farm (as shown on **Figure 5**), which warrants additional consideration.

The site report for Swan Coastal Catchment Bore 616 (site reference 61601079) located within and presumably owned by the turf farm details drilling, screening, pump testing and production supply recommendations for the abstraction of groundwater from the bore (DWER 2022a). The report states the bore was drilled to 63 m BGL (approximately -41 m AHD) and screened from 52 m BGL to 62 m BGL (-30 m AHD to -40 m AHD). The recommended supply rate was 10 L/s. The presence of headworks on the bore was confirmed by Hyd2O during groundwater monitoring. While the *Water Register* (DWER 2024b) indicates that there are other bores located within the same groundwater management area and (superficial) aquifer no details are available as to whether these bores are drilled to the deeper soil profile.

The abstraction of superficial groundwater and subsequent losses to evapotranspiration would be expected to result in a depression in local groundwater levels. However, the observed mounding of groundwater beneath the turf farm suggests an additional source of water is being applied to the superficial aquifer that exceeds the additional losses to evapotranspiration from irrigation (which is expected to be around 80% of irrigated water). Based on the observed groundwater mounding, the available information regarding bore screened depth, and the ability for the identified production bore to abstract groundwater at sufficient rate to fulfill the requirements of the allocation (through pumping at the recommended 10 L/s for approximately 13.5 hours per day), it is assumed that the 176,000 kL/year allocation is being abstracted from the underlying Leederville aquifer.

The remainder of the superficial groundwater allocations within the MRS amendment area, which are mostly associated with rural residences, total 84,655 kL and are assumed to be utilised for irrigation of garden areas and to be abstracted from the superficial aquifer as licensed.

Irrigated water (which includes the 84,655 kL of superficial abstraction and 176,000 kL of assumed Leederville abstraction and 32,500 kL of domestic supply from current IWSS connections) is subject to the following interactions which have been based on previous research provided in PRAMS documentation (DoW 2009b):

- Irrigation water lost to interception: 10%
- Amount of irrigation water becoming recharge: 20%
- The remainder of irrigated water is assumed to be taken up by evapotranspiration: 70%

3.2.4 Groundwater throughflow

The groundwater throughflow assessment has been based on investigations undertaken within and around the MRS amendment area as described in **Section 2**. These include geotechnical investigations (test pits, borehole logs and permeability testing) and groundwater level investigations (metered groundwater datalogger data and manual measurements). The specific inputs and how they are utilised for the groundwater throughflow assessment are detailed further in the *Groundwater Throughflow Technical Assessment* provided in **Appendix C**.

In summary, the rate of flow has been calculated using Darcy's law which calculates flow through a porous medium based on the bulk cross-sectional flow area, the hydraulic gradient and the permeability of the medium (Equation 1).

(1)

$$Q = -kA\frac{dh}{dl}$$

where Q, the flow rate, is related to the hydraulic conductivity (k), bulk cross-sectional area (A) and the hydraulic gradient ($\frac{dh}{dl}$).

The bulk cross sectional flow areas at the boundaries of the MRS amendment area are the cross sectional areas between the base of the aquifer and the MGL determined from the groundwater contours.

The location of the groundwater throughflow boundaries and flow directions are shown on **Figure 8**, and **Figure 9** with a summary of the groundwater throughflow results and calculations (both inflow and outflow) are provided in Table C1 and C2 of **Appendix C** with the results used in **Section 4**.

Groundwater throughflow leaving the MRS amendment area is determined in the same manner as groundwater throughflow entering the MRS amendment area, which uses measured soil permeability, groundwater flow direction and gradient, and depth of permeable soil. Depending on the location of the outflow boundary, some of the throughflow leaving the MRS amendment area will become groundwater inflow to the downstream area, and this is quantified and accounted for in the WBA. The extent of groundwater throughflow boundaries are shown on **Figure 8** and **Figure 9**, and a detailed description of the analysis of groundwater throughflow (both inflow and outflow) is provided in **Appendix C**.

3.2.4.1 Superficial (regional/deep) groundwater throughflow

Groundwater throughflow is the lateral flow of groundwater which occurs through the deeper sandy or clayey sand profile and occurs at two levels beneath the MRS amendment area; within thin sand overlying a seasonal perched system and within the deeper superficial formation. Throughflow is driven by the groundwater gradient and direction where it occurs across the MRS amendment area boundary and the cross-sectional area of the soil profile through which water can flow. Lithology for deeper DWER bores (61601079, 61607580 and 61671956) (DWER 2020) indicate that the MRS amendment area is underlain by a lower permeability clay layer at approximately 27 m BGL. The lower boundary for groundwater throughflow is the base of the regional (superficial) aquifer based on DWER groundwater mapping (DWER 2024a). This is located approximately 27 m BGL (0 m AHD) and aligns with the clay layer noted previously.

Both the gradient and direction of groundwater flow across the MRS amendment area is influenced by the groundwater mound underlying the turf farm, however the effect is lessened as spatial separation from this groundwater mound increases. From pre-development groundwater investigations it was found that groundwater flows are influenced by the groundwater mound which is presumed to be caused by irrigation via deeper aquifers beneath the MRS amendment area and the highly variable subsurface geological conditions with a concentration of low permeability soils adjacent to Tonkin Highway (Hyd2O 2024). The effect of this mound causes the groundwater to flow radially away from the mound (see **Figure 8**). As discussed in **Section 2.6.1**, the borehole permeability values were adopted as the horizontal permeability for the majority of the MRS amendment area (except for a small portion of the site which has been identified by geophysical mapping with the presence of deep, lower permeability soils) where a 50% reduction factor has been applied to the permeability values.

In the post-development environment the turf farm irrigation ceases and it is acknowledged that in absence of other factors this lack of irrigation water may affect groundwater levels locally. A key principle adopted within the DWMS is to locate stormwater management areas in the vicinity of the existing groundwater mound to maintain the annual pre-development groundwater recharge and flow directions at that location (Hyd2O 2024). This approach utilises the recharge estimates presented within the WBA and considers the recharge to groundwater under three scenarios:

- Across the entire MRS amendment area
- Within a 29 ha area that encompassed the groundwater mound
- Localised 14 ha area associated with the existing turf farm.

Results of this are presented within the DWMS and indicate that there will be an overall minor increase in annual recharge across the site post-development. The implementation of a targeted stormwater management approach applied to the area of the existing mound results in a similar annual recharge to the pre-development environment. It is likely that localised changes in seasonal distribution of rainfall may impact the recharge at this location. However, given the existing geological conditions and groundwater gradients this is considered unlikely to impact the groundwater flow directions in this area. Based on the above the groundwater mound is expected to be maintained in the post-development environment through the implementation of a target stormwater management approach applied to the area of the existing mound. Therefore, for the purposes of this water balance assessment, groundwater throughflow will continue to occur radially from the MRS amendment area due to the continued presence of the groundwater mound. Note that this is within the deeper superficial aquifer (i.e. not shallow perched groundwater).

It is not anticipated that coordinated major earthworks that would modify the deeper soil profile will be implemented across the MRS amendment area and therefore, the pre-development and post-development soil profiles are expected to be consistent due to the general site characteristics requiring minimal interference during development. Also of note is measured groundwater levels in the superficial aquifer being several metres lower than the measured perched (shallow) groundwater levels (see **Section 3.2.4.2**) observed along the western boundary, and therefore changes in magnitude or flow direction within the MRS amendment area is unlikely to affect shallow groundwater throughflow that is expected to occur along the western boundary and beneath the GBSW in proximity to the MRS amendment area

3.2.4.2 Perched (shallow) groundwater throughflow

Seasonal perched groundwater (which exists in the thin layer of sand above a lower permeability clay layer) has been observed in groundwater bores located adjacent to Tonkin Highway (GW5S, GW8S and GW9S) as well as within two bores to the north of the MRS amendment area (WG4S and WG10S).

Based on measured groundwater levels, bores GW4S and GW10S appear to be hydraulically upstream of the shallow Tonkin Highway bores (e.g. GW5, GW9) (discussed in **Section 2.7.2**). However, the perched systems at these locations are unlikely to be connected given the deep sandy profile and lack of shallow clays in bores WG3 and WG7S/D situated between these two locations. Based on this it is expected that localised perched groundwater will generally disperse into immediately adjacent areas to infiltrate through to the superficial aquifer (at WG3/7) and along the clay layer towards bore WG10. The base and location of the localised perched areas is based on available bore logs and ranges between 15.14 m AHD and 20.11 m AHD.

While shallow clay conditions have been observed to the west of the MRS amendment area (approximately aligning with Tonkin Highway) perched shallow groundwater would flow towards this boundary and leave the MRS amendment area. However, due to the presence of Tonkin Highway, it is expected that the shallow soil profile would be intersected by an impermeable road base layer. It is therefore expected that Tonkin Highway would create an impermeable flow boundary which effectively inhibits the flow of perched shallow groundwater towards the west, resulting in a no flow boundary condition. This is reflected in the results of the WBA presented in **Section 4**.

Based on the above, flow of perched groundwater is expected to discharge from the MRS amendment area to the north only (via the WG4 to WG10 pathway). No flow is expected to the west due to the presence of Tonkin Highway (via the sections of identified and indicated as perched systems along the western boundary). As any perched system flow is driven by rainfall it is expected that perched flow would be seasonal, and likely only occurring in months of higher rainfall (i.e. May – September).

The shallow soil profile found within this portion of the MRS amendment area is not expected to be modified from the proposed development, and infiltration is likely to be dispersed through the MRS amendment area. Therefore, there are no drivers for change to there being no shallow/perched groundwater leaving the site towards the GBSW from this portion of the MRS amendment area. This also aligns with the DBNGP which will not be developed as the *Dampier to Bunbury Pipeline Act 1997* prohibits development within this corridor. It is expected that any shallow/perched groundwater which does flow towards the western boundary of the MRS amendment area would be intercepted by the DBNGP (which is assumed to be constructed using highly permeable sands and aggregates) which would promote the downward percolation of groundwater.

Therefore, the only perched groundwater expected to leave the site (horizontally) is from the higher permeability soil pathway located along the northern boundary. No westerly flows of perched shallow groundwater are expected towards the GBSW (found across Tonkin Highway to the west of the development) due to the presence of the DBNGP and Tonkin Highway found along the western boundary of the MRS amendment area.

The seasonal peak perched groundwater level contours and throughflow pathways are shown on **Figure 9**.

3.2.5 Evapotranspiration

The rate of evapotranspiration is dependent primarily on the land use and associated soils found beneath these land uses (as well as independent climatic factors). Developed areas that are predominately roof/road/hardstand have minimal rates of evapotranspiration while heavily vegetated areas have relatively higher evapotranspiration rates. The depth of the groundwater relative to the surface can have an effect on the rate of evapotranspiration where the capillary fringe is close to the surface of the soil profile (this can increase the amount of evapotranspiration). For the MRS amendment area this is not a significant consideration due to the large depth to groundwater beneath the majority of the WBA area and the poorly defined spatial extent of shallow perched groundwater conditions (and which only occurs in minor areas along the boundaries).

Previous research undertaken during the development of the PRAMS (DoW 2008, 2009a, b, c, d) has demonstrated that the estimation of evapotranspiration can be performed through the use of a VFM for regional scale investigations of evapotranspiration. However, the losses to evapotranspiration can also be determined by quantifying all other components of the assessment as a percentage of rainfall, such as groundwater recharge, surface runoff and interception. This method is useful for smaller scale evapotranspiration assessments as published data for similar land uses can provide sufficient levels of detail for the estimation of evapotranspiration (W. Dawes [CSIRO] 2022, pers. comm., 10 October). With all components quantified from these published PRAMS values they are removed from the indicative rainfall for the MRS amendment area (and irrigation water if applied) to estimate evapotranspiration.

The methodology that has been prescribed by for the estimation of evapotranspiration has been followed within the MRS amendment area and delineated into several RRUs which are based on soil type, vegetation type and land use. This has been done for the pre-development and post-development environments. Each land use has been spatially categorised and parameterised based on the generally observed soil profile, groundwater depth and vegetation cover. For the purposes of the WBA it is assumed that the soil profile and groundwater regime do not change as a result of future development, therefore changes to vegetation cover is the key component in determination of evapotranspiration.

As detailed in **Appendix D**, for the pre-development environment, 37.3% of rainfall is determined to become recharge to groundwater, 10.3% is intercepted by vegetation/leaf litter, 7.1% becomes surface runoff and 45.3% of rainfall is estimated to be taken up by evapotranspiration. For the post-development environment the land uses change to become more urbanised (i.e. less vegetation and more impervious surfaces) which influence the evapotranspiration estimation. In the post development scenarios 51.2% of rainfall is determined to become recharge to groundwater, 6.8% is intercepted by vegetation/leaf litter, 8.3% becomes surface runoff and 33.6% of rainfall becomes evapotranspiration.

For the purposes of determining evapotranspiration, irrigation water (abstracted from groundwater beneath the MRS amendment area and from the IWSS) has been considered separately, but in the same manner as rainfall. Assumptions for the amount of evapotranspiration from this source of water are consistent between the pre-development and post-development environment and as per PRAMS methodology (see **Section 3.2**). Evapotranspiration of irrigation water applied to the site is then combined with the evapotranspiration estimated from rainfall to provide the total estimated evapotranspiration.

4 Water Balance

4.1 Water balance assessment

A conceptual water balance has been developed for the WBA area which considers the pre-development and post-development environments of the MRS amendment area and surrounding UE and UI areas. For the post-development environment, two scenarios have been considered: one where the UE and UI areas are not developed, and one where these areas are developed for urban uses as per the MRS amendment area. This approach allows analysis of the potential impacts to the WBA from the development of the upstream catchments. This section presents the quantification and summation of the water balance elements discussed in **Section 3**.

The pre-development environment WBA has quantified each component of the assessment and has provided a basis for assessing the impacts of the proposed development. The water balance assessment calculates the magnitude and direction of the movement of water attributable to each of the elements described in **Section 3**. Each element is detailed further within the respective technical summaries (see **Appendices B**, **C**, **D** and **E**).

Two post-development water balance scenarios have been considered for the WBA, one which assumes the upstream UE and UI areas are urbanised and one which assumes that the upstream UE and UI areas are not urbanised. These scenarios both follow the same methodology as the pre-development water balance. It assumes that rainfall remains the same i.e. it assumes that future rainfall and climate conditions are reflective of the period assessed in the WBA. The primary factors which influence the post-development water balances are the amount of impervious area resulting from the urban development proposed for the MRS amendment area and the development condition of the upstream catchments (i.e. whether it becomes urbanised or not urbanised).

The pre-development and post-development water balances are presented in **Table 5**.

4.1.1 Superficial aquifer recharge

The post-development WBA has determined that in both post-development scenarios there will be an increase in available water for the MRS amendment area. This water will likely become recharge to the superficial aquifer system located beneath the MRS amendment area. The annual amount of rainfall that will become recharge to the superficial aquifer in the pre-development scenario is 313,871 kL and in the two post-development scenarios is 379,011 kL.

4.1.2 Urban expansion and investigation area recharge

Recharge generated by the UE and UI areas (the upstream catchments) adjacent to the MRS amendment area are considered as these areas could potentially be urbanised in the post-development scenario. It is assumed that all previous WB components for the post-development scenario will be applicable to these areas. A conservative approach for estimating groundwater recharge is to proportion the recharge determined for the MRS amendment area to the upstream catchments area (Ct 1US and 2US). Using this approach the areas of the upstream catchments are approximately 52.5% of the MRS amendment area. Therefore, the groundwater recharge generated by the upstream catchments is 198,981 kL for the urbanised post-development scenario.

4.1.3 Interpretation of water balance and impacts

The water balance shows that, as a result of urbanisation, the following responses can be inferred for post-development environments as compared to pre-development conditions:

- Increased (slightly) groundwater abstraction from the superficial aquifer beneath the MRS amendment area (due to irrigation of POS and School areas)
- Decreased groundwater abstraction from the deeper Leederville aquifer beneath the MRS amendment area (due to cessation of irrigation from the deeper aquifer)
- Reduction in rainfall and irrigation water interception (due to less vegetation and overall less irrigation)
- Increase in surface water runoff and drainage (due to more impervious surfaces)
- Increase in groundwater recharge and through flow within the superficial aquifer beneath the MRS amendment area and UE and UI areas (due to increased recharge resulting from less vegetation and more impermeable surfaces).

Overall, in the post-development scenarios evapotranspiration within the WBA area is reduced, and while this is offset by a minor increase in surface water runoff, there is a net increase in water within the WBA areas. Given the permeable sandy profile beneath most of the MRS amendment area and proposed stormwater management approach, the increase in (or residual) water volume will result in an increase in groundwater recharge to the superficial aquifer. Surface water outflows for the MRS amendment area increase by approximately 11% to 24%. Evapotranspiration decreases by approximately 26% for rainfall and 43% for irrigation water (both groundwater and IWSS) from pre-development levels. Both of these influences can be attributed to the increase in urbanisation, reduction of vegetation across the MRS amendment area and reduction in irrigation water application from the proposed development.

Groundwater throughflow has not been calculated for the UE/UI areas in the pre and post-development environment due to the conceptual understanding of the site (see **Section 2.9**) which indicates the UE/UI areas are located at the top of the catchment to the east of the MRS amendment area which will direct GW throughflow away from the MRS amendment area.

Whilst the MRS amendment area will experience increased recharge to groundwater from urban development groundwater flows are expected to approximate pre-development flows due to the post-development stormwater management approach discussed in **Section 3.2.4.1** and in the DWMS (Hyd2O 2024). Given the radial direction of flows exiting the MRS amendment area there is the potential for impacts to occur to GBSW and the MKSEA area. However, given the post-development groundwater flows are expected to approximate pre-development flows and that the superficial aquifer is several metres below the shallow perched conditions experienced along the western boundary of the site and the portion of GBSW near the site, the development of the MRS amendment area will not affect localised perched conditions beneath GBSW.

Table 5: Wattle Grove water balance

Water balance component	Pre-development (kL)	Post-development (kL) – UE, UI areas undeveloped	Post-development (kL) – UE, UI areas fully developed
Inflows			
Rainfall	928,888	928,888	928,888
Upstream catchment inflows	34,536	34,536	48,210
Irrigation water application (of superficial aquifer origin)	84,655	123,694	123,694
Irrigation water application (of Leederville aquifer origin)	176,000	0	0
Irrigation water application (from IWSS)	32,500	46,000	46,000
Groundwater throughflow (superficial aquifer)	32,212	32,212	32,212
Total inflows	1,288,791	1,165,330	1,179,004
Outflows			
Rainfall interception	95,346	63,529	63,529
Irrigation water interception	29,316	18,206	18,206
Groundwater abstraction (of superficial aquifer origin)	84,655	123,694	123,694
Surface water runoff and drainage outflow (inclusive of upstream flows)	100,337	111,422	125,096
Groundwater throughflow (superficial aquifer)	346,081	411,223	411,223
Groundwater throughflow (perched groundwater)	7,280	7,280	7,280
Evapotranspiration (of rainfall)	420,566	312,427	312,427
Evapotranspiration (of irrigation water and IWSS)	205,209	117,549	117,549
Total outflow	1,288,791	1,165,330	1,179,004

4.1.4 Water balance changes to GBSW

The MRS amendment area is immediately bound by Tonkin Highway to the west, with GBSW in proximity to the west of Tonkin Highway. Post-development surface water runoff flows from the MRS amendment area will have a contribution to the export of water to the GBSW. The post development scenario with both the MRS amendment area and the upstream catchments being fully developed have been considered in the context of impacts to GBSW. **Table 6** presents the changes in surface water runoff between the pre-development and post development scenarios and the potential impacts this has to GBSW.

Table 6: Wattle Grove water balance post-development percentage change

Water balance component	Pre-development (kL)	Post-development change (%) to overall water balance – UE, UI areas fully developed	Post-development change (%) to the west of site
Inflows			
Rainfall	928,888	0%	0%
Upstream catchment inflows	34,536	+39.6%	0%
Irrigation water application (of superficial aquifer origin)	84,655	+46.1%	0%
Irrigation water application (of Leederville aquifer origin)	176,000	-100%	0%
Irrigation water application (from IWSS)	32,500	+41.5%	0%
Groundwater throughflow (superficial aquifer)	32,212	0%	0%
Outflows			
Rainfall interception	95,346	-33.4%	0%
Irrigation water interception	29,316	-37.9%	0%
Groundwater abstraction (of superficial aquifer origin)	84,655	+46.1%	0%
Surface water runoff and drainage outflow (inclusive of upstream flows)	100,337	+24.7%	+16.4%
Groundwater throughflow (superficial aquifer)	346,081	+18.8%	0%
Groundwater throughflow (perched groundwater)	7,280	0%	0%
Evapotranspiration (of rainfall)	420,566	-25.7%	0%
Evapotranspiration (of irrigation water and IWSS)	205,209	-42.7%	0%

The impacts to GBSW from the development of the MRS amendment area and upstream catchments are minimal with the only noted change being an increase in surface runoff exported from the MRS amendment area. The volume of surface water runoff exported from the MRS amendment area toward the GBSW is noted as increasing by 16.4%, however it is noted that this only represents 0.4% of the overall water balance.

Whilst groundwater throughflow is noted as increasing in the post-development environment this can be attributed to the increase in available water (from recharge) to the superficial aquifer. This increase recharge will assist in maintaining the groundwater mound, alongside the proposed stormwater management approach detailed in the DWMS, and so changes to groundwater flow towards GBSW are unlikely to occur. This increased recharge (65,142 kL) represents 5.5% of the overall water balance (1,179,004 kL).

4.2 Climate change sensitivity

The WBA has been developed to be a representation of the recent average hydrological system and therefore does not initially consider the impacts of climate. To provide a more robust WBA which considers any potential future climate change impacts relevant inputs should be included which account for a warmer, drier climate.

To account for climate change factors, a future climate prediction dataset was obtained from DWER to assess changes to key water balance inputs due to climate change (rainfall and evapotranspiration) (DWER 2021). The dataset from DWER is based on the climatic scenario projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset (associated with the Intergovernmental Panel on Climate Change's (IPCC) 4th assessment report) (IPCC 2007). The DWER dataset uses the climate scenario projections to predict future climate data extrapolated from an observed climate baseline obtained from the Australian climate database named 'SILO' (Queensland Government 2021). The DWER climate prediction dataset provides predicted future climatic data in daily intervals for three climate change scenarios (wet, med, dry) at a time horizon of 2050 and 2100. The predictions are geographically based and as such the dataset obtained for this assessment has been calculated specifically for location of the assessment. The 2050 and 2100 'Dry' scenarios were selected for the climate change assessment as a pessimistic/conservative prediction.

Rainfall, associated runoff and evapotranspiration are the most significant components of the water balance by magnitude and future climate prediction data is available for rainfall, making assessment of climate response possible. While there will likely also be a direct effect on the other smaller-magnitude water balance components, future climatic predictions (specifically relevant to the MRS amendment area) for these components are not readily available. However, these components are altered indirectly due to flow on effects from changes in other components due to changes in water availability, which has been considered as part of this sensitivity analysis.

Future climate change predictions from DWER (2021) are summarised in **Table 7** with comparison made to the latest 11 years (2010-2020) of climate observations (from the SILO data provided by DWER). The rainfall reduction is applied as a modification to the annual runoff model such that these cumulatively approximate the predicted annual rainfall. The relative change of rainfall (-4.4% and -34.5%) from the 2010-2020 baseline has been applied to the associated water balances process to estimate the impact of climate change. The rainfall reduction resulting from climate change affects the following water balance components:

- Rainfall
- Upstream catchment flows
- Rainfall interception
- Surface water runoff from the MRS amendment area
- Evapotranspiration.

Table 7: Climate change factors

Climate Change Factor	Baseline average (2010-2020) (DWER, SILO 2021)	Future climate prediction (DWER 2021) percentage change from 2010-2020 baseline	
		Dry 2050	Dry 2100
Annual rainfall (mm) (Gosnells)	656	627 (-4.4%)	430 (-34.5%)
Annual rainfall used in the surface water balance (mm) (Jandakot hourly dataset)	735	702 (-4.4%)	481 (-34.5%)

The water balance was revised based on the predicted rainfall with the same methodology described in **Section 3**. For the assessment of climate change factors two post-development environments have been considered, one where the upstream catchments are undeveloped (remain rural residential) and one where they are fully developed (urbanised) for the two climate change scenarios considered. The resulting water balance incorporating climate change factors is summarised in **Table 8** and **Table 9**.

For the undeveloped upstream catchment recharge decreases to the superficial aquifer beneath the MRS amendment area to 358,334 kL in the Dry 2050 scenario, which is a reduction of 5.5% in comparison to the post-development environment without climate change factors. The Dry 2100 scenario shows recharge further decreasing to 214,939 kL, which is a reduction of 43.3% to the post-development scenario and effectively indicating that there will be minimal net additional recharge to the superficial aquifer (when compared to the pre-development environment).

For the fully developed upstream catchment recharge decreases to the superficial aquifer beneath the MRS amendment area to 358,370 kL in the Dry 2050 scenario, which is a reduction of 5.4% in comparison to the post-development environment without climate change factors. The Dry 2100 scenario shows recharge further reducing to 214,931 kL, which is a reduction of 43.3% to the post-development scenario and effectively indicating that there will be minimal net additional recharge to the superficial aquifer (when compared to the pre-development environment).

As is the case in the post-development water balance without climate change, the key influences of urbanisation are shown to be a decrease in evapotranspiration resulting in an increase in groundwater recharge. With the inclusion of climate change, rainfall reduces which significantly reduces surface water runoff leaving the MRS amendment area.

Overall, the impact of climate change on the water balance is relatively small in the Dry 2050 scenario but more significant for the Dry 2100 scenario. The most significant impact is seen in the surface water inflows and outflows for the MRS amendment area, which reduce by approximately 8% to 10% in the Dry 2050 scenario and 59% to 60% in the Dry 2100 scenario when compared to the post-development environment.

It is noted that changes to storm intensity are also expected to occur due to climate change, however are generally poorly understood at this stage, as described in ARR (Ball J *et al.* 2019). Longer term average rainfall influences are represented in the water balance through inclusion of the climate change rainfall predictions provided by DWER. This has been used to account for the change of annual rainfall magnitude within the water balance, which is assessed over an annual time period.

The effects of the two climate change scenarios for impacts on GBSW have been considered during this WBA. These have been undertaken using the same methodology as presented in **Section 4.1.4**. For the Dry 2050 scenario with fully urbanised upstream catchments the surface water runoff exported from the MRS amendment area to GBSW reduces from 16.4% (in the post-development scenario without climate change factors) to 5.1% which represents 0.1% of the overall water balance. For the Dry 2100 scenario with fully urbanised upstream catchments the surface water runoff exported from the MRS amendment area reduces by 60.4%.

Table 8: Wattle Grove water balance with climate change factors with upstream catchments undeveloped

Water balance component	Post-development (kL)	Post-development (kL) Dry 2050	Post-development (kL) Dry 2100
Inflows			
Rainfall	928,888	887,963	608,350
Upstream catchment inflows	34,536	33,214	17,700
Irrigation water application (of superficial aquifer origin)	123,694	123,694	123,694
Irrigation water application (of Leederville aquifer origin)	0	0	0
Irrigation water application (from IWSS)	46,000	46,000	46,000
Groundwater throughflow (superficial aquifer)	32,212	32,212	32,212
Total inflows	1,165,330	1,123,083	827,956
Outflows			
Rainfall interception	63,529	60,684	41,580
Irrigation water interception	18,206	18,206	18,206
Groundwater abstraction (of superficial aquifer origin)	123,694	123,694	123,694
Surface water runoff and drainage outflow (inclusive of upstream flows)	111,422	102,641	45,979
Groundwater throughflow (superficial aquifer)	411,223	390,546	247,151
Groundwater throughflow (perched groundwater)	7,280	7,280	7,280
Evapotranspiration (of rainfall)	312,427	302,483	226,517
Evapotranspiration (of irrigation water)	117,549	117,549	117,549
Total outflow	1,165,330	1,123,083	827,956

Table 9: Wattle Grove water balance with climate change factors with upstream catchments fully developed

Water balance component	Post-development (kL)	Post-development (kL) Dry 2050	Post-development (kL) Dry 2100
Inflows			
Rainfall	928,888	887,963	608,350
Upstream catchment inflows	48,210	43,523	21,269
Irrigation water application (of superficial aquifer origin)	123,694	123,694	123,694
Irrigation water application (of Leederville aquifer origin)	0	0	0
Irrigation water application (from IWSS)	46,000	46,000	46,000
Groundwater throughflow (superficial aquifer)	32,212	32,212	32,212
Total inflows	1,179,004	1,133,392	831,5258
Outflows			
Rainfall interception	63,529	60,684	41,580
Irrigation water interception	18,206	18,206	18,206
Groundwater abstraction (of superficial aquifer origin)	123,694	123,694	123,694
Surface water runoff and drainage outflow (inclusive of upstream flows)	125,096	112,950	49,549
Groundwater throughflow (superficial aquifer)	411,223	390,582	247,143
Groundwater throughflow (perched groundwater)	7,280	7,280	7,280
Evapotranspiration (of rainfall)	312,427	302,447	226,524
Evapotranspiration (of irrigation water)	117,549	117,549	117,549
Total outflow	1,179,004	1,133,392	831,525

5 Conclusions

The MRS Amendment area is characterised as a groundwater recharge area given the sandy soils, minimal surface outflows and high groundwater throughflow leaving the site. Groundwater within the superficial aquifer that does flow in a westerly direction is a modest component of the water balance, and given that the superficial aquifer is several metres below the shallow perched conditions experienced along the western site boundary and beneath the portion of GBSW near the site, the changes to recharge beneath the MRS amendment area will not affect localised perched conditions beneath GBSW.

A conceptual water balance has been developed which considers the pre-development and post-development environments of the MRS amendment area and the UE and UI areas. The pre-development environment WBA has quantified each component of the assessment and has provided a basis for assessing the impacts of the proposed development.

The result of this WBA shows that there is a net increase in available water and this is attributable to the increased areas of impermeable surface and removal of pasture and vegetated areas that will likely occur as a result of urbanisation within the proposed development and UE and UI areas. These land use changes affect evapotranspiration, surface runoff and drainage which in turn result in an overall increase in available water of 65,141 kL within the MRS amendment area. Given the permeability of soils within the MRS amendment area, and the ability for stormwater management infrastructure to be located within permeable areas, this increase in available water will result in increased recharge to the superficial aquifer. This increase in recharge will assist, alongside the proposed stormwater management approach for the development, in maintaining the existing groundwater mound beneath the MRS amendment area. Groundwater flows are expected to be maintained and will continue to flow radially away from the mound. It is noted that groundwater which flows to the west towards Tonkin Highway is the same direction as GBSW but due to the lower elevation at which that this flow occurs, it is not expected to impact GBSW.

The WBA has identified that the key drivers of the hydrological regime within the WBA areas as surface water runoff and evapotranspiration. The proposed development will result in significantly increased hardstand area, reducing the evapotranspiration (and rainfall interception) for the MRS amendment area. The increased area of impermeable surfaces (such as roads, roofs, etc.) will also impact the other identified key driver of the WBA, which is surface water runoff. The overall volume of rainfall which becomes surface water runoff has been found to increase slightly as a result of urbanisation. This increase in surface water runoff can be managed through the logical placement of stormwater management infrastructure to ensure any additional surface water generated as a result of development is captured, treated and infiltrated on site. This will ensure that no additional surface water runoff enters GBSW.

The available water volume recharging the superficial aquifer could potentially increase groundwater depth beneath the MRS amendment area, as well as any surrounding areas that are directly connected to the superficial aquifer. However, none of the water balance components are significantly influenced by groundwater elevation due to the pre-existing depth of the superficial aquifer found beneath the MRS amendment area. It is therefore concluded that the urbanisation of the MRS amendment area will not adversely impact the existing hydrological regime in GBSW.

The effect of climate change has been incorporated into the water balance model as a separate scenario that adopts reduced rainfall patterns. The assessment for climate change has been based on the 'Dry' climate scenario at a time horizon of 2050 and 2100 and assumes that rainfall is expected to decrease by 4.4% and 34.5% respectively as per DWER estimates.

The predicted rainfall has influenced the following components of the water balance:

- Rainfall
- Upstream catchment flows
- Rainfall interception
- Surface water runoff and drainage
- Evapotranspiration.

The flow-on impacts of these changes also effect groundwater driven processes (throughflow and recharge).

The outcomes of the climate change sensitivity showed that in the Dry 2050 scenario the impact of the assessed climate changes was relatively small, being similar to the post-development (urbanised) water balance. Surface water flows reduced by approximately 10%, when compared to the base case post-development scenario, but were still greater than the pre-development environment. This results in a reductions of surface water runoff exported towards GBSW from 16.4% to 5.1% in the Dry 2050 scenario, which represents 0.1% of the total water balance. Evapotranspiration and rainfall decreased further from the pre-development scenario as a direct result of the reduction in rainfall associated with climate change. Reduction to the other water balance components were also noted as a result of the reduction in rainfall.

The Dry 2100 scenario indicates more significant reductions in surface water runoff from the site overall will occur with a reduction of approximately 60% when compared to the base case post-development scenario, or approximately 50% lower than pre-development levels. Surface water runoff exported towards GBSW also reduces by approximately 57% when compared to the base case post-development scenario. Evapotranspiration and interception also reduce significantly, being a portion of rainfall and irrigation. Increases to recharge to the superficial aquifer system beneath the MRS amendment area under this scenario are minimal with recharge to the superficial aquifer approximating the pre-development environment.

6 References

6.1 General references

The references listed below have been considered as part of preparing this document.

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6.2 Online references

The online resources that have been utilised in the preparation of this report are referenced in **Section 7.1**, with access date information provided in **Table R1**.

Table R 1 Access dates for online references

Reference	Date accessed	Website or dataset name
(BoM 2020)	November 2020	Climate Data Online
(DWER 2024a)	January 2024	Perth Groundwater Map
(DWER 2022b)	October 2022	Water Information Reporting
(DWER 2024b)	January 2024	Water Register
(Queensland Government 2020)	May 2020	SILO Climate Database
(Queensland Government 2021)	May 2021	SILO Climate Database

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Figures

Figure 1: MRS amendment area Location

Figure 2: Topography and Groundwater Contours

Figure 3: Geomorphic Wetlands and Bush Forever

Figure 4: Regional Geology and Investigations

Figure 5: Groundwater Investigations

Figure 6: Hydrological Features

Figure 7: Post-development Surface Water Runoff

Figure 8: Superficial Groundwater Throughflow

Figure 9: Perched Groundwater Throughflow

Figure 10: Pre-development Evapotranspiration

Figure 11: Post-development Evapotranspiration

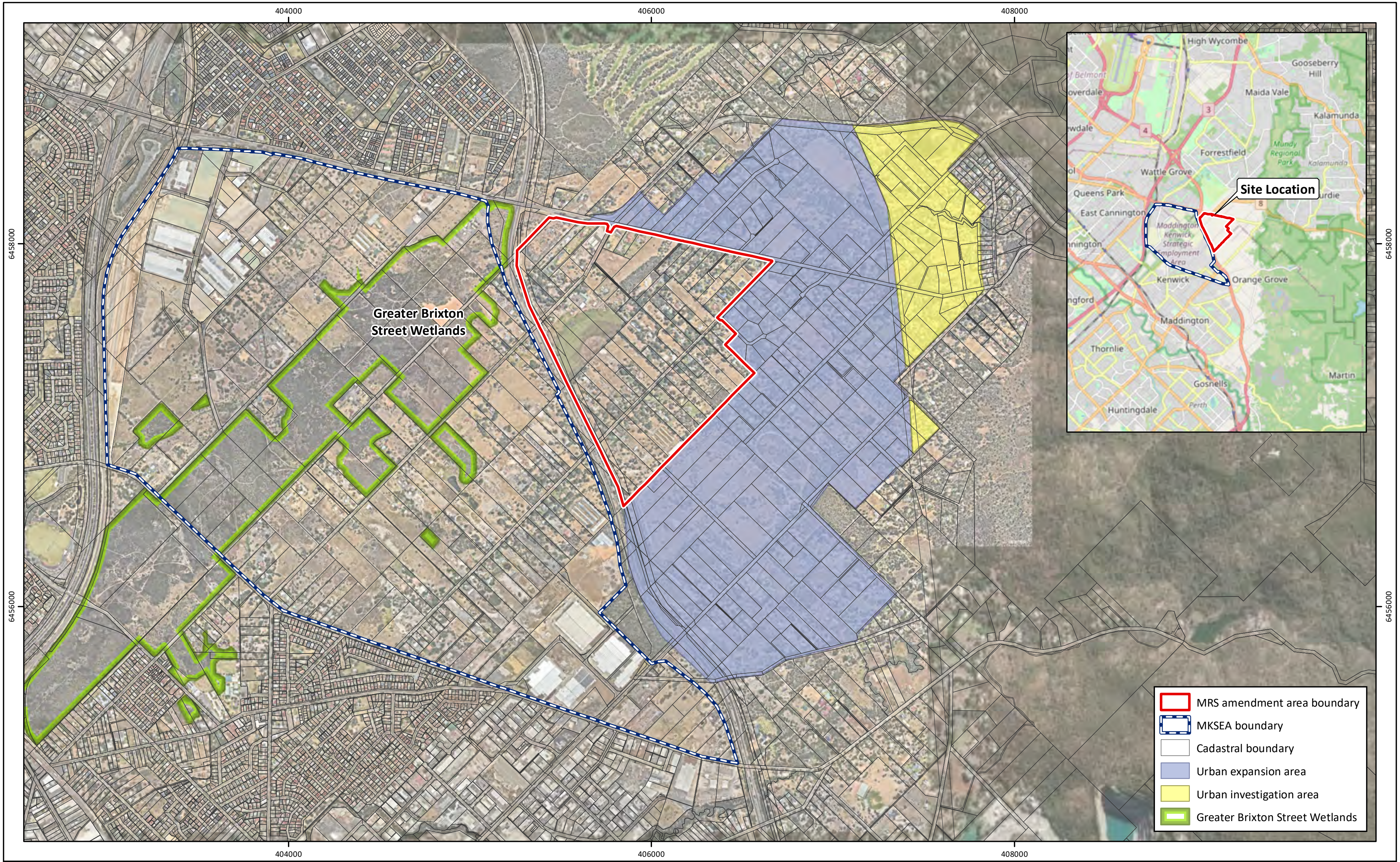

Figure 1: **MRS Amendment Area Location**

Project:	Water Balance Assessment Wattle Grove South
Client:	Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F01a

Drawn:	GAR
Date:	06/01/2023
Checked:	BPB
Approved:	DPC
Date:	12/05/2023

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Scale: 1:27,500@A4
GDA 1994 MGA Zone 50

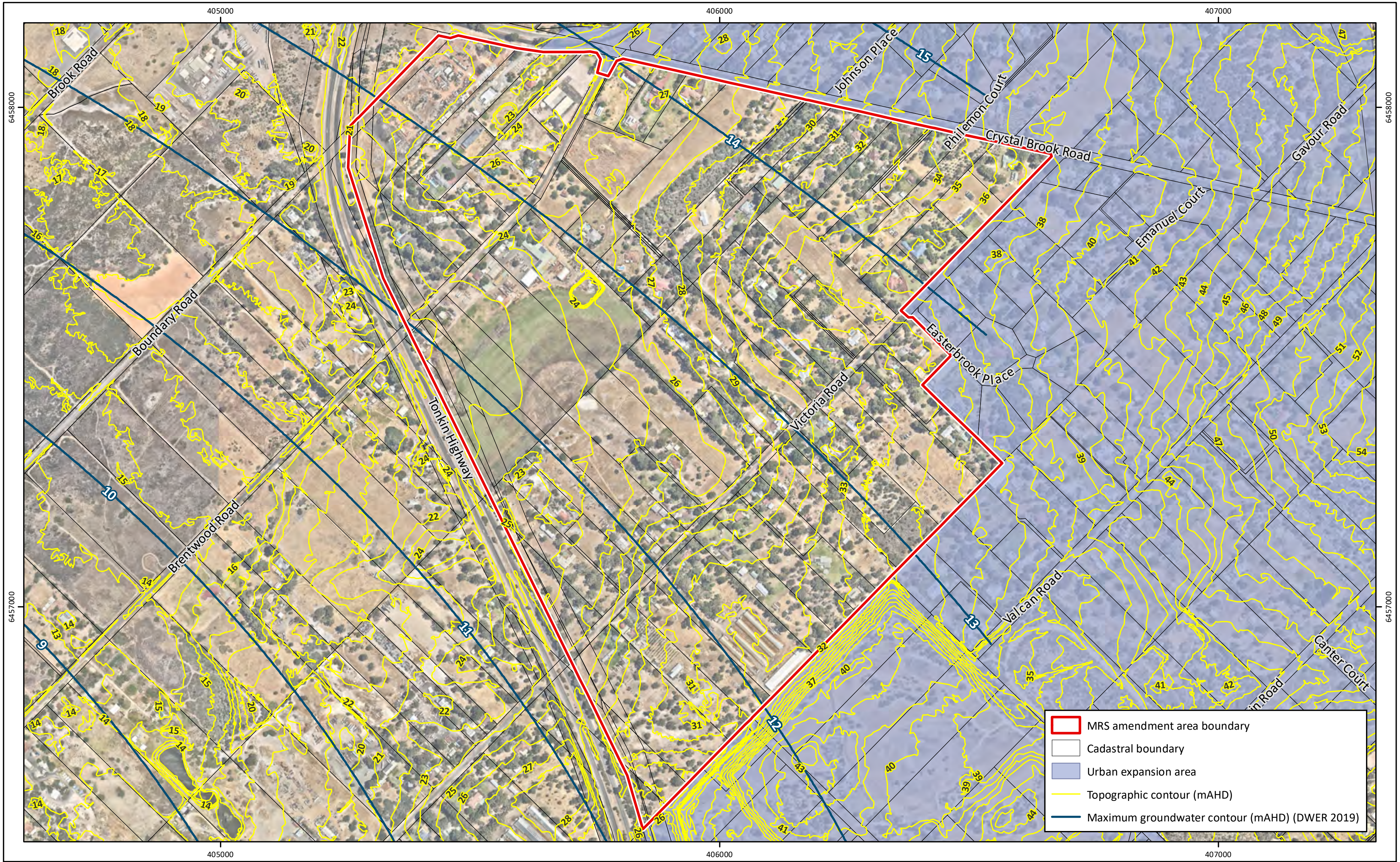

Figure 2: **Topography and Regional Groundwater Contours**

Project:	Water Balance Assessment Wattle Grove South
Client:	Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F02b

Drawn:	GAR
Date:	18/01/2024
Checked:	BPB
Approved:	DPC
Date:	23/01/2024

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emerge ASSOCIATES

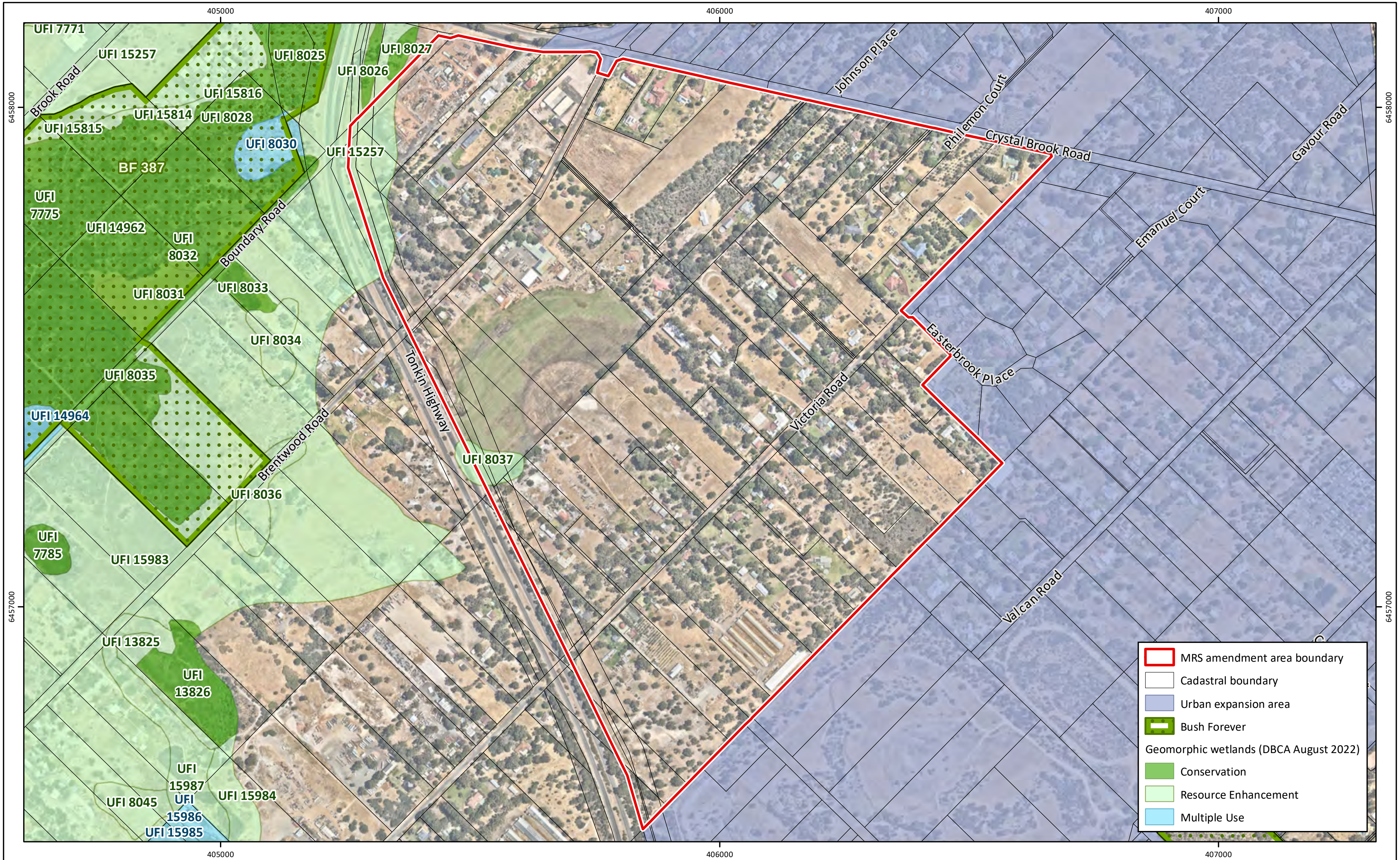

Figure 3: **Geomorphic Wetlands and Bush Forever**

Project: Water Balance Assessment
Wattle Grove South
Client: Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F03a
Drawn: GAR
Date: 06/01/2023
Checked: BPB
Approved: DPC
Date: 19/01/2023

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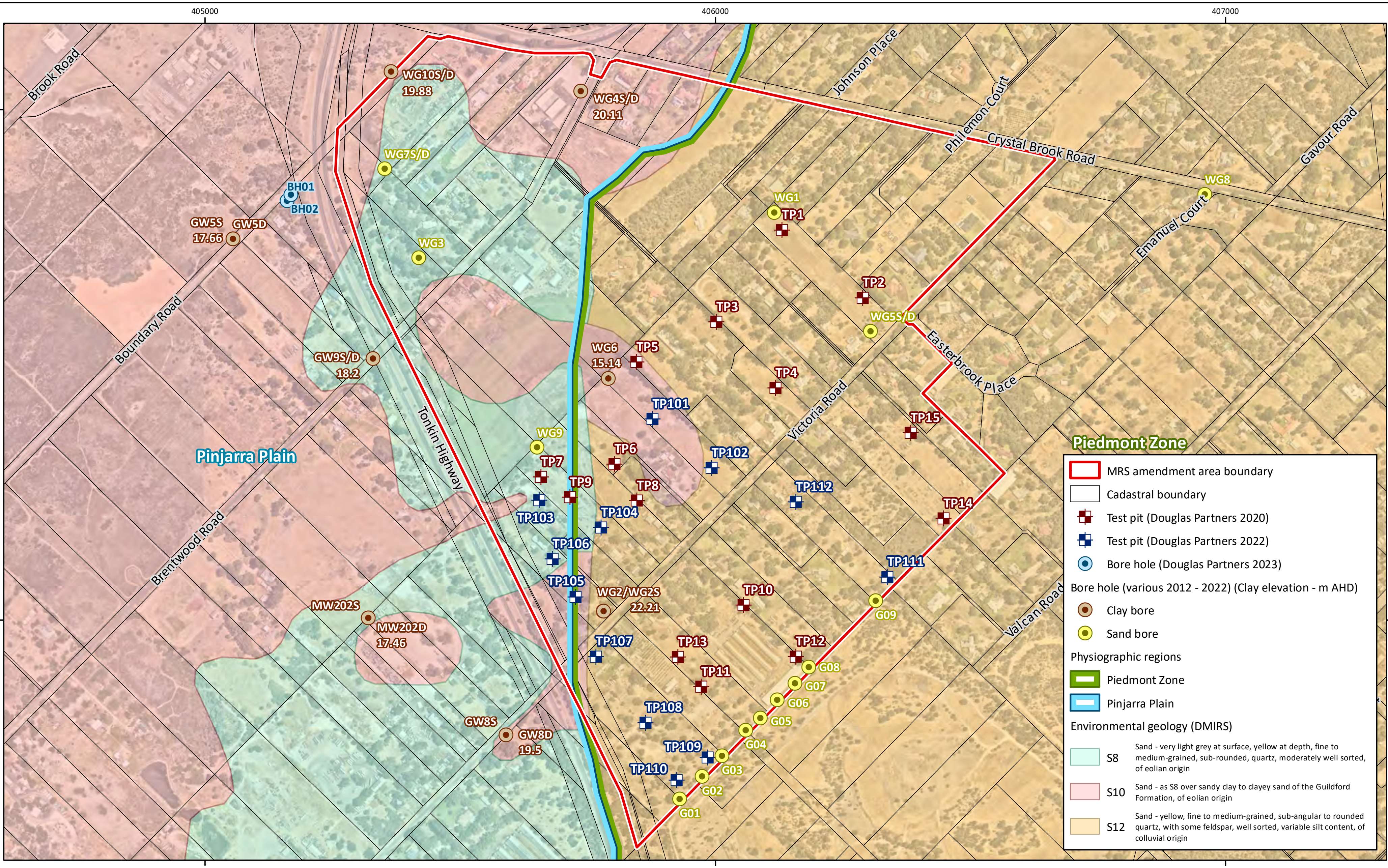

Figure 4: **Regional Geology and Investigations**

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GDA 1994 MGA Zone 50

Project:	Water Balance Assessment Wattle Grove South
Client:	Hesperia Pty Ltd

Plan Number:	
EP22-002(03)--F04d	
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Checked:	BPB
Approved:	DPC
Date:	23/01/2024

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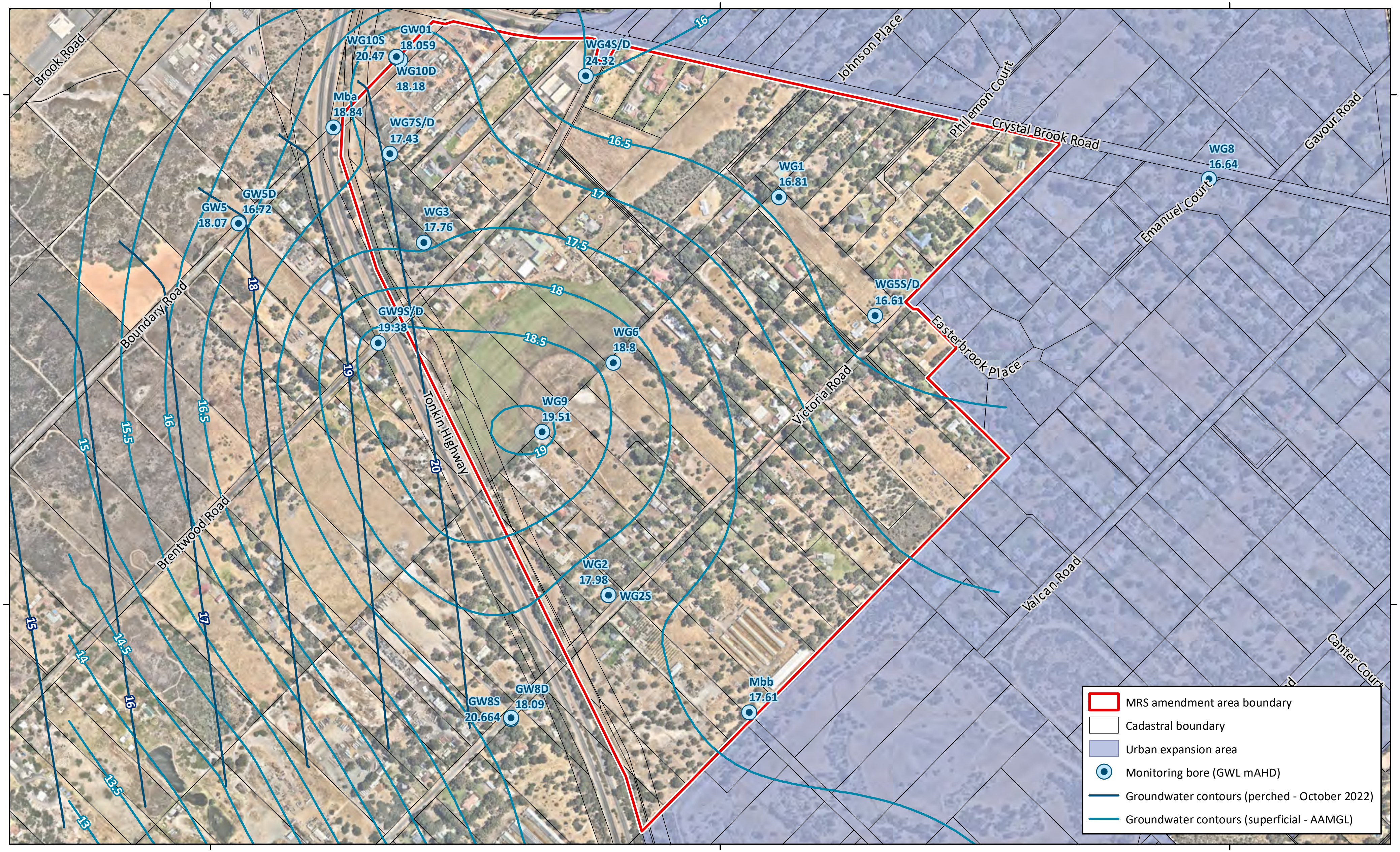

Figure 5: **Groundwater Investigations**

Project:	Water Balance Assessment
	Wattle Grove South
Client:	Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F05b

Drawn:	GAR
Date:	06/01/2023
Checked:	BPB
Approved:	DPC
Date:	11/05/2023

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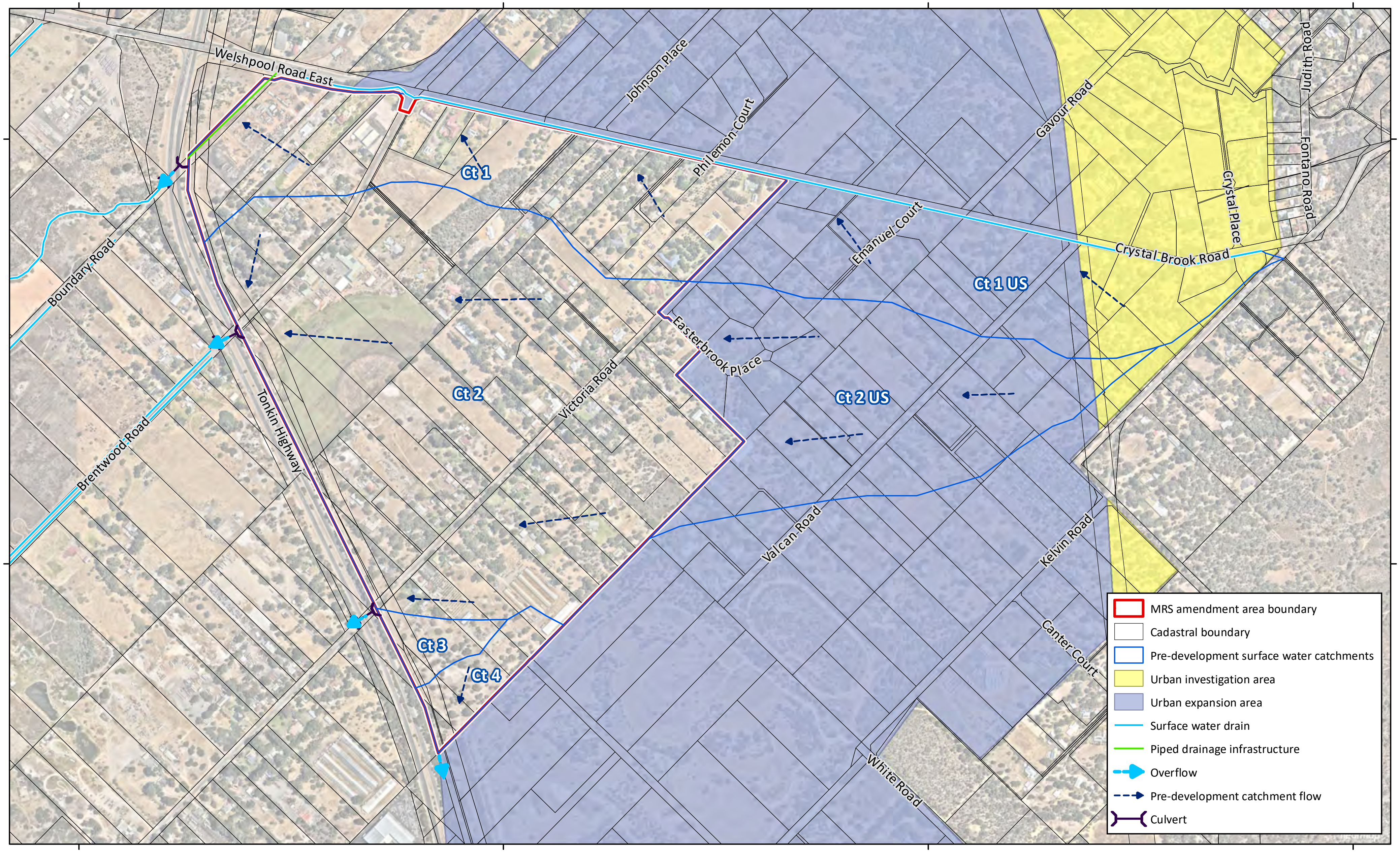

Figure 6: **Hydrological Features**

Project:	Water Balance Assessment Wattle Grove South
Client:	Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F06a

Drawn:	GAR
Date:	06/01/2023
Checked:	BPB
Approved:	DPC
Date:	19/01/2023

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GDA 1994 MGA Zone 50

emerge ASSOCIATES

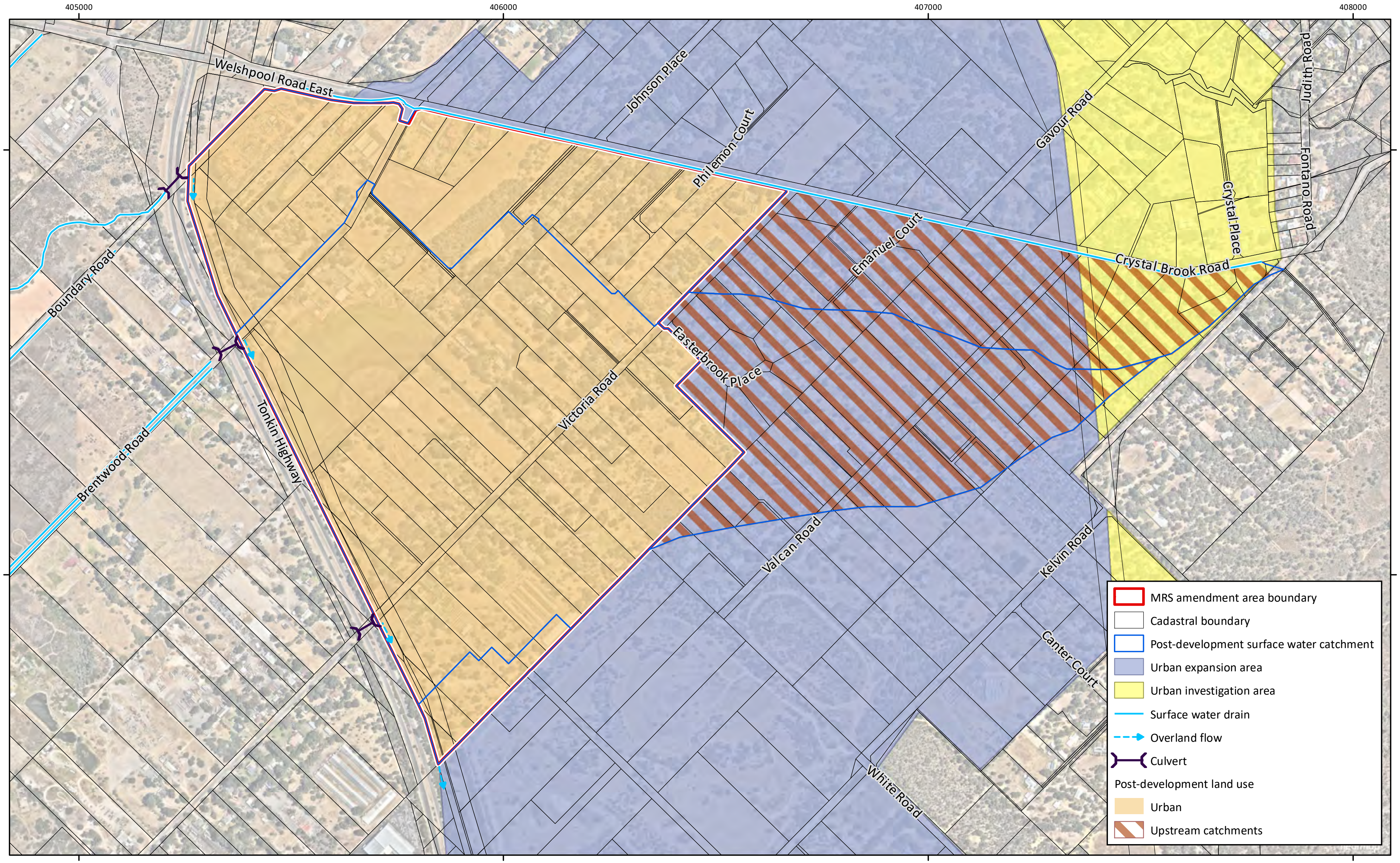

Figure 7: **Post-Development Surface Water Runoff**

Project: Water Balance Assessment, Wattle Grove South

Client: Hesperia Pty Ltd

Plan Number: **EP22-002(03)--F07a**

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Date: 06/01/2023
Checked: BPB
Approved: DPC
Date: 19/01/2023

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emerge ASSOCIATES

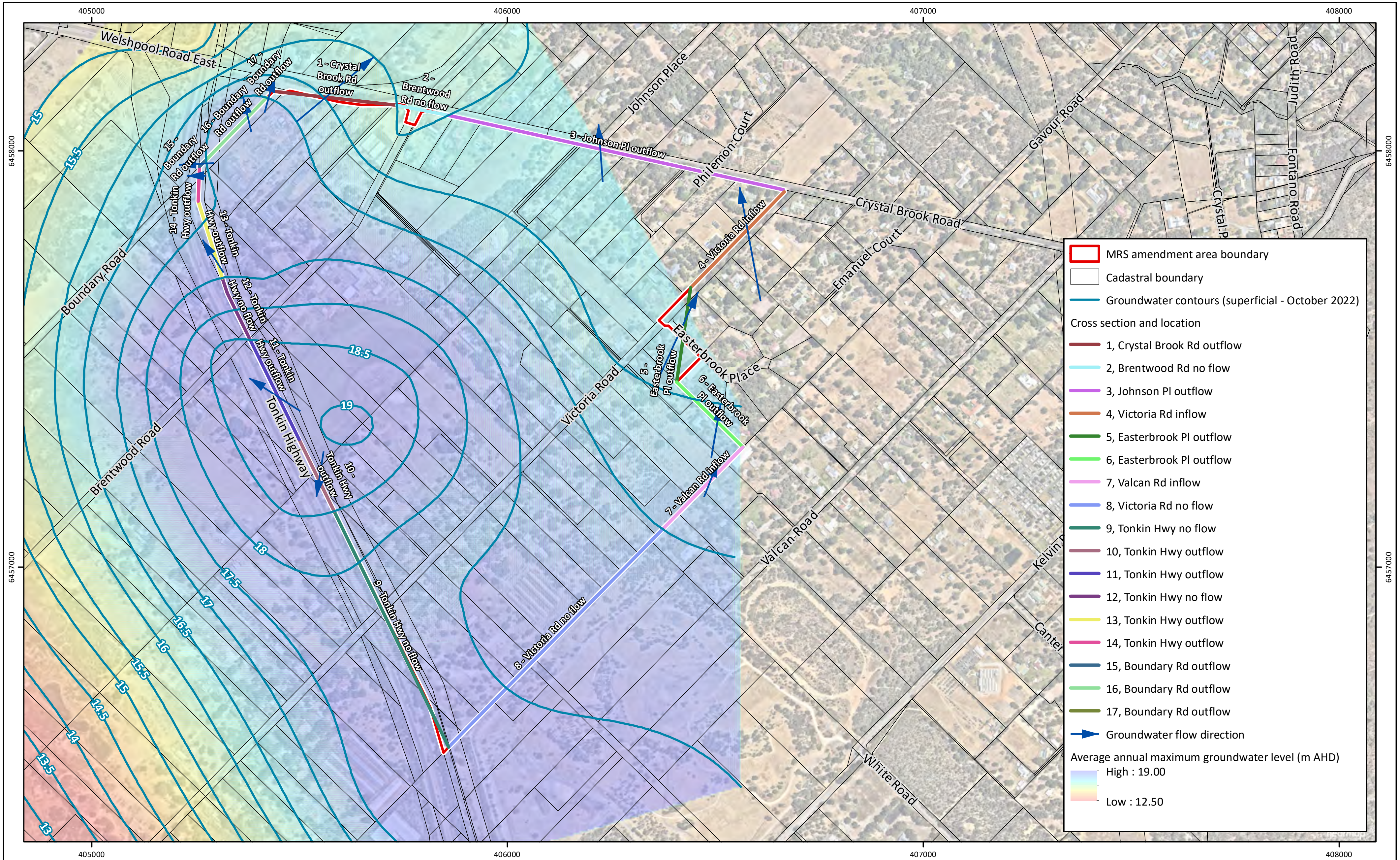

Figure 8: **Superficial Groundwater Throughflow**

Project: Water Balance Assessment
Wattle Grove South

Client: Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F08e
Drawn: GAR
Date: 18/01/2024
Checked: BPB
Approved: DPC
Date: 23/01/2024

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emerge ASSOCIATES

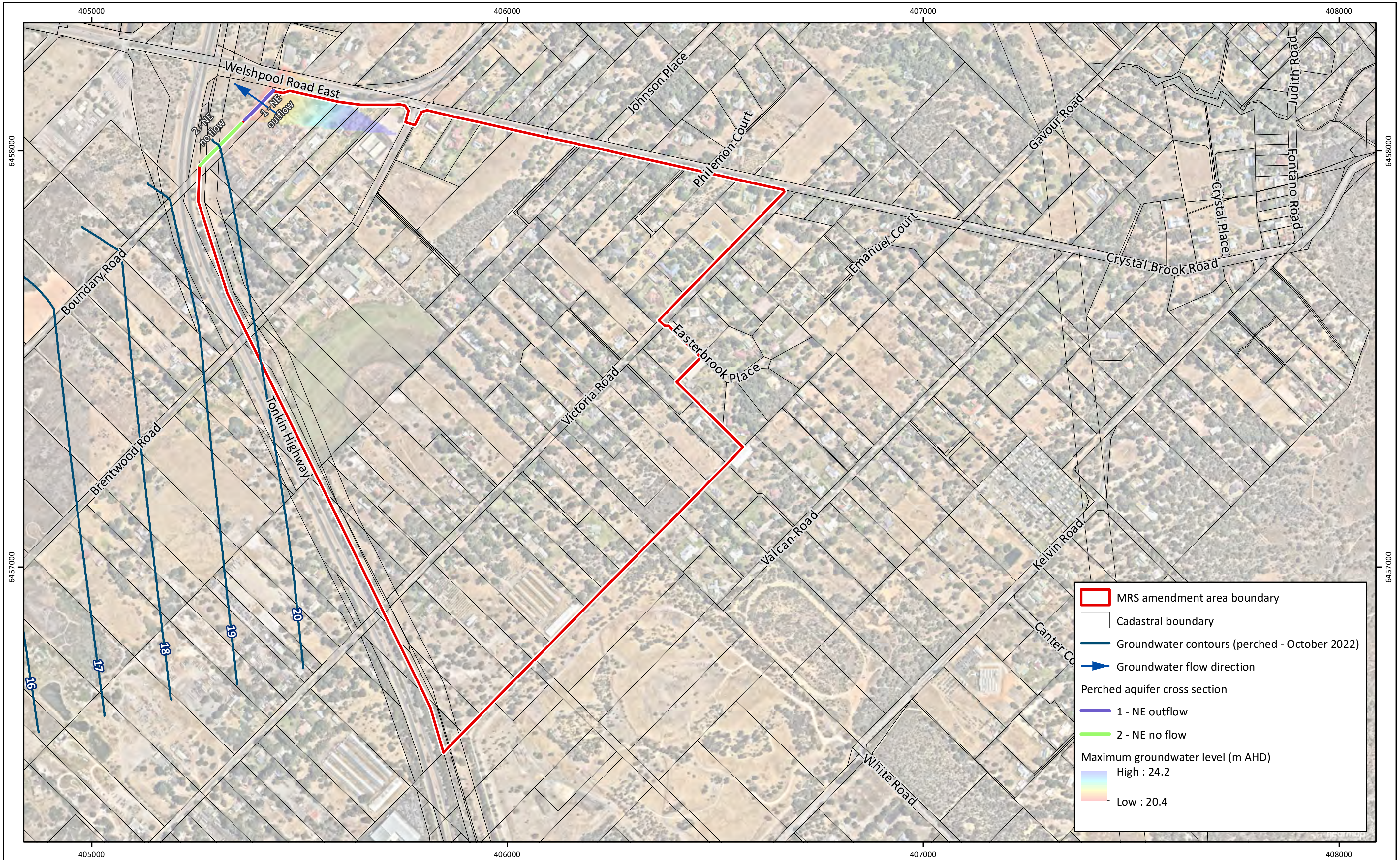

Figure 9: **Perched Groundwater Throughflow**

Project:	Water Balance Assessment Wattle Grove South
Client:	Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F10d
Drawn: GAR
Date: 18/01/2024
Checked: BPB
Approved: DPC
Date: 23/01/2024

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emerge ASSOCIATES

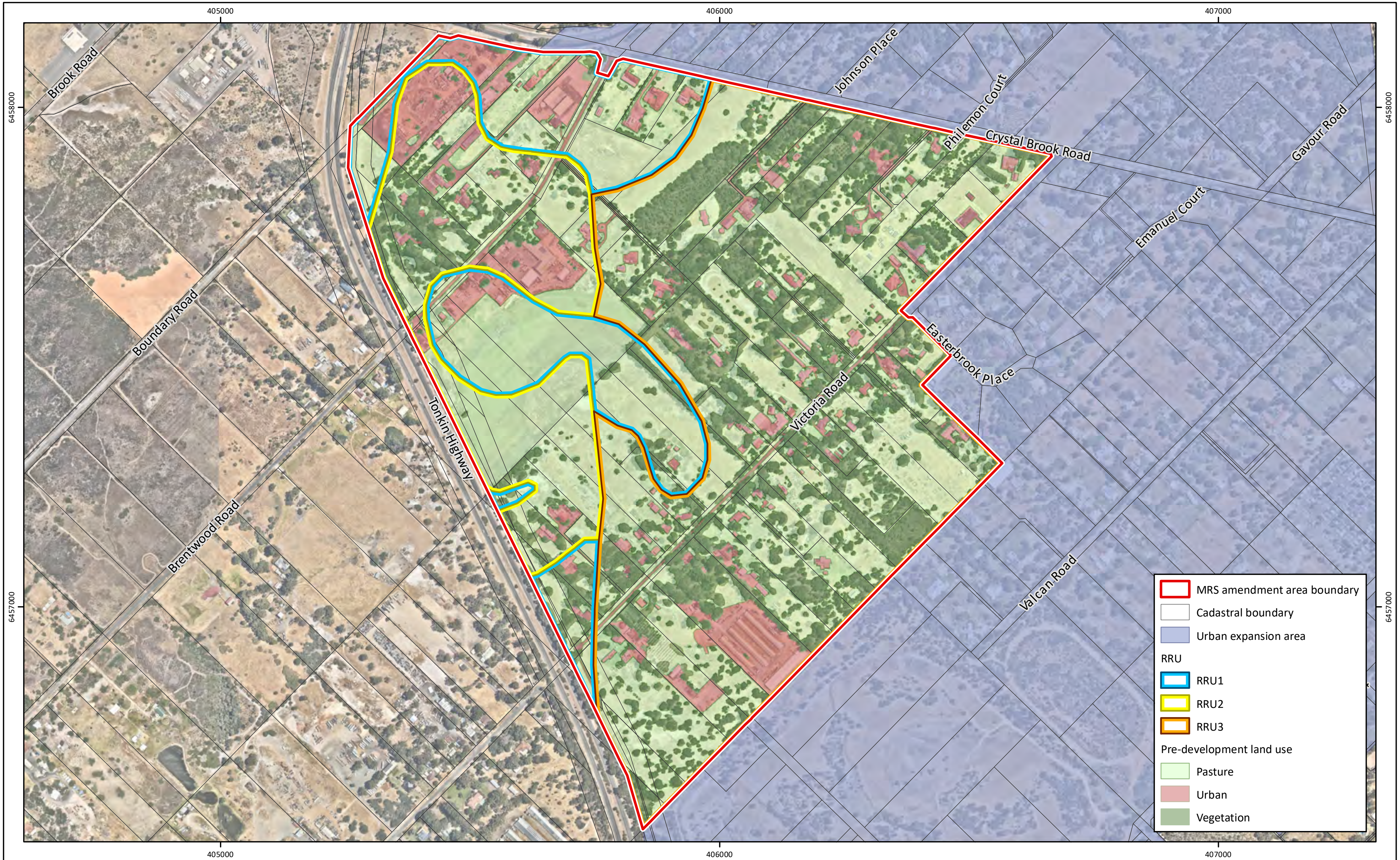


Figure 10: Pre-Development Evapotranspiration

Project: Water Balance Assessment
Wattle Grove South

Client: Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F11b
Drawn: GAR
Date: 18/01/2024
Checked: BPB
Approved: DPC
Date: 18/01/2024

emerge ASSOCIATES

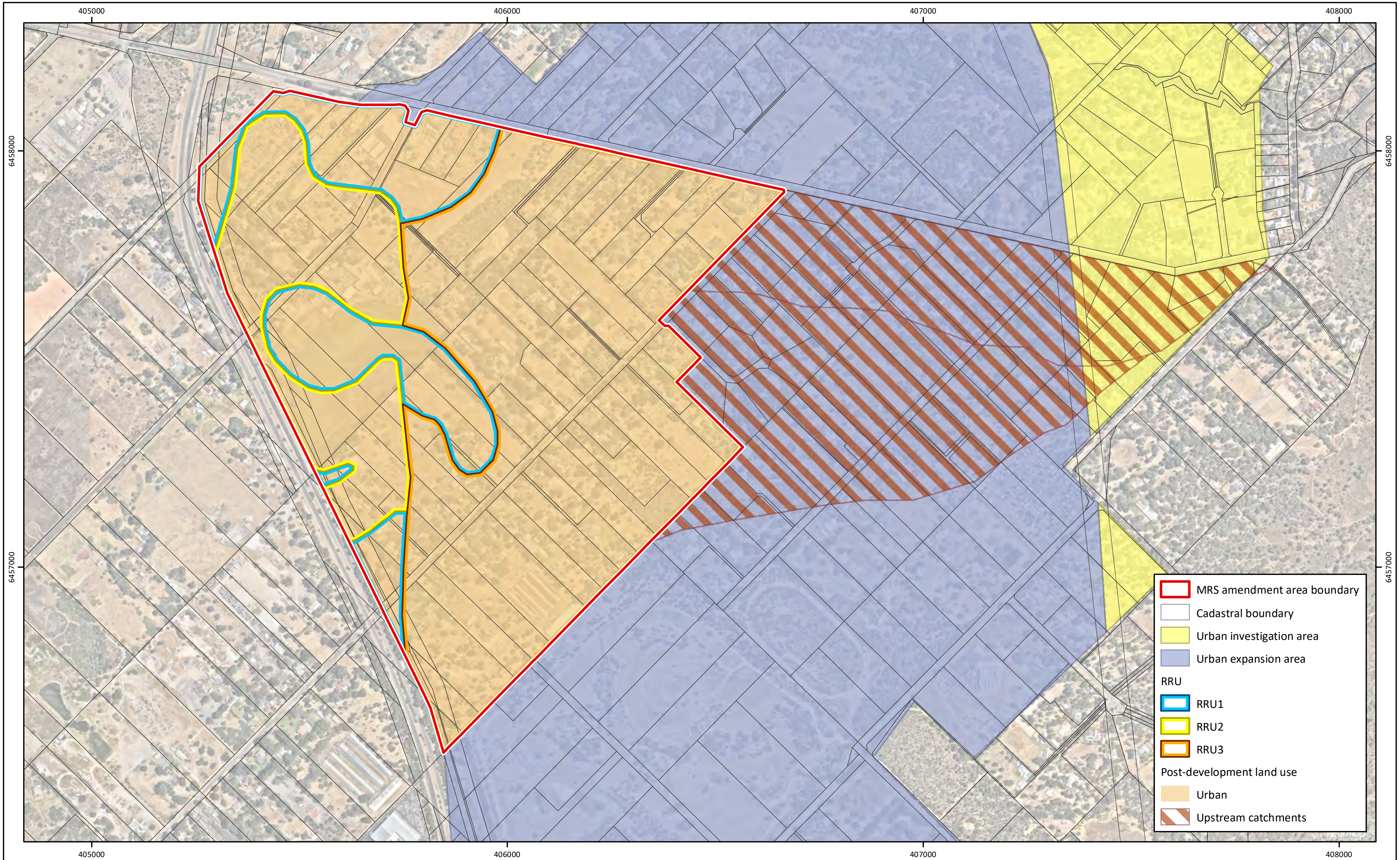


Figure 11: **Post-Development Evapotranspiration**

Project: Water Balance Assessment
Wattle Grove South

Client: Hesperia Pty Ltd

Plan Number:
EP22-002(03)--F12b
Drawn: GAR
Date: 18/01/2024
Checked: BPB
Approved: DPC
Date: 23/01/2024

emerge ASSOCIATES

Appendix A

Environmental Review Instructions (excerpt)

Prepared by EPA (2022)

3. Preliminary key environmental factors and required work

The preliminary key environmental factors for the environmental review are:

1. Inland Waters;
2. Flora and Vegetation;
3. Terrestrial Fauna;
4. Social Surroundings, and
5. Greenhouse Gas.

Table 3 outlines the work required for each preliminary key environmental factor and contains the following elements for each factor:

- **EPA factor** and **EPA objective** for that factor.
- **Relevant activities** – the development activities that may have a significant impact on that factor.
- **Potential impacts and risks** to that factor.
- **Required work** for that factor.
- **Relevant policy and guidance** – EPA (and other) guidance and policy relevant to the assessment.

Table 3 Preliminary key environmental factors and required work

Inland Waters	
EPA objective	To maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected.
Relevant activities	• Clearing of vegetation and alteration of natural drainage regimes for future development and associated infrastructure.
Potential impacts and risks	• Impacts to current surface and ground water cycles (alteration of hydrological regimes) resulting in impacts to significant wetlands and waterways within and nearby to the amendment area, including the Yule Brook and Greater Brixton Street Wetlands (GBSW). • Impacts to water quantity and quality of significant wetlands and waterways within and nearby to the amendment area. • Impact to the hydrology and biodiversity of the GBSW. • Loss of foreshore functions and groundwater and/or surface water dependent vegetation and impacts to other water dependent ecosystems.
Required Work	1. Identify and assess the values and significance of hydrological and geological characteristics within the amendment area and surrounding area including for the broader Wattle Grove Urban Expansion and

	Urban Investigation area, particularly in relation to the GBSW, and describe these values in a local and regional context. 2. Identify and map wetlands and watercourses within and adjacent to the amendment area including urban expansion and urban investigation areas and through work from the instructions below identify any areas proposed to be impacted. 3. Map groundwater contours for the regional and perched groundwater tables over the amendment area using site specific monitoring data and monitoring data from other nearby bores including the Department of Water and Environmental Regulation (DWER) and Department of Biodiversity Conservation and Attractions (DBCA) sites to establish the groundwater flow direction. Assess results in comparison to previous regional mapping completed within the local area (amendment area, urban expansion and investigation areas). Liaise with DWER to obtain any monitoring data further to the publicly available data base. Additional long-term and extensive groundwater flow direction investigations (such as additional monitoring bores and an extended period of data collection) may be required to support groundwater flow mapping that is not consistent with the DWER mapping. Ensure that all superficial bores used in creating the regional groundwater contours are not perched, and represent the groundwater in superficial aquifer. 4. Map the surface water catchment for the amendment, urban expansion and urban investigation areas, and map the contribution of pre development surface water flows to the surrounding wetlands and water courses. 5. Describe the total water cycle for the amendment area in the context of it being within the Yule Brook Catchment and with consideration of the surrounding urban expansion and urban investigation area. Discuss the hydrology and hydrogeology, particularly as it relates to wetland and ecological diversity within and nearby to the amendment area. Include information and discussion on the water budget for the area, the existing drainage management practices and any known impacts on the wetlands and waterways in, and nearby to the amendment area. 6. Using a pre and post development water balance model, characterise the existing hydrology of the site and existing sub surface flow contribution to the GBSW; and assess the potential impacts (direct and indirect) of the proposed change in land use associated with the amendment, and urban expansion and investigation areas, on water quantity and quality of surface and ground waters and subsurface flow contribution in relation to nearby significant wetlands and waterways The following should be considered in the development of any model: • The model should be developed in consultation with DWER and DBCA and consider inputs of the PRAMS groundwater flow model inputs.

	• Provide details of the existing geological and hydrogeological conditions used in conceptualising any modelling undertaken. • The groundwater water balance and groundwater resources in the Superficial aquifer should consider PRAMS input parameters using the flow-net analysis with the Darcy equation. Groundwater throughflow from the site toward the GBSW should be calculated with consideration of the Darcy equation. • Demonstrate the water balance is based on an understanding of both the groundwater minimum and maximum for the amendment area and the GBSW. The assessment of soil/sediment gravimetric and volumetric water contents, where perched aquifers are suspected, is also required to adequately inform the water balance. • Minimum data and information required to support an appropriate water balance is listed below with accompanying published data. – Minimum groundwater levels (collected April-May) – as shown in the published data logger data presented in WA wetlands conference poster (Bourke et. al. 2018). – Groundwater levels (minimum and maximum) presented in metres below ground level – required to assess wetland flora and fauna and terrestrial vegetation groundwater dependency and threats (e.g. waterlogging, acidification and salinisation). Lambers (2019). – Volumetric water content, water retention and hydraulic conductivity – see Davis and Cahill (2018) for horizontal hydraulic conductivity calculations using surface nuclear magnetic resonance (SNMR). – Water quality within GBSW is known to be spatially varying (Davis and Cahill 2018, and Lambers 2019). A spatial, temporal and lithological interpretation of water quality data is therefore required against water balance modelling outcomes to assess threats to wetland flora and fauna and terrestrial vegetation. 7. Calculate the additional recharge from the proposed change in land use associated with the amendment, and the resultant impact to the groundwater flow velocity and direction toward the GBSW. This should also include identification of the additional recharge from the urban expansion and investigation areas. 8. Demonstrate that predevelopment surface water and groundwater flows to the Yule Brook and GBSW are maintained post development as a result of the proposed change in land use associated with this amendment, and urban expansion and investigation areas.

	9. Estimate post development nutrient input and export rates resulting from the proposed change in land use, including through the use of DWER's Urban Nutrient Decision Outcomes (UNDO) model. 10. Predict the extent, severity and duration of potential impacts further to items 5 to 9, including changes to local and regional groundwater flows and levels, drawdown, local water quality and impacts to other groundwater users as a result of the proposed change in land use associated with the Amendment, and urban expansion and investigation areas, and provide measures to mitigate these impacts. 11. Determine the boundaries of wetlands and/or buffer requirements to wetlands within and adjacent to the amendment area proposed to be retained. Boundary and buffer studies should consider the characteristics of hydrology, hydric soils and wetland vegetation, and the water balance of the wetland/wetland dependent vegetation. 12. In the context of the below, items 6, 8 and 11 should model existing conditions of, and potential changes to, groundwater and surface water chemistry, particularly in relation to salinity and soil sodicity, that will result from the proposed change in land use associated with this amendment, and urban expansion and investigation areas. Research in the southern area of the GBSW has shown the area is characterised by aquifers with locally elevated salinities and a water table that fluctuates from at or above the surface, to below ground level and there may be a risk from the provision of more groundwater or surface water to the GBSW, as this may persist into summer months and concentrate solutes in the root zone as it evaporates. 13. Describe how the principles of water sensitive urban design will be incorporated and implemented in the amendment area, consistent with the *Better Urban Water Management* framework (WAPC, 2008) and the Stormwater Management Manual for Western Australia (DWER 2004-2007) and other relevant guidelines. 14. Detail and discuss how future drainage practices within the site, is to be managed, considering the broader catchment. This management should ensure the hydrological balance and water quality of significant wetlands and watercourses within and nearby to the amendment area (such as the GBSW and Yule Brook) will be maintained. 15. Describe how drainage management practices could be adapted in the future to mitigate impacts of climate change on significant wetlands and waterways, within and adjacent to the amendment areas. 16. Using the mitigation hierarchy, detail and discuss how development activities will avoid and manage mobilisation of potentially poor-quality groundwater resulting from past agricultural land uses.

	17. Describe the planning or other mechanisms that will ensure drainage management will protect significant wetlands and watercourses within and adjacent to the amendment area. 18. Describe the ongoing management requirements for the amendment area to ensure the hydrology of significant wetlands and watercourses within and nearby to the amendment area is maintained. 19. Prepare a district water management strategy in accordance with the Guidelines for district water management strategies (DoW, 2013). 20. Prepare a monitoring program including management objectives, baseline conditions, public reporting and measures to be implemented in the event of non-compliance to management objectives. 21. Based on the outcomes of the above and taking into consideration the principles of avoidance and minimisation, identify an environmentally acceptable area for development. 22. Provide a summary of residual impacts of future development and associated infrastructure within and adjacent to the amendment areas. 23. Describe any proposed avoidance, mitigation and management measures that demonstrate the EPA's objectives can be met. 24. Describe the planning mechanisms that are to be applied to ensure impacts are managed to meet the EPA's objectives.
Relevant policy and guidance	***EPA Policy and Guidance*** *Statement of Environmental Principles, Factors, Objectives and Aims of EIA*, EPA, 2021. *Environmental Factor Guideline – Inland Waters*, EPA, June 2018. **Other policy and guidance** *Better Urban Water Management*, Western Australian Planning Commission, October 2008. Bourke L, Brown K, Paczkowska G. Characterising the condition and function of the Greater Brixton Street Wetlands, Kenwick, Western Australia, to inform conservation management. Poster presented at the 14th Annual WA Wetland Management Conference 2018, 2nd February, Bibra Lake, WA. Davis, Aaron; Cahill, Kevin. Surface nuclear magnetic resonance soundings in the Greater Brixton Street Wetlands. Perth, WA: CSIRO; 2018. Davis, Aaron; Cahill, Kevin. Ground-based time-domain electromagnetic soundings in Greater Brixton Street Wetlands. Perth, WA: CSIRO; 2018. Department of Biodiversity, Conservation and Attractions, A methodology for the evaluation of wetlands on the Swan Coastal Plain, Western Australia, 2017.

	Guideline for the determination of wetland buffer requirement, Draft, Department of Planning and Infrastructure, 2005. *Stormwater Management Manual for Western Australia* (DWER 2004-2007). *Guidelines for district water management strategies* DoW, 2013. *Identification and investigation of acid sulphate soils and acidic landscapes*, Department of Environment Regulation, June 2015. Lambers . Introduction and overview. In: Lambers H ed. A jewel in the crown of a global biodiversity hotspot. Perth: Kwongan Foundation and the Western Australian Naturalists' Club In, 2019 *Operational policy 4.3: Identifying and establishing waterways foreshore areas,* Department of Water, September 2012. *Treatment and management of soil and water in acid sulphate soil landscapes*, Department of Environment Regulation, June 2015 *Environment Protection and Biodiversity Conservation Act 1999 and approved conservation advices on relevant MNES.*

Flora and Vegetation	
EPA objective	To protect flora and vegetation so that biological diversity and ecological integrity are maintained.
Relevant activities	Clearing of vegetation, addition of fill, and alteration of natural drainage regimes for future development and associated infrastructure.
Potential impacts and risks	Direct and indirect loss of significant flora and vegetation, including threatened and priority ecological communities, threatened and priority flora, and vegetation complexes poorly represented in existing conservation reserves (Guildford Complex and Forrestfield and Southern River Complex). Potential impacts include: • Direct loss through clearing, • Loss of fauna habitat (vegetation loss) short and long term, • Impacts to wetland and riparian vegetation and ground water dependant ecosystems within and nearby to the amendment area (including GBSW) through changes to hydrology, • Spread or intensification of weeds and *Phytophthora* dieback, • Fragmentation.
Required work	25. Identify and characterise the flora and vegetation present and likely to be present within the amendment area, in accordance with EPA Technical Guidance – Flora and Vegetation Surveys for Environmental Impact Assessment, December 2016. For existing flora and vegetation

Appendix B

Surface Water Runoff

TECHNICAL ASSESSMENT

Project Name	**Wattle Grove South MRS Amendment 1388/57 Water Balance Assessment**
Project Number	**EP22-002**
Assessment Component	**Surface Water Runoff**

Introduction

This document is a technical summary and is intended to be read in conjunction with the *Wattle Grove South Amendment 1388/57 Water Balance Assessment* (the WBA), which covers the Wattle Grove South amendment area (the MRS amendment area).

One of the key components of the WBA is the quantification of the annual volume of surface water runoff conveyed into and discharging from the MRS amendment area. Surface water runoff is rainfall that is not retained/infiltrated at source resulting in rainfall becoming runoff. This occurs when rainfall intensity which exceeds the infiltration and storage capacity of soils and surfaces. Consideration is also given to the flow direction of runoff into the MRS amendment area from upstream catchments and discharges from the MRS amendment area.

The surface water runoff assessment is based on a detailed catchment assessment and preparation of surface water runoff assessments previously undertaken within and around the MRS amendment area by Hyd2O (2022) and Emerge Associates (Emerge Associates 2017, 2021). Surface water runoff investigations have included assessment of catchments, runoff routing, land use assessment and determination of the associated infiltration/storage ‘loss’ rates for each land use. Surface water assessments have been undertaken for both the pre-development and post-development environments and accounts for upstream catchments. The relevant assessment details are summarised in this document which are largely based on the work undertaken as part of the DWMS for the MRS amendment area prepared by Hyd2O (2022).

Data and inputs

The data and inputs used to determine the annual runoff volumes are summarised below.

- **Rainfall**

Rainfall data was obtained from the Bureau of Meteorology (BoM) (BoM 2020). The data comprises of gauged rainfall (in mm) at Jandakot Aero (Station 9172) in half hourly increments between 1/1/2010 00:00 and 31/12/2019 24:00. The data was condensed into one hour intervals to be compatible with the hourly loss rate units adopted in the modelling methodology (discussed below). The Jandakot dataset is used for the surface water balance calculations as it is the closest station with continuous rainfall observations available in a frequency of one hour or less.

- **Catchment extent and inflow locations**

The extent of both internal and upstream catchments in both the pre-development and post-development environments have been digitised based on topography and a preliminary structure plan layout provided by the client. The resulting catchments are generally consistent with those detailed in the DWMS for the MRS amendment area, with exception of a portion of the northernmost catchment which does not enter the MRS amendment area and therefore does not feature in water balance calculations, and some minor changes in flow direction owing to an updated preliminary land use plan. The catchments have been derived from the publicly available 1 m topographic LiDAR contours and inflow/discharge locations and directions have been taken from data provided by Main Roads WA, City of Gosnells Intramaps, site inspection and culvert surveys. These catchments only incorporate the land that contributes to the catchments of the MRS amendment area and so do not include the entire Urban Expansion/Investigation (UE and UI) areas. A summarised breakdown of catchment areas, flow directions and the discharge types are provided in **Table B1** and **Table B2** for the pre-development and post-development environments respectively. The catchments are shown for the pre-development and post-development environments in **Figure 7** of the WBA report respectively.

Table B1: Pre-development catchment summary

Catchment	Area (ha)	Runoff discharge direction	Runoff discharge type
Ct 1	32.56	Boundary Road streamline (GBSW)	Culvert crossing
Ct 2	86.80	Brentwood Road (MKSEA)	Culvert crossing
Ct 3	2.83	Victoria Street (MKSEA)	Culvert crossing
Ct 4	4.21	South (Tonkin Hwy)	Overland flow
Ct 1 US	28.28	Ct 1	Overland flow
Ct 2 US	38.06	Ct 2	Overland flow

Table B2: Post-development catchment summary

Catchment	Area (ha)	Runoff discharge direction	Runoff discharge type
Ct 1	40.83	Boundary Road streamline (GBSW)	Culvert crossing
Ct 2	81.55	Brentwood Road and Victoria Street (MKSEA)	Culvert crossings
Ct 3	3.91	South (Tonkin Hwy)	Overland flow
Ct 1 US	28.28	Ct 1	Overland flow
Ct 2 US	38.06	Ct 2	Overland flow

Table B1 and **Table B2** shown that the catchment areas are only slightly modified from pre to post development based on the preliminary land use plan which is subject to change. All discharge methods and locations remain unchanged.

- **Land use areas and loss rates**

Pre-development and post-development land use categorisations and loss rates for the MRS amendment area have been adopted from the DWMS and based on the preliminary structure plan layout. The land use details and loss rates are summarised in **Table B3** and **Table B4** and the extent of land uses are shown in **Figures 10** and **11** of the WBA for the pre-development and the post-development environments respectively. The 'runoff coefficient' presented is determined by converting an event based initial loss (IL in mm) and continuing loss (CL in mm/hr) rate to an annual coefficient by analysing annual rainfall and runoff at an hourly timestep. This approach is further described in following pages.

Land use types and infiltration losses are largely influenced by the underlying near-surface soil types and surface coverage/landuse (i.e. vegetation, asphalt etc.). It is common for vegetation/litter interception losses to influence landuse categorisation (e.g. pasture, native vegetation delineation), however interception losses are accounted for in the evapotranspiration component of this water balance and so are not included in land use delineation and loss rates for the surface water component to avoid minor double counting.

For the purposes of runoff assessment, the pre-development land use has been categorised as a single land use due to generally consistent near-surface soils and land use. The effective impervious area of this land use has been assumed to be zero due to the small portion of impervious areas and the lack of any connected impervious areas, un-kerbed roads and lack of local natural or formal drainage within the MRS amendment area.

A 45 mm initial loss (IL) was added to the catchment losses for post-development lot and road impervious areas to account for on-lot soakage and downstream infiltration structures (such as bio-retention areas (BRAs) designed to retain runoff from the first 15mm of rainfall, and flood detention basins, designed to manage up to a 1% AEP event.

Table B3: Pre-development land use summary

Land use	Contributing area (ha)	Initial loss (mm)	Continuing loss (mm/hr)	Percentage impervious (effective)	Runoff coefficient
MRS amendment area					
Rural residential (Existing)	126.39	20	4	0%	7.1%
Upstream					
Rural residential (Existing)	66.34	20	4	0%	7.1%

Table B4: Post-development land use summary

Land use	Contributing area (ha)	Initial loss (mm)	Continuing loss (mm/hr)	Percentage impervious	Runoff coefficient
MRS amendment area					
Commercial	14.07	Fully retained			0%
POS	14.06	45	4	0%	2.6%
Residential	68.03	45 (pervious and (impervious)	4 (pervious) 0.1 (impervious)	80%	11.0%
Road	25.86	45 (pervious and (impervious)	4 (pervious) 0.1 (impervious)	70%	11.0%
School	4.25	Fully retained			0%
Upstream					
Urban Expansion	66.34	Mixed – see ***Table B5*** below			9.9%

The upstream catchments have been considered to be developed for the purposes of the post-development surface water balance. The preliminary land use of these areas are proposed to be urban, however the final layout and composition is unknown and will likely not be determined for some time. The land use composition for the UE and UI areas has then been based on the preliminary land use plan for the MRS amendment area, with the exception of school and commercial areas, which have been redesignated to residential. A summary of the preliminary land use composition for the MRS amendment area and that assumed for the upstream Urban Expansion area is provided in **Table B5.**

Table B5: Land use proportional summary

Land use proportion	Commercial	POS	Residential	Road	School
MRS amendment area	11.1%	11.1%	53.9%	20.5%	3.4%
Urban Expansion	0%	11.1%	68.3%	20.5%	0%

Methodology

Runoff volumes

Runoff is calculated via the subtraction of loss rates from the rainfall values. This accounts for localised retention (e.g. due to topography or storages) and infiltration into the soil profile. Runoff is not subject to any further infiltration or transmission loss; the loss rates are purely rainfall abstraction and any runoff is then assumed to be discharged from the assessment area or upstream catchment at the identified locations.

The IL and CL was applied to the rainfall (in mm) on an hourly timestep basis and this was undertaken separately for each land use. where both the IL and CL amounts are exceeded by the rainfall amount for a given hourly timestep, runoff occurs; otherwise, no runoff occurs. The available IL value is tracked throughout the time series and resets (i.e., the IL value becomes fully available again for rainfall abstraction) after a full day where rainfall does not exceed 1 mm, representing the infiltration and evaporation of rainfall.

This calculation was completed for each hourly timestep over the rainfall data period (i.e. 2010-2019), for each land use type (i.e. for each unique IL and CL combination). This resulted in a total runoff value (in mm) over 2010-2019 for each land use, which was then averaged over that 10 year period to produce the final runoff coefficient adopted for each land use.

The IL and CL rates and resulting average runoff coefficient for land use is provided in **Table B3** and **Table B4**.

Runoff and flow routing

Runoff that is discharged from the MRS amendment area is an outflow from the water balance assessment. Upstream runoff is accounted for as an inflow to the MRS amendment area. Any runoff from upstream areas is assumed to be conveyed through the MRS amendment area without any transmission losses as the soils are likely fully saturated during rainfall events sufficiently large enough to produce upstream runoff.

Climate Change Sensitivity

The baseline pre-development and post-development water balance assessment has been developed to be a representation of the recent average hydrological system based on observed data and therefore inherently does not account for any potential future impacts of a warmer, drier climate. The effect of climate change has been incorporated into the water balance model as a separate process through assessment of climate change on the post-development scenario. It is noted that predicting changes to rainfall patterns and magnitude and soil absorption (of which runoff is a dynamic outcome) due to warming is difficult and the consideration of climate change sensitivity should be considered as a rough estimate.

To account for climate change factors, Emerge Associates obtained a future climate prediction dataset from DWER which includes rainfall predictions (DWER 2021). The data is based on the climatic scenario projections from the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset (associated with the Intergovernmental Panel on Climate Change's (IPCC) 4th assessment report) (IPCC 2007). The DWER dataset uses the climate scenario projections to predict future climate data extrapolated from an observed climate baseline obtained from the Australian climate database named 'SILO' (Queensland Government 2021).

The DWER climate prediction dataset provides predicted future climatic data in daily intervals for three climate change scenarios (wet, med, dry) at a time horizon of 2050 and 2100. The predictions are geographically based and as such the dataset obtained for this assessment has been calculated specifically for location of the assessment (i.e. Wattle Grove). The 2050 and 2100 Dry scenarios were selected for the climate change assessment as a conservative/pessimistic prediction.

A summary of the future climate change factors predictions from DWER (2021) are summarised in **Table B6** with comparison made to the latest 11 years (2010-2020) of climate observations (from the SILO data provided by DWER).

Table B6: Rainfall climate change factors

Climate Change Factor	**Baseline average (2010-2020) (DWER, SILO 2021)**	**Future climate prediction (DWER 2021) percentage change from 2010-2020 baseline**	
		Dry 2050	**Dry 2100**
Annual rainfall (mm) (Gosnells)	656	627 (-4.4%)	430 (-34.5%)
Rainfall reduction (mm/hr)	0	-0.056	-0.597
Annual rainfall used in the surface water balance (mm) (Jandakot hourly dataset)	735	702 (-4.4%)	481 (-34.5%)

To account for the predicted changes to annual rainfall, the rainfall magnitude of each hourly timestep in the surface water balance was reduced by a fixed amount. The amount of rainfall reduction was calculated such that the reduction would result in the average annual runoff decreasing proportionally to the corresponding predicted future change. For example, the Dry 2050 scenario shows a decrease of 4.4% from the baseline average. The same percentage is taken from the baseline average of the Jandakot dataset. The Jandakot dataset is used for the surface water balance calculations as it is the closest station with continuous rainfall observations available in a frequency of one hour or less. This adjusted rainfall is applied to both the MRS amendment area and the UE and UI areas (i.e. upstream catchments). Other than the adjusted rainfall the climate change surface water balance calculations follow the same procedure as the baseline scenarios.

Results and summary

The surface water components of the overall water balance are summarised in **Table B7** for the pre-development and post-development environments. The post-development environment for the undeveloped (not urbanised) and developed (urbanised) UE and UI areas are presented for impacts to discharge from the MRS amendment area. Post-development climate change estimates for the Dry 2050 and Dry 2100 DWER future climate change predictions consider the developed UE and UI areas only.

Note that the surface water balance components are the quantification of the various surface water/runoff elements and are not intended to comprise a wholistic water balance. The main WBA report details consideration of the other water balance components such as evapotranspiration, groundwater throughflow, recharge, etc.

Table B7: Surface water balance summary

Surface water balance components (m^3/year)	Pre-development	Post-development UE & UI areas undeveloped	Post-development UE & UI areas developed	Post-development (Dry 2050) UE & UI areas developed	Post-development (Dry 2100) UE & UI areas developed
Direct rainfall (falling on the MRS amendment area)	928,888	928,888	928,888	887,963	608,350
Runoff generated from rainfall on the MRS amendment area	65,889	76,886	76,886	69,427	28,279
Upstream catchment inflows	34,536	34,536	48,210	43,523	21,269
Total water infiltrated on the MRS amendment area	863,088	852,002	852,002	818,536	580,071
Total runoff discharging from the MRS amendment area (inclusive of upstream inflows)	100,337	111,422	125,096	112,950	49,549
Runoff to MKSEA (total)	66,472	77,960	85,804	77,474	33,586
Runoff to GBSW (total)	31,674	31,036	36,866	33,283	15,058
Runoff to south (total)	2,191	2,426	2,426	2,194	904

References

Bureau of Meteorology (BoM) 2020, *Rainfall data, Jandakot Aero 2010-2020*.

Emerge Associates 2017, *Maddington Kenwick Strategic Employment Area - Precinct 3A Local Water Management Strategy*, EP14-056(09)--009F RLE, F.

Emerge Associates 2021, *Local Water Management Strategy - Lot 414 Grove Road, Maddington Kenwick Strategic Employment Area*, EP17-055(01)--005I ASC, Version I.

Hyd2O 2022, *Wattle Grove South District Water Management Strategy*.

Intergovernmental Panel on Climate Change (IPCC) 2007, *Fourth Assessment Report*.

Appendix C

Groundwater Throughflow

TECHNICAL ASSESSMENT

Project Name	**Wattle Grove South MRS Amendment 1388/57 Water Balance Assessment**
Project Number	**EP22-002**
Assessment Component	**Groundwater Throughflow**

Introduction

This document is a technical summary and is intended to be read in conjunction with the *Water Balance Assessment Wattle Grove South* (the WBA), which covers the amendment 1388/57 area which is bound by Tonkin Highway (west), Welshpool Road East (north), Crystal Brook Road, Victoria Road and Easterbrook Road (east) and the rear boundaries of lots fronting Victoria Road (south) and referred to as the 'MRS amendment area'.

This document summarises the calculation of the groundwater throughflow component of the WBA. Groundwater throughflow is the lateral flow of water through the soil profile. As part of the WBA, the annual groundwater throughflow volumes flowing through the assessment area boundaries have been calculated, the methodology and results are summarised below.

Data and input

The groundwater throughflow assessment is based on investigations undertaken within and around the assessment areas. These include geotechnical investigations (test pits, infiltration testing) and groundwater level investigations (manual measurements). These are summarised below.

Sand profile depth, spatial distribution and permeability

The MRS amendment area is situated within a transitional area between the Piedmont Zone of the Darling Scarp and the Pinjarra Plain, resulting in a complex and heterogeneous soil profile. Bassendean sands and Guildford formation clays have been observed. Clay soils vary greatly in concentrations and locations but generally are limited to the west of the MRS amendment area near to the surface, and also to the north of the MRS amendment area and sporadically in the centre of the MRS amendment area. The majority of the MRS amendment area did not display an underlying shallow clay layer. The observations to date indicate that near-surface groundwater within the MRS amendment area can be delineated into a regional superficial unconfined aquifer and to a lesser (western and northern) extent a perched system within the layer of sand above a lower permeability clay layer.

Bore logs and lithology for deeper DWER bores (61601079, 61607580 and 61671956) (DWER 2022b) indicate that the MRS amendment area is underlain by a lower permeability clay layer at approximately 27 m BGL. The base of the regional aquifer was assumed as 0 m AHD based on DWER groundwater mapping (DWER 2022a), while the base of the perching which occurs at the top of the shallow clay layer is based on available bore logs and ranges between 15.14 m AHD and 20.11 m AHD.

A geophysical investigation assessed the soil profile beneath the MRS amendment area to a depth of 50 m BGL and found that the soils were generally non-uniform and complex. A large area of interpreted lower permeability soil was identified along Tonkin Highway (western boundary) and areas of higher permeability soil were identified along Crystal Brook Road (northern boundary) and Johnson Place (outside of the MRS amendment area to the north) (GBG 2023).

Permeability testing was performed using a borehole permeameter constant head test. Test pit locations and permeability rates are summarised in **Table 2**, **Table 3** and **Figure 4** of the WBA. Permeability across the MRS amendment area varied between 6 m/day and 34 m/day. Based on the locations of test sites it is assumed that the majority of the rates were measuring permeability of the upper sandy soils. The underlying clayey sand/sandy clay and clay layer will likely result in soil permeability decreasing with depth to some extent. Falling head permeability tests undertaken on the deeper, fine grained silty sand soil profile (9 to 15 m BGL) adjacent to Tonkin Hwy to the west of the site determined permeability rates varied from 1.62 $\times10^{-5}$ m/s to 9.75 $\times 10^{-5}$ m/s. A permeability of 2.4 $\times10^{-4}$ m/s was adopted for the majority of the deeper soil profile beneath the site except for specific areas along the western boundary where 1.2 $\times 10^{-5}$ m/day was used. A permeability of 2.89 $\times10^{-4}$ m/s has been adopted for the shallow soil profile.

Maximum groundwater elevations

Groundwater depths were measured on three occasions (2022/08/26; 2022/10/10 and 2022/10/27) in a number of groundwater monitoring bores within the MRS amendment area for both the regional superficial unconfined aquifer and a perched system.

Pre-development scenario

Average Annual Maximum groundwater level (AAMGL) contours for the superficial aquifer have been derived from the measured ground water levels (supplied by the proponent). The complete extent of the groundwater monitoring bore dataset and the associated AAMGL contour dataset are shown in **Figure 5** of the WBA. The extent of the mapping has been expanded to cover the MRS amendment area. Groundwater generally moves radially away the highest groundwater elevation around existing turf farm located centrally within the MRS amendment area.

Post-development scenario

The high groundwater elevations centrally within the MRS amendment area can be attributed to localised geological conditions and groundwater abstraction from the deeper aquifer at this location. Expected post-development AAMGL contours for the superficial aquifer have been assumed to remain unchanged from the pre-development environment due increase recharge to the superficial aquifer and proposed stormwater management approach which are expected to maintain the groundwater mound. Based on the above, groundwater flows beneath the site are unlikely to change post-development with the continued presence of the groundwater mound.

Perched system

Higher groundwater levels have been observed in bores GW5S, GW9S and GW8S, located to the west of Tonkin Highway, and in WG4S and WG10S to the north of the MRS amendment area, and these are concluded to represent localised perching. Based on measured groundwater levels, bores GW4S and GW10S appear to be hydraulically upstream of the shallow Tonkin Highway bores. However, these perched systems are unlikely to be connected given the deep sandy profile and lack of perched system in bores WG7S/D and WG3 which are situated between these two locations. Measured depth within the shallow bores were used to derive the maximum groundwater level (MGL) contours for the assumed perched groundwater locations in the northern part of the MRS amendment area (WG4S and WG12S). Long term AAMGL for the perched system is not available, therefore the derived maximum groundwater levels (MGL) was used. The perched system in the north western and south western part of the MRS amendment area, east of Tonkin Highway is likely not hydraulically connected to the perched system to the west of Tonkin Highway due to shallow clay layer. It is assumed that there is no flow from the perched system from the MRS amendment area to the west and south west of the area. Perched groundwater is expected to be present during months with higher rainfall. Based on historical rainfall it is assumed that perched groundwater will be present for five months annually (May to September). **Figure 9** of the WBA shows the MGL contours used for the perched system.

Methodology

Groundwater throughflow rate within the soil profile has been calculated using Darcy's law (*1*):

(1)

$$Q = -kA\frac{dh}{dl}$$

where the flow rate (Q), is related to the hydraulic conductivity (k), bulk cross sectional area (A) and the hydraulic gradient ($\frac{dh}{dl}$).

Hydraulic conductivity

The average of the measured permeability between HTS1 - HTS3 (i.e. 20.73 m/d) was used as the hydraulic conductivity for the regional aquifer since these test pits are considered representative of the soils beneath the area based on location and depth of the test pits. A reduction factor of 0.5 was applied to the permeability used for throughflow from the western boundary (towards Tonkin Highway) based on the large area of lower permeability soil identified as part of the geophysical investigation (GBG 2023) and the lower permeability rates determined within the deeper soil profile along Tonkin Highway. This reduction factor has been applied to groundwater cross-sections 11, 13, 14, 15 and 16 (see **Table C1**).

The average of the measured permeability between the bores HTS3 and HTS2, closest to the throughflow locations (i.e. 24.95 m/d) was used as the hydraulic conductivity for the perched system.

Bulk cross sectional flow area

Pre- and post-development scenarios

The bulk cross sectional flow areas at the boundaries of the MRS amendment area are the areas between the base of the aquifer (0 m AHD) and the AAMGL determined from the groundwater contours.

Cross sections were derived from the AAMGL dataset at the boundaries of the MRS amendment area. The locations of the cross sections are shown in **Figure 8** of the WBA. The derived bulk cross sectional flow areas for each cross section are detailed in **Table C1**.

Some locations where the WBA boundary orientation is perpendicular to the groundwater contours (and therefore parallel to groundwater flow) were excluded as the resulting incident groundwater flow would be zero.

Perched system

The bulk cross sectional flow areas at the boundaries of the MRS amendment area, for the perched system, are the areas between base of the perched aquifer (top of the clay layer) and MGL determined from the groundwater contours.

Cross sections for the perched system at the north, west and south western boundaries of the MRS amendment area (corresponding with the clay layer) were derived from the MGL dataset. The locations of the cross sections are shown in **Figure 9** of the WBA. The derived bulk cross sectional flow areas for each cross section are detailed in **Table C2**.

Groundwater gradient and direction

The hydraulic gradient has been derived from the AAMGL contour dataset. The gradient has been taken at locations representative of the weighted groundwater gradient for each cross section, these are shown as groundwater flow direction arrows in **Figure 8** of the WBA for the pre-development and post development scenarios and **Figure 9** for the perched system.

Gradients were calculated from the change in groundwater elevation along the length of these vectors. The hydraulic groundwater gradients are provided in **Table C1** for the pre- and post-development scenario and **Table C2** for the perched system.

The direction of the groundwater flow relative to the orientation of the cross sections have also been noted. These angles of incidence have been accounted for in the respective flow calculations and are provided in the Tables.

Results and summary

Pre-development scenario

The horizontal groundwater flow rate has been calculated using Darcy's law (*1*) from the components summarised in **Table C1** and the permeability for each cross-section location. Flow has been assumed to occur across the saturated part of the cross-sectional area. The final yearly flow across each cross section is provided in **Table C1**.

A visual example of the cross sectional data is provided in **Plate C1** and **Plate C2**, which displays Cross Sections 3 (outflow to the north east) and 10 (outflow to the west of the MRS amendment area).

Table C1: Pre-development and post-development groundwater throughflow summary

Cross section/ location		Cross sectional area (m^2)	Groundwater gradient	Angle of incidence (degrees)	Flow (m^3/yr)	Flow direction
1 -	Crystal Brook Rd outflow	4,918	0.41%	46.57	111,774	Out from MRS amendment area
2 -	Brentwood Rd no flow	-	-	-	-	No flow
3 -	Johnson Pl outflow	13,386	0.07%	73.26	69,527	Out from MRS amendment area
4 -	Victoria Rd inflow	5,273	0.04%	54.91	11,652	Into MRS amendment area
5 -	Easterbrook Pl outflow	3,767	0.04%	16.39	3,240	Out from MRS amendment area
6 -	Easterbrook Pl outflow	3,705	0.15%	55.28	35,207	Out from MRS amendment area
7 -	Valcan Rd inflow	4,634	0.15%	23.50	20,560	Into MRS amendment area
8 -	Victoria Rd no flow	-	-	-	-	No flow
9 -	Tonkin Hwy no flow	-	-	-	-	No flow
10 -	Tonkin Hwy outflow	3,587	0.27%	34.51	41,473	Out from MRS amendment area
11 -	Tonkin Hwy outflow	4,971	0.20%	30.84	19,760	Out from MRS amendment area
12 -	Tonkin Hwy no flow	-	-	-	-	No flow
13 -	Tonkin Hwy outflow	3,319	0.37%	15.56	12,513	Out from MRS amendment area
14 -	Tonkin Hwy outflow	1,417	0.43%	87.23	23,054	Out from MRS amendment area
15 -	Boundary Rd outflow	389	0.51%	42.21	5,094	Out from MRS amendment area
16 -	Boundary Rd outflow	3,529	0.10%	58.13	11,662	Out from MRS amendment area
17 -	Boundary Rd outflow	383	0.90%	29.28	12,779	Out from MRS amendment area

Plate C1: Indicative Cross Section 1

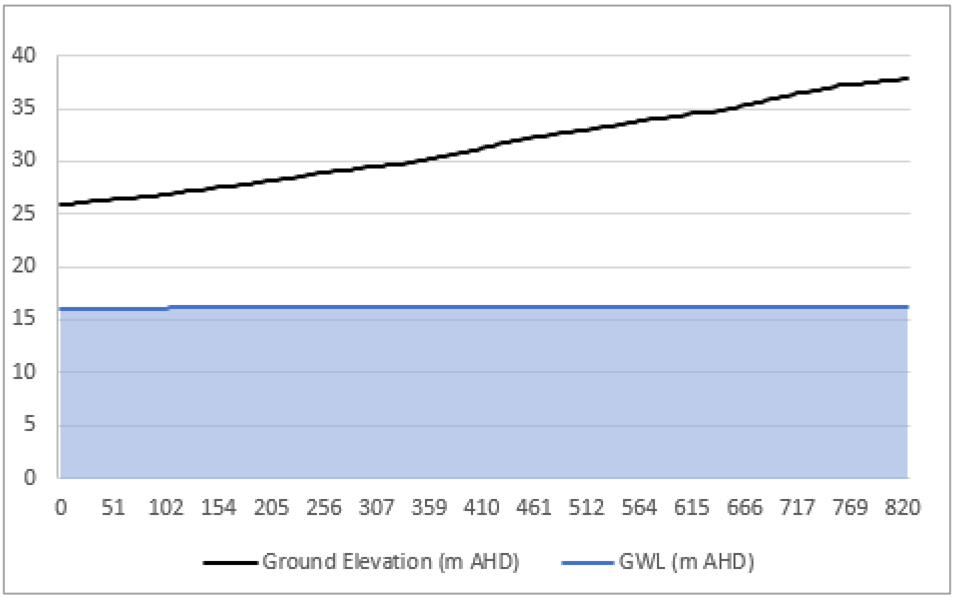
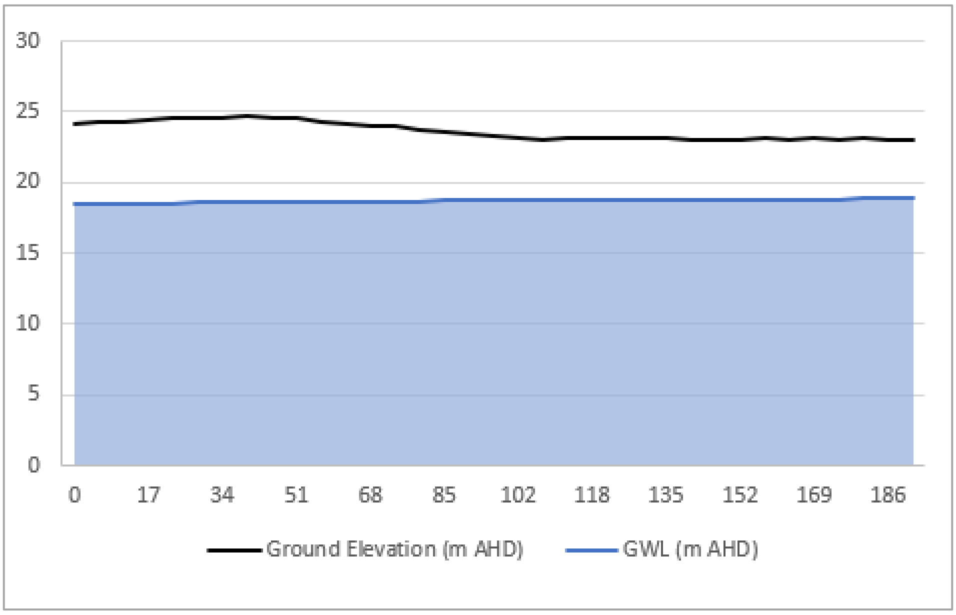


Plate C2: Indicative Cross Section 10



Post-development scenario

As the presence of the groundwater mound is expected to remain unchanged in the post-development scenario (see Section 3.2.4.1 of the WBA) the groundwater assumptions and summary presented in **Table C1** is expected to apply to the post-development scenario.

Perched system

The horizontal groundwater flow rate has been calculated using Darcy's law (*1*) from the components summarised in **Table C2** and the permeability for each cross-section location. Flow has been assumed to occur across the saturated part of the cross-sectional area. The final yearly flow across each cross section is provided in **Table C2**. It is assumed that groundwater flow from the perched system will not change post development.

A visual example of the cross-sectional data is provided in **Plate C3**, which displays Cross Sections 1 (outflow to the north).

Table C2: Perched system groundwater throughflow summary

Cross section/ location		**Cross sectional area (m^2)**	**Groundwater gradient**	**Angle of incidence (degrees)**	**Flow (m^3/yr)**	**Flow direction**
1 -	Boundary Rd outflow	68	1.19%	80.22	7,280	Out from MRS amendment area
2 –	Boundary Rd outflow	-	-	-	-	No flow

Plate C3: Perched system indicative Cross Section 1

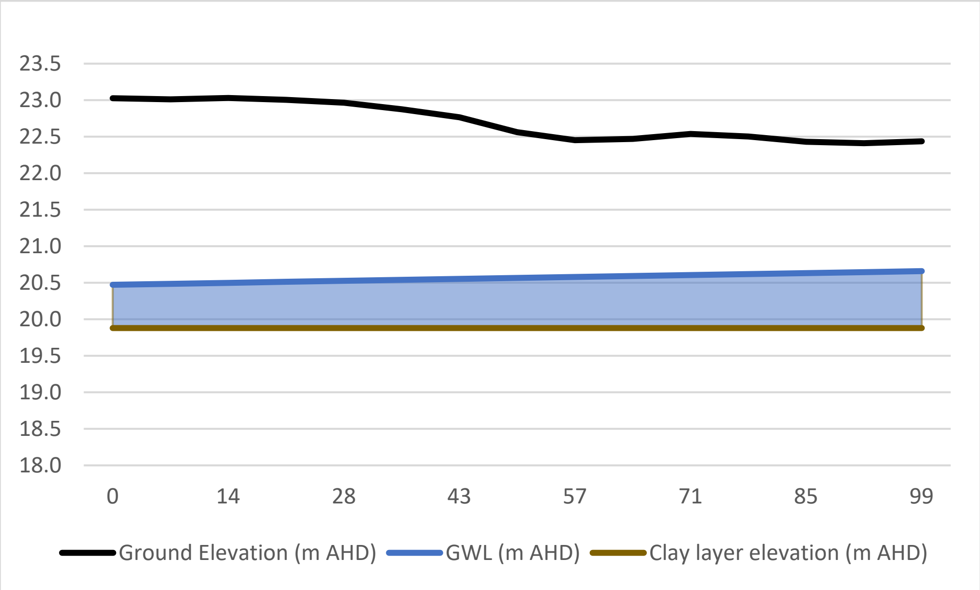


Table C3 summarises the total groundwater inflow and outflow from MRS amendment area as used in the water balance.

Note that the groundwater throughflow is not intended to comprise a wholistic water balance. The main WBA report details consideration of the other water balance components such as evapotranspiration, recharge, surface water, etc.

Table C3: Summary table

Scenario	**Superficial Aquifer**		**Perched**
	Pre-development	Post Development	Pre- and post-development
Inflow	32,212	32,212	-
Outflow	346,081	346,081	7,280

References

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Appendix D

Evapotranspiration

TECHNICAL ASSESSMENT

Project Name	**Wattle Grove South MRS Amendment 1388/57 Water Balance Assessment**
Project Number	**EP22-002**
Assessment Component	**Evapotranspiration**

Introduction

This document is a technical summary and is intended to be read in conjunction with the *Wattle Grove South Amendment 1388/57 Water Balance Assessment* (the WBA), which covers the Wattle Grove South amendment area (the MRS amendment area).

This document summarises the evapotranspiration components of the WBA. Evapotranspiration is determined indirectly through the quantification of other components in the water balance which are deducted from available water within the WBA area. Quantification of these components is based on published values presented in *Perth Regional Aquifer Modelling System* (PRAMS) documentation published by the Department of Water and Environmental Regulation (DWER formerly Department of Water/ DoW), and alignment with other components of the water balance (e.g. groundwater throughflow, rainfall, runoff, etc.).

Data and inputs

The data and inputs used to determine the annual evapotranspiration volumes are summarised below.

- Annual rainfall
- Groundwater abstraction / irrigation water (when applicable)
- Soil types (from regional soil mapping and MRS amendment area investigations)
- Land uses
- Vegetation type.

Delineation of MRS amendment area into representative recharge units

Several soil types and land use categories were distinguished in the pre-development and the post-development environments. For this assessment three distinct representative recharge units (RRU) areas (RRU1, RRU2, RRU3) have been determined based off the regional soil mapping, which are consistent with MRS amendment area investigations (soil bore logs) undertaken by Hyd2O (2022). The categorisation of land uses/types for the pre-development environment was based on MRS amendment area inspections and aerial photography/satellite imagery and the land uses can be broadly categorised as either ‘Pasture’ (i.e. areas which predominately cleared with a low ground cover of grasses or similar) or ‘Vegetation’ (i.e. areas which are more densely vegetated and/or native trees, shrubs or similar) or ‘Urban’ (i.e. areas where pre-existing commercial development/hardstand, residential development and/or roads).

Land uses/types for the post-development environment were informed by a similar process as the pre-development environment. Land uses/types change to ‘Commercial’ (i.e. areas which are intended to generate profit and associated roads), ‘Residential’ (i.e. areas intended for human habitation, made up of suburban and associated roads), ‘School’ (i.e. educational facilities with associated sporting oval) or ‘Public Open Space’ (i.e. areas intended for public enjoyment and protection of existing vegetation).

The spatial extent of the RRUs and land types are shown on **Figures 10** and **11** of the WBA report for the pre-development and post-development environments respectively. The areas of each land type within each WBA area are summarised in **Table D1** and **Table D2**.

Table D1: Evapotranspiration land type area summary – pre-development

Land type	**Area (m^2)**		
	RRU1	**RRU2**	**RRU3**
Pasture	169,621	136,391	388,793
Vegetation	27,819	49,049	304,502
Urban	48,356	54,328	83,878

Table D2: Evapotranspiration land type area summary – post development

Land type	**Area (m^2)**		
	RRU1	**RRU2**	**RRU3**
Commercial	63,414	115,429	-
Residential	161,445	98,462	641,943
School	-	-	42,532
Public Open Space	22,394	25,648	92,676

Evapotranspiration by difference method

The losses to evapotranspiration for the WBA area have been determined by quantifying all other components of the assessment as a percentage of rainfall, such as groundwater recharge, surface runoff and interception. This method is useful for smaller scale evapotranspiration assessments as published data for similar land uses can provide sufficient levels of detail for the estimation of evapotranspiration (W. Dawes [CSIRO] 2022, pers. comm., 10 October). Published data that has been used for the determination of evapotranspiration has been obtained from research undertaken during the generation of the PRAMS modelling and is presented in this document.

PRAMS has been jointly developed by DWER and Water Corporation to assist with groundwater resource management. As part of the PRAMS development a Vertical Flux Model (VFM) was developed, with assistance from the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to assess the temporal and spatial recharge to the aquifers beneath the Swan Coastal Plain. From these developments several studies have been published which make used of PRAMS (DoW 2008, 2009a, b, c, d) to estimate the recharge values for various types of soil, landuse and vegetation across the Swan Coastal Plain and a percentage of rainfall which becomes groundwater recharge.

As indicated the method adopted to estimate the evapotranspiration for the WBA area is through the quantification of the recharge, runoff and interception. A calibration of the outcome is achieved by taking the difference between all inputs and outputs of the water balance for the WBA area, and then calibrating the outcome to evapotranspiration rates adopted in other studies.

The background information and data from MRS amendment area investigations is presented in Section 2 of the WBA report.

Groundwater abstraction

Within the WBA area there are 14 licences to abstract groundwater from the superficial aquifer beneath the MRS amendment area that are registered with DWER. The groundwater allocation for these licences ranges from 2,400 kL/year up to 176,000 kL/year. Combined these bores abstract a total of 260,655 kL of water from beneath the MRS amendment area each year and assumed to be used predominantly for irrigation. It is noted that while all licenses are from the superficial aquifer, the logged depth of bores (based on information from the WIN database) may indicate that the extraction is occurring from a deeper confined aquifer. This is particularly the case for the turf farm located centrally within the amendment area, which has a reported screened depth of -30 m AHD to -40 m AHD (52m below ground level (BGL) to 62m BGL), and this would likely place the extraction into a deeper and presumably confined aquifer. For this assessment it is assumed that the full allocation is extracted every year and applied to the WBA area.

In the pre-development environment the total volume of this abstraction was determined for all bores within the MRS amendment area. This abstracted water is assumed to be irrigated across the MRS amendment area with the following assumptions being applied to this water:

- Irrigation water intercepted by MRS amendment area vegetation: 10%
- Amount of irrigation water becoming recharge: 20%

These assumptions are based on previous research presented in PRAMS documentation (DoW 2009b). The remaining volume of abstracted groundwater is then assumed to become evapotranspiration for the MRS amendment area with these values applied to the assessment after the evapotranspiration generated by rainfall is determined.

In the post-development environment it has been assumed that the existing private bores will be removed from the MRS amendment area and that all residential lots (including homestead lots) and commercial lots will be connected to the Water Corporation Integrated Water Supply Scheme (IWSS). This will cause a reduction in the amount of groundwater abstracted from the WBA area for the post-development environment. The only areas of land that will utilise groundwater will be 'Public Open Space' and 'School' land uses and are based on a prescribed irrigation rate (6,750 kL/ha/year) to determine the amount of groundwater abstracted from the superficial aquifer.

Vegetation - Pasture

The existing environment within the WBA areas is predominantly pasture, with some woody trees that are sparsely interspersed in the western regions of the MRS amendment area with increasing density towards the eastern portion of the WBA area.

Research undertaken by during PRAMS development (DoW 2009b) has found that approximately 30% to 45% of the rainfall becomes recharge to groundwater over areas of pasture. However, the soil type found beneath these areas of pasture also has an impact on the recharge estimate whereby increased amounts of fine grained soil, such as silts and clays, reduces the amount of rainfall that becomes recharge, and in some cases (such as Guildford Clays) this recharge value can be as low as 5% (Farrington *et al.* 1989; DoW 2009a, b).

Previous research into the aquifer systems found beneath the Perth region have defined a range of recharge assumptions that have been assessed for the various soil units, these recharge values assume that rainfall that falls over a given unit of soil will have a ratio of rainfall to runoff which has been robustly assessed in the creation of the PRAMS model.

Based on subsurface investigations within the WBA area the following recharge assumptions have been made for pasture land use for each soil unit which define the RRU areas:

- RRU1: 33 %
- RRU2: 38 %
- RRU3: 45 %.

Vegetation

The 'vegetation' in the WBA area (i.e. vegetation that is not pasture/grasses) is made up of pockets of remnant native and non-native vegetation which is associated with the commercial and residential developments within the MRS amendment area.

During the development of PRAMS (DoW 2008, 2009a, b, c, d) it was found that recharge is moderately impacted by vegetation with vegetation density having the biggest impact on estimation of the percentage of rainfall that becomes recharge. Vegetation density is a consideration of the amount of leaf coverage (or canopy) over a defined area. This assessment was carried out mostly on Banksia woodlands located north of Perth but the estimated recharge values can be applied to the majority of vegetation found on the Swan Coastal Plain.

Assessment of vegetation density for the WBA area has been undertaken through the use of aerial imagery/satellite imagery and MRS amendment area inspections. The delineation of the vegetation for the MRS amendment area has determined the areas of vegetation found in the pre-development environment. For the assessment of evapotranspiration the vegetation landuse has been considered in isolation (i.e. only the extent of the leaf canopy for individual stands of vegetation) across the MRS amendment area. Due to this the assumed density of the majority of vegetation was determined to be of 'low' with an assumed recharge value of 38% being used for the estimation of vegetation evapotranspiration. For the vegetation in the eastern region of the MRS amendment area (associated with RRU3) the density was determined to be 'medium' with an assumed recharge value of 18% for the estimation of evapotranspiration.

Urban, Commercial and Residential

Urban environments, which are defined as being made up of residential and commercial landuses, consist of large amount of impermeable surfaces (i.e. roofs, paved areas, roads, etc). These environments also have minimal areas of vegetation associated with their landuse. As such urban environments are considered to have increased recharge values due to the point sources of recharge/discharge, recharge sources that bypass the soil column through subsurface retention structures (such as soakwells/infiltration basins) and direct evaporation from surfaces with no vegetation (DoW 2009b).

For the pre-development environment the urban areas (both commercial and residential) were mapped from aerial imagery to determine an approximate area of the impermeable surface. Based on this mapping the following recharge assumptions have been made for urban land use for each soil unit which define the RRU areas:

- RRU1 (S_{10} soil unit): 59 %
- RRU2 (S_8 soil unit): 63 %
- RRU3 (S_{12} soil unit): 50 %.

For the post-development environment the estimation of recharge is done through the application of the linear equation as recommended by PRAMS (DoW 2009b). This is due to these post-development landuses being made up of a mixture of impermeable surfaces (such as roads, roofs and paving) and vegetation (from garden beds and streetscapes). The linear equation to determine the recharge for urban environments is as follows:

$$R = \alpha \times P - \beta \times PE \qquad (1)$$

Where *R* is net recharge, *P* is rainfall, *PE* is pan evaporation and coefficients α and β are constants based on the urban environment. These constants are noted as ranging from 0.4 to 0.75 depending on the urban environment (DoW 2009b).

The following values, which are based on the parameters presented in PRAMS documentation (DoW 2009b), have been used in the linear equation for the assessment of evapotranspiration:

- α = 0.75 for 'Commercial', 0.48 for 'Residential', 0.4 for 'POS' and 'School' land uses
- β = 0 for 'Residential' and 'Commercial'
- *PE* = 1800 mm/year.

It is also noted that post-development 'Commercial' lots (excluding associated roads) has no surface runoff as these are proposed to be fully retained lots that will not be discharging surface runoff from the WBA area. How surface runoff is estimated is presented later in this documents.

Public Open Space areas

No 'Public Open Space' land use is found within the WBA area for the pre-development environment and so is not considered for this scenario.

For the post-development environment a portion of the MRS amendment area is proposed to be established as 'Public Open Space' land use for the associated residential development. For this component of the evapotranspiration assessment the amount of rainfall that falls onto these areas and the irrigation water applied to them must be considered. For rainfall, the linear equation that has been recommended by PRAMS can be applied for quantifying recharge. For this the same rainfall amount that has been previously used is applied here with an α = 0.40 used for 'Parklands/Market Gardens'. Irrigation, water is assumed to be abstracted from superficial groundwater beneath the MRS amendment area at a prescribed irrigation rate (6,750 kL/ha/year) and this is applied to the proposed areas of 'Public Open Space'. As per PRAMS documentation (DoW 2008) it is assumed that 20% of this abstracted groundwater will return to the aquifer beneath the MRS amendment area as recharge. The same interception value (10%) is also used to account for turfed and planted areas found with these land uses.

School area

No 'School' land use is found within the WBA area for the pre-development environment and so is not considered for this scenario.

For the post-development environment a portion of the MRS amendment area is proposed to be established as 'School' land use. This landuse is considered as a mixture of the post-development 'Commercial' and 'POS' land uses as the runoff from the school MRS amendment area is proposed to be fully retained, and the sporting ovals associated with the school will be irrigated in a similar manner to the 'Public Open Space' areas. For this assessment 50% of the 'School' land use is quantified in the same method as the 'Commercial' land use and 50% is quantified using the same methodology as the 'Public Open Space' areas.

Surface Runoff

A surface water runoff assessment has been undertaken to quantify the annual volume of runoff conveyed into and discharging from the MRS amendment area (see Appendix A of the WBA). This assessment is based on the detailed catchment assessment and surface water runoff assessments previously undertaken by Hyd2O (2022) and Emerge Associates (Emerge Associates 2017, 2021). This surface runoff assessment has considered both the pre-development and post-development environments and accounts for upstream catchments.

From the surface water runoff assessment the following runoff recharge assumptions have been made:

- Pre-development environment:
  - ‘Pasture’ and ‘Vegetation’ land use: 7.1% of rainfall becomes surface runoff
  - ‘Urban’ land use: 7.0% of rainfall becomes surface runoff.
- Post-development environment:
  - ‘Commercial’ land use: 7.0% of rainfall becomes surface runoff from associated roads, commercial lots are fully retained and are assumed to produce no runoff
  - ‘Residential’ land use: 9.1% of rainfall becomes surface runoff
  - ‘Public Open Space’: 7.1% of rainfall becomes runoff while irrigation water is assumed to generate no surface runoff due to the nature of water application to these surfaces.

Rainfall interception

A portion of rainfall will be physically intercepted and stored on the leaves and branches of vegetation and litter found on the surface prior to it reaching the ground surface. This will eventually evaporate and hence constitutes a loss of water from the WBA area. It was observed during PRAMS development (DoW 2009b) that the values can vary from 7% (low density vegetation) to 12% (high density vegetation) of rainfall occurring over vegetated areas.

For the pre-development environment, based on the assumed recharge value for ‘Vegetation’ land use previously presented in this document being generally ‘low’ there will be an associated with lower interception due to reduced leaf mass and litter density. For the purposes of this assessment the following rainfall interception values have been assumed:

- ‘Pasture’ land use: 11%
- ‘Vegetation’ land use: varies from 7% to 9% dependant on vegetation density
- ‘Urban’ land use: 11%

For the post-development environment the land uses become increasingly urbanised so there is a general reduction in the amount of rainfall being intercepted. Rainfall that is intercepted is likely from the ponding and trapped lows that can occur from this land use (i.e. gaps in paving, porosity of roads, ponding of rainfall in road reserves, etc). For the purposes of this assessment the following interception values have been assumed:

- ‘Commercial’ and ‘School’ buildings land use: 5%
- ‘Residential’ land use: 7%
- ‘Public Open Space’ and ‘School’ oval land use: 11%

Evapotranspiration for WBA area

The recharge values discussed in this document were applied to each RRU and land use to quantify the amount of recharge, surface runoff and interception generated. The summation of these values was then removed from the rainfall amount to estimate the evapotranspiration for the WBA area. The abstracted groundwater, which has been considered as irrigation water for the MRS amendment area, was then assessed separately using the same method for rainfall evapotranspiration. These two evapotranspiration values were then combined to provide the total evapotranspiration for the WBA area.

In addition, two scenarios where the effects of climate change have been considered on the proposed development. These scenarios are based on future climate predictions by DWER which are presented in **Appendix B**. A summary of these climate change scenarios is a follows:

- Dry 2050 indicates an approximate reduction of rainfall in the vicinity of the WBA area of 4.4%, this represents and average annual rainfall of 702 mm.
- Dry 2100 indicates an approximate reduction of rainfall in the vicinity of the WBA area of 34.5%, this represents an average annual rainfall of 481 mm.

Results and Summary

The quantified components of the assessment of evapotranspiration is summarised in **Table D3** for the pre-development and post-development environments, including estimates for the Dry 2050 and Dry 2100 DWER future climate predictions.

Note that the evapotranspiration components are the quantification of the various components and are not intended to comprise a wholistic water balance. The main WBA report details consideration of the other water balance components such as groundwater throughflow, recharge, surface water, etc.

Table D3: Evapotranspiration summary

Evapotranspiration component (m³/year)	**Pre-development**	**Post-development**	**Post-development (Dry 2050)**	**Post-development (Dry 2100)**
Direct rainfall (falling on MRS amendment area)	928,888	928,888	887,963	608,350
Irrigation water (abstracted from groundwater resources)	260,655	123,694	123,694	123,694
Irrigation water (from domestic supply)	32,500	46,000	46,000	46,000
Interception (rainfall)	95,346	63,529	60,684	41,580
Interception (irrigation)	29,316	18,206	18,206	18,206
Surface Runoff (rainfall)	65,752	76,886	69,427	28,279
Recharge (rainfall)	346,347	476,054	454,730	311,547
Net recharge (irrigation)	-26,024	-89,755	-89,755	-89,755
Evapotranspiration (rainfall)	**420,566**	**312,427**	**302,447**	**226,524**
Evapotranspiration (irrigation)	**205,209**	**117,549**	**117,549**	**117,549**
Total Evapotranspiration	**625,775**	**429,976**	**419,996**	**344,073**

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Appendix E

Salinity and Sodicity

TECHNICAL ASSESSMENT

Project Name	**Wattle Grove South MRS Amendment 1388/57 Water Balance Assessment**
Project Number	**EP22-002**
Assessment Component	**Salinity and Sodicity**

Introduction

This technical summary is intended to be read in conjunction with the *Wattle Grove South Amendment 1388/57 Water Balance Assessment* (the WBA), which covers the Wattle Grove South amendment area (the MRS amendment area). This document assesses the potential impacts of salinity and soil sodicity to the surface water and groundwater of the MRS amendment area and upstream catchments (urban expansion (UE) and urban investigation (UI) areas) presented in the WBA. Changes in water chemistry to these water sources present a risk to the water quality of the surrounding environment, particularly the nearby Greater Brixton Street Wetlands (GBSW) and where groundwater is close to the surface.

Soil salinity is the result of soluble salts (often associated with near surface groundwater interactions), concentrating within the shallow soil profile. The ions in salt that are responsible for causing salinity in soils are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and chlorine (Cl^-).

Soil salinity occurs due to the soluble salts binding to clay particles found in soil due to their large surface area and inherent surface reactivity (ionic charge being positive or negative). These salts can be naturally occurring due to redistribution by water or caused by human activity (such as irrigation). Soluble salts may be transported through the soil profile by the movement of water, this can be through the groundwater; both vertically and horizontally. Seasonal variations in groundwater movement have the potential to transport increasing amounts of salt to the shallow soil profile. During dry periods the groundwater elevations can recede to the deeper soil profile due to lack of recharge from rainfall and increased evaporation. In areas where groundwater has receded the dissolved salts can bind to clay particles as it dries and remain in the shallow profile. During periods of increased rainfall groundwater level can rise and bound salts become re-saturated and are released back into solution, becoming part of the groundwater. As this process is repeated due to climatic cycles this can have the effect of increasing the concentration of salt within the shallow soil profile, resulting in soil salinity.

Soil sodicity is where the proportion of sodium ions resulting from soil salinity is excessive, leading to a loss of soil structure.

If the salts that are deposited in the shallow soil profile contain elevated amounts of Na^+ ions these can displace other ions (such as K^+, Ca^{2+}), leading to a change in the proportion Na^+ in the soil and an impact to soil structure. Once the Na^+ within the soil concentrates to an amount that it begins to affect the soil structure then this soil is considered to be sodic. Sodicity degrades the properties of soil by weakening the bonds between the soil particles. These structural problems commonly present as (DPIRD 2021):

- Soil become waterlogged when wet
- Reduced water infiltration capacity
- Dispersive soils (standing water becomes cloudy)
- Excessive shrinking/swelling behaviour when dry/wet
- Susceptibility to erosion
- Form hard setting crust when dry
- Abnormal/poor vegetation growth.

Given the development of soil salinity/sodic soil conditions requires groundwater to be at or have the potential to be at the surface, this will only be relevant to the parts of the site which display these conditions.

Existing conditions of the MRS amendment area

Previous research into the GBSW undertaken by the Environmental Protection Authority (EPA) has identified the presence of soil salinity within the shallow soil profile and the presence of salt tolerance vegetation (EPA 2022); this is most relevant to the areas southwest of Brixton Street (Wanaping Block) which are well removed from the MRS amendment area. A summary of concerns raised from this investigation are presented below:

- Changes in the water balance could lead to groundwater level rise close to the natural surface for capillary action to draw up salt, which create sodic soil conditions.
- Groundwater salinity is possibly driven by upward discharge of the saline Leederville aquifer beneath GBSW.
- Evaporation is a driving factor for concentrating salts in clayey sediments within GBSW.
- Increases in shallow groundwater levels can lead to waterlogging of soils.

Due to the proximity of the GBSW to the MRS amendment area (GBSW is west of Tonkin Highway) it is understood that there are concerns that the elevation of groundwater beneath GBSW may be altered due to the change in landuse from the proposed development. An increase in groundwater levels could potentially impact soil chemistry. Increases to groundwater levels could transport additional dissolved salts (solutes) from the shallow soil profile to the surface in areas where groundwater may not have previously intersected the surface (i.e. within GBSW). These solutes may persist and concentrate within the soils over the drier summer months (due to evaporation) may potentially impact the condition and health of vegetation within GBSW.

Groundwater level

Groundwater levels have been measured from a series of bores in the vicinity, and within, the MRS amendment area (see Section 2.7.2 of WBA). These indicate that the groundwater levels across the MRS amendment area are significantly lower than the natural surface (> 10 m below ground level (BGL)) for the majority of the site, and this is highly unlikely to change as a result of development within the MRS amendment area due to the permeable sandy soils beneath the site.

Assessment of recharge to groundwater has been considered (see Section 4.1.1 of WBA) which indicates that the MRS amendment area will experience an increase in groundwater recharge due to the proposed development. However, the overall increase to recharge will be vertically towards the deeper and permanent superficial aquifer, and not to the margins which display shallow perched conditions. Groundwater levels are several metres below the natural surface and therefore not expected to rise enough to deposit salts to the surface.

There is a relatively minor westerly margin of the site where thin sand over clay conditions exist, however the drivers for groundwater levels in this area will not change as a result of development of the MRS amendment area.

The risk of salt being draw up to the surface, which create saline/sodic soil conditions, is not considered to be a concern for the MRS amendment area. Further, given that there will be no changes to shallow (perched) groundwater conditions as a result of development of the MRS amendment area (either within the site or adjacent), there are no drivers to change the shallow groundwater levels beneath GBSW, and therefore, no potential impacts to soil chemistry of GBSW are expected.

Upward discharge from Leederville aquifer

The investigation of groundwater conditions (see Section 2.7 of WBA) indicates a multi-layered aquifer system beneath the MRS amendment area. This system includes the Leederville aquifer which underlies the Superficial Swan aquifer. An assessment of the degree of connectivity between these aquifer systems has been undertaken to understand the degree of vertical groundwater movement. This assessment suggests that there is limited to no connectivity between the Superficial Swan and Leederville aquifer beneath the MRS amendment area.

Therefore, the risk of saline groundwater upwardly discharging from the Leederville aquifer beneath the MRS amendment area, and thereby contributing to soil salinity, is considered to be minimal and will not impact the MRS amendment area or GBSW.

Evaporation concentrating salt within clayey sediments in shallow soil profile

Investigations into the soil conditions of the MRS amendment have been undertaken (see Section 2.6 of WBA). Soils found within the MRS amendment area are generally considered to be sand with finer grained soils (such as clays and silts) being located along the western boundary and northern boundary. Due to the majority of the MRS amendment area being classified as sandy material the risk of salt being concentrated within shallow soil profile is considered to be minimal.

The finer grained soil located along the western and northern boundaries of the MRS amendment area present some potential that salt could be concentrated at these locations from evaporation. However, there are no drivers present (resulting from future development in the MRS amendment area) to change the shallow groundwater levels. Therefore the following conclusions are made for these areas:

- Rainfall deposited onto these locations, which is considered to have a low salt content, will not be contribute to soil salinity.
- The soil that surrounds these locations within the MRS amendment area are classified as sandy, and will promote the draining of water into the deeper soil profile and away from these locations, as currently occurs. These areas will therefore have a low potential for loss of groundwater from the soil profile due to evaporation.

Based on these conclusions the risk of evaporation concentrating salt within the shallow soil profile in the MRS amendment area and immediate surrounds as a result of development within the MRS amendment area is minimal to non-existent. As the potential for evaporation concentrating salt within the shallow soil profile is considered to be minimal it is also concluded that there will be no potential for increased salt concentrations within GBSW due to evaporation (as a result of changes resulting from development within the MRS amendment area).

Waterlogged soils

The waterlogging of soils is evidence of a possible sodic soil, as water is unable to infiltrate into the deeper soil profile (potentially due to the structureless soil caused by sodicity). For the majority of the MRS amendment area this is not of concern as the measured water table is of significant depth below the natural surface (up to 10 m BGL). The permeable nature of the soils found across the majority of the MRS amendment area (sands) also promotes the free draining of surface water into the deeper soil profile, thereby mitigating the risk of waterlogging occurring.

For the minor areas of finer grained soil, found along the western and northern boundary of the MRS amendment area, whilst there is some potential for waterlogging of these soils to occur, the groundwater levels in these areas will not rise as a result of development in the MRS amendment area. Further, due to the likely fresh nature of the perched groundwater system associated with these locations waterlogging in these locations is of minimal concern.

Summary

Soil salinity and sodicity have been identified as of concern for GBSW due to proposed development of the MRS amendment area changing existing landuses, and therefore changing hydrological conditions which affect GBSW. If groundwater within the shallow soil profile beneath GBSW were to rise this could potentially increase soil salinity within the shallow soil profile of GBSW. Such increased salinity can induce soil sodicity which has been identified as a concern for GBSW.

While salinity has been noted within the adjacent GBSW the soils within the MRS amendment areas are geologically distinct, generally consisting of sandy soils to depth with areas of finer grained clay/silt soil generally found along the western and northern boundaries. In comparison, GBSW consists of majority fine grained soils with smaller deposits of sandy soil. The depth to groundwater is also different with GBSW consisting of shallow depths to the water table while the MRS amendment area has a significant depth to groundwater (10 m BGL). This is of importance as salt can be transported to the surface via capillary force if the water table is close to the surface. While it has been noted in the WBA that there will be an increase to recharge from the proposed development this will generally infiltrate towards the deeper and permanent superficial aquifer, and not to the margins which display shallow perched conditions. Groundwater levels are several metres below the natural surface and therefore not expected to change enough to cause a rise in groundwater which would deposit salts to the surface.

The more saline Leederville aquifer, while being located beneath the MRS amendment area, likely has no/minimal connection to the Superficial Swan aquifer. With minimal connection noted between these aquifer systems (and the depth to groundwater) it is unlikely that the Leederville aquifer will contribute to soil salinity for GBSW and the MRS amendment area.

The results of this investigation into the impacts of soil salinity and sodicity indicate that there is minimal concern from the proposed development increasing soil salinity with GBSW due to the permeable nature of soils and significant depth to groundwater found within the MRS amendment area. For the minor portions of the site which exhibit some potential for shallow groundwater to be close to the surface, there are no drivers to change the existing groundwater conditions and therefore it is concluded that the risk of soil salinity and sodicity changing as a result of the proposed change in land use in the MRS amendment area and the urbanisation of the UE and UI areas is negligible. When considering impact from the proposed development it is considered that there is no potential risk for an increase to soil salinity and sodicity to GBSW.

References

Department of Primary Industries and Regional Development (DPIRD) 2021, *Identifying dispersive (sodic) soils*, <https://www.agric.wa.gov.au/dispersive-and-sodic-soils/identifying-dispersive-sodic-soils#:~:text=severely%20dispersive%20topsoils.-,Measure%20the%20exchangeable%20sodium%20percentage,than%2015%20(Table%201).&text=No%20dispersion%20evident%20after%2024%20hours.>.

Environment Protection Authority (EPA) 2022, *Environmental values and pressures for the Greater Brixton Street Wetlands on the Swan Coastal Plain*, Western Australia.