Regional Water Management Strategy

Muchea

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Executive Summary

The Department of Planning, Lands and Heritage (DPLH) has engaged Emerge Associates to prepare a water management strategy for the Muchea area (herein referred to as 'the site') to form a key input into the Western Australia Planning Commission (WAPC) update of the Muchea Industrial Park Structure Plan (MIP-SP). This regional water management strategy (RWMS) has been prepared to identify the environmental assets and values present, confirm the existing hydrological regime across the site, and understand the implications to water management across the site from proposed and potential land use changes.

The site covers approximately 6,580 ha within the Shire of Chittering (SoC) and is located approximately 40 km north of the Perth central business district. The site is zoned under the *Town Planning Scheme No. 6* (Scheme) (SoC 2004) and includes agricultural resource, industrial development, light industrial, rural residential, townsite (i.e. the Muchea townsite) and a number of other categories. High level investigations over the site have identified key existing constraints and issues across the site including:

- High groundwater levels and seasonal inundation occur across the majority of the site.
- A number of significant waterways and wetlands are located across the site, along with other environmental assets including threatened ecological communities and priority ecological communities.
- Large surface water flooded areas occur following minor and major rainfall events.
- Limited water supply and wastewater servicing options exist due to the location and constraints of population/land uses across the site.
- A significant gap in monitoring data exists both spatially and temporally for groundwater levels, groundwater quality and surface water quality.

Development proposals within the site need to address the data gaps, and consider the environmental constraints and risk posed by proposed land uses and available water management measures, especially in relation to water quality (groundwater and surface water).

This RWMS provides guidance regarding current infrastructure solutions, management measures, ongoing maintenance recommendations, and relevant existing environmental considerations across the site for:

- Water resourcing and supply options
- Wastewater servicing
- Surface water management
- Groundwater management
- Waterway and wetland management.

Risks to water management across the site from proposed and potential land use changes can be managed through implementation of appropriate management measures, which are summarised below (including within **Table E 1** through **Table E 3**). However, ongoing maintenance of systems is key to ensuring the protection of water quality and environmental assets into the future.

Table E 1: Water resource and supply options for the site

Supply potential	Potable		Non-potable		Section detailed	Responsibility	
Water resource	Potential source	Treatment requirements	Potential source	Treatment requirements		Government stakeholders*	Ongoing management
Rainwater harvesting	Yes	Minor	Yes	Minor	See **Section 5.2.1**	SoC, DoH, DPLH, ERA	Owner/operator
Stormwater harvesting	Dependent	Variable, likely to be significant.	Yes	Variable, likely to be minor.	See **Section 5.2.2**	SoC, DoH, DPLH, ERA	Owner/operator
Surface water extraction	Yes, subject to demonstration of viability	Minor to significant	Yes, subject to demonstration of viability	Variable, likely to be minor or none.	See **Section 5.2.3**	SoC, DoH, DWER** (licencing only), DPLH, ERA	Owner/operator
Groundwater abstraction	Yes, subject to demonstration of viability	Variable, likely to be minor.	Yes, subject to demonstration of viability	Variable, likely to be minor.	See **Section 5.2.4**	SoC, DoH, DWER** (licencing only), DPLH, ERA	Owner/operator
Domestic wastewater	Currently infeasible	Inhibitively stringent, constrained by available technology.	Unlikely, subject to feasibility	Significant	See **Section 5.2.5**	SoC, DoH, DPLH, ERA	Owner/operator
Trade waste	Currently infeasible	Variable, likely to be inhibitively stringent.	Unlikely, largely dependent on wastewater quality	Variable, likely to be significant	See **Section 5.2.5**	SoC, DoH, DPLH, ERA	Owner/operator
Grey water	Currently infeasible	Inhibitively stringent	Yes	Minor	See **Section 5.2.5**	SoC, DoH, DPLH, ERA	Owner/operator
MAR	Yes (following abstraction)	Significant treatment prior to injection, minor treatment following abstraction	Yes	Significant prior to injection, minor to none following abstraction	See **Section 5.2.6**	SoC, DoH, DWER, DPLH, ERA	Owner/operator

** Local and state government agencies who may provide advice or approval(s) for the proposed water supply option. Their involvement is highly dependent on the site context, the proposed water resource and uses, and the water supply option itself.*

*** DWER do not recommend the consumption of surface water or groundwater unless it is suitably treated and meets DoH requirements.*

Table E 2: Wastewater servicing options for the site

Treatment options	Incompatible			Restricted			Unconstrained			Section	Responsibility	
	Residential wastewater	Industrial wastewater	Trade waste	Residential wastewater	Industrial wastewater	Trade waste	Residential wastewater	Industrial wastewater	Trade waste		Government stakeholders*	Ongoing management
Centralised reticulated sewer	Yes	Yes, subject to WWTP facilities	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	**Section 6.1.1**	DWER, SoC, DPLH, ERA	Licenced service provider
Decentralised reticulated sewer	Yes	Yes, subject to WWTP facilities	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	**Section 6.1.2**	DWER, SoC, DPLH, ERA	Licenced service provider
Primary treatment - septic tanks/leach drains	No	No	No	No	No	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	No	**Section 6.2.1**	DoH, SoC, DWER	Lot owner
Secondary treatment - pre-approved ATUs	No	No	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	No	**Section 6.2.2**	DoH, SoC, DWER	Lot owner
Secondary treatment - site specific ATUs/treatment plants	No	No	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	**Section 6.2.2** and **6.3.1**	DoH, SoC, DWER	Lot owner
Containment devices and practices	No	No	Yes	No	No	Yes	No	No	Yes	See **Section 6.3.2**	SoC, DWER	Lot owner
Treatment WSUD measures	No	No	Yes	No	No	Yes	No	No	Yes	See **Table 8**.	SoC, DWER	Lot owner or SoC
Off-site treatment storage	No	No	Yes	No	No	Yes	No	No	Yes	See 6.3.3	SoC, DWER	Lot owner

** Local and state government agencies who may provide advice or approval(s) for the proposed wastewater servicing option. Their involvement is highly dependent on the site context and the wastewater servicing option itself.*

Table E 3: Structural stormwater management options for the site

Stormwater management category	Management response examples	Description	Primary objective achieved	Secondary objective achieved	Rainfall event managed
Retention and detention	End of pipe (i.e. basins, sub-surface storage, RWTs)	• Retain stormwater (infiltrated or evaporated) or detain stormwater to meet pre-development flow rates (controlled discharge). • Typically located at the catchment low point. • A large variety of solutions in many forms are available. Can provide water reuse storage.	Quantity	Quality	Minor and major
	Pond/urban lake	• Ponds or urban lakes can be integrated into the stormwater management system to provide detention storage. • Can provide amenity and reuse storage.	Quantity / social value	Quality	Varies
	Constructed/rehabilitated wetland	• Stormwater runoff is treated within wetlands through a number of biochemical and physical processes, which are primarily facilitated by submerged and emergent vegetation (Śarmā 2018). Runoff is also detained and/or retained. • A high flow or bypass should be configured to circumvent major event flows.	Quality	Quantity / social value	All
Infiltration	Soakwell, pervious pavement, swale	• Infiltrates runoff at source and reduces pollutant mobilisation. • Decreases effective imperviousness across a catchment.	Quality	Quantity	Small
Treatment	BRA, rain gardens, tree pits, vegetated swale	• WSUD features that treat stormwater within a vegetated area underlain by nutrient removing soils/media. • A large variety of solutions in many forms are available.	Quality	Quantity / social value	Small
Conveyance	Living stream	• A living stream is a vegetated, meandering stream that mimics the characteristics of natural waterways. Living stream can be constructed, rehabilitated from degraded streamlines or retrofitted to an existing stormwater conveyance system (e.g. a drain). • When implemented correctly they can provide greatly improved water quality, promote biodiversity and create an attractive landscape feature, while maintaining the safe conveyance of stormwater.	Quantity / quality	Social value	All
	Drain/swale	• Vegetated channel to convey runoff that decreases the effective imperviousness across a catchment. Runoff is also detained and/or retained. • Can convey runoff at a shallower grade than pit and pipe networks, and be utilised to control groundwater rise.	Quantity	Quality / serviceability	All

Groundwater management strategies are required to manage the potential impacts and risks of development through consideration of groundwater levels and quality. The application of groundwater level management strategies will depend on the proposed land use, other water management approaches, and the level of risk posed by the site conditions. These strategies include:

- Only developing areas with adequate existing separation to groundwater.
- Importing fill to provide adequate separation to groundwater.
- Utilising surface or subsoil drainage networks to locally control groundwater.
- Utilising alternative construction methods and materials.

The overarching principle of maintaining or improving groundwater quality can be achieved by managing the load of pollutants being applied to the site (e.g. from land use practices, disposal of wastewater) and through ensuring appropriate development practices are adhered to (e.g. stormwater management, wastewater management).

Protection of the waterways and wetlands present across the site can be accomplished through ensuring inflows (surface and groundwater) are appropriately managed as well as through direct protection and management of the assets themselves. Once foreshore areas and wetland boundaries are identified, they can be protected within reserves, through appropriate zoning within contributing catchment areas, by preparation of management plans, and ongoing monitoring.

Broad land use management, monitoring and ongoing maintenance recommendations for the site have been based upon the assessment of the existing land uses and environment, potential development within the MIP and wider site area, and the servicing and water management measures outlined within this document. These recommendations have been assigned to the agency that would typically undertake these works and are:

- Monitoring:
    - A regional monitoring program should be progressed to identify regional-scale changes between existing and post-development parameters.
    - Should this not be progressed (or more detailed coverage of individual lots be required), localised monitoring should be conducted by the proponent to support development proposals.
- Surface runoff modelling and flood mapping:
    - The regional flood model should be calibrated through comparison to measured flow rates at key control points within Ellen Brook.
    - Future development proposals will need to appropriately consider surface flowpaths and flooding on their property and appropriate management of the associated risks, which will likely require additional surface runoff modelling.
- Technical assessments be completed (where relevant) including geotechnical investigations, flora and fauna surveys, wetland and waterway assessments, and land capability assessments.

- Land use management:
  - Seek to remove land uses that are determined to be incapable of responding to land use constraints through appropriate water management measures.
  - Intensification of agriculture should not be approved within the incompatible and restricted on-site wastewater risk areas shown in **Figure 16** due to increased nutrient loading from fertiliser application and/or stock access. Exceptions should only be considered where a detailed land capability assessment is provided.
  - Minimum residential lot sizes should be compliant with the *Government Sewerage Policy* (DPLH 2019) where on-site wastewater disposal is proposed.
- Water supply and wastewater servicing:
  - The location of all groundwater abstraction bores proposed for potable water supply be assessed and approved by a responsible agency.
  - Assessment of all lot-scale water supply options and on-site wastewater solutions consider water management constraints holistically.
- Record keeping and auditing:
  - A database should be implemented by a responsible agency to track the technologies and infrastructure approved and constructed.
  - A compliance auditing system should be utilised to ensure ongoing compliance of approved systems is being demonstrated by proponents. Implementation of systems will be subject to practical limitations and resourcing capacity of the Shire.

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1 Introduction

1.1 Background

The Department of Lands and Heritage (DPLH) has engaged Emerge Associates to prepare a water management strategy for the Muchea area including the townsite, industrial park and surrounding agricultural land (herein referred to as 'the site') to form a key input into the Western Australia Planning Commission (WAPC) update of the Muchea Industrial Park Structure Plan (MIP-SP).

The site covers approximately 6,580 ha within the Shire of Chittering (SoC) and is located approximately 40 km north of the Perth central business district, as shown in **Figure 1**.

The site is zoned under the *Town Planning Scheme No. 6 (Scheme)* (SoC 2004) and is mostly zoned agricultural resource with some areas zoned rural residential and townsite, and some small areas of industrial zoned land. The DPLH is progressing an update to the MIP-SP (previously referred to as the Muchea Employment Node (MEN)), which is located within the site. Existing land uses, anticipated land use changes and development of the MIP are discussed further in **Section 2**.

1.2 Purpose of this report

The site contains a range of environmental assets and constraints that will need to be appropriately considered and where necessary accommodated within any future planning and development.

This regional water management strategy (RWMS) has been prepared to confirm the existing hydrological regime across the site, identify the environmental assets and values present, and understand the implications of proposed and potential land use changes in the area. The RWMS has utilised existing information available for the site, along with detailed surface runoff modelling (discussed in **Section 3.5.2**) to inform the recommendations and identify further investigations required to fully understand the constraints of the site. Recommendations relate to the implications and viability of land use changes in the site to ensure that future development can be delivered in a manner that is environmentally sustainable.

The RWMS details the existing constraints and opportunities for water management across the site, with the MIP detailed further to incorporate the proposed industrial land use. The constraints and opportunities detailed in this RWMS can be used to help inform revisions to the MIP-SP.

This RWMS has been prepared in accordance with *Better Urban Water Management* (WAPC 2008), considering the *Guidelines for District Water Management Strategies* (DoW 2013c), and the requirements and expectations of the DPLH, the SoC and the Department of Water and Environmental Regulation (DWER).

1.3 Policy framework

There are a number of State and Local Government policies of relevance to the site. These policies include:

- *Assessment and Management of Contaminated Sites* (DER 2014)
- *Better Urban Water Management* (WAPC 2008)
- *Bush Forever* (Government of WA 2000)
- *Decision Process for Stormwater Management in Western Australia* (DWER 2017)
- *Government Sewerage Policy* (DPLH 2019)
- *Guidance Statement No. 33: Environmental Guidance for Planning and Development* (EPA 2008)
- *Liveable Neighbourhoods Edition 4* (WAPC 2007)
- *Local Planning Policy No. 16: Roads and Drainage* (SoC 2007a)
- *Local Planning Policy No. 6: Water Supply and Drainage* (SoC 2008)
- *Local Planning Policy No. 33: Muchea Industrial Park Design Guidelines* (SoC 2017)
- *Local Planning Strategy* (SoC 2019)
- *Operational Policy 4.3: Identifying and establishing waterways foreshore areas* (DoW 2012a)
- *Planning Bulletin No. 64: Acid Sulfate Soils* (WAPC 2009)
- *State Planning Policy 2.9 Water Resources* (WAPC 2006)
- *State Water Plan* (Government of WA 2007)
- *State Water Strategy* (Government of WA 2003).

In addition to the above policies, there are a number of published guidelines and standards available that provide direction regarding water management that is of relevance to this RWMS.

- *Australian Rainfall and Runoff (*Engineers Australia 2016)
- *Australian Runoff Quality* (Engineers Australia 2006)
- *Code of practice for the Design, Manufacture, Installation and Operation of Aerobic Treatment Units* (DoH 2001)
- *Ellen Brook Flood Study* (WAWA 1987)
- *Environmental health information sheet – Aerobic treatment units* (DoH 2011a)
- *Guidance on use of rainwater tanks* (DOH 2018a)
- *National Water Quality Management Strategy* (ANZECC and ARMCANZ 2000a)
- *Stormwater Management Manual for Western Australia* (DoW 2007b)
- *Supplement to Regulation 29 and Schedule 9 - Wastewater system loading rates* (DoH 2016)
- *Swan Canning Water Quality Improvement Plan* (SRT 2009c)
- *Local Water Quality Improvement Plan – Ellen Brook Catchment* (SRT 2009a)
- *Water Note 23: Determining foreshore reserves* (WRC 2001b)
- *Water tanks on your property* (DoH 2018b)
- *Water quality protection note* (WQPN) *index* (DoW 2015c)
    - Many WQPNs will be relevant to certain scenarios. Specific mention of WQPNs has been made throughout the RWMS, however this index (and any WQPNs published since the creation of the index) should be considered where appropriate.

1.4 Previous studies

1.4.1 Ellen Brook Flood Study

The *Ellen Brook Flood Study* (WAWA 1987) was prepared to provide peak flow and flood level estimates at specific locations within the Ellen Brook, from Rutland Road (located approximately 6 km south of the site) to the confluence with the Swan River (approximately 28 km downstream of the site). Two runoff and routing models were utilised (FLOUT and RORB) with results of each being within 8% of each other.

The peak flow and flood elevation identified at Rutland Road were 81 m^3/s and 35.05 m AHD (WAWA 1987). Peak flow rates for the 1%, 2% and 4% annual exceedance probability (AEP) event discharging from Railway Parade gauging station (station number 616189 - located approximately 8 km upstream of the Ellen Brook and Swan River confluence) were identified as 97 m^3/s, 86 m^3/s and 75 m^3/s, respectively.

1.4.2 Northlink WA Stage 3, Hydrogeological Report - Northern Section

A hydrogeological report was completed by Golder Associates (2017b) covering Stage 3 of the Perth to Darwin National Highway Project (Northlink). The intent of the report was to identify relevant hydrogeological characteristics within the vicinity of the Northlink footprint. In particular the main focus was to determine the design groundwater level for the development. These were determined in consideration of subsoil conditions identified in the *Factual Geotechnical Report* (Golder Associates 2017a) and groundwater monitoring. The detailed groundwater monitoring results are appended to the report (Golder Associates 2017b).

1.4.3 MEN Local Structure Plan 1 Local Water Management Strategy

The *MEN Local Structure Plan 1 Local Water Management* (LWMS) was prepared by Emerge Associates (2017) to support water management within the MEN Local Structure Plan (LSP) 1 area on behalf of Sirona Capital Management Pty Ltd.

The MEN LSP 1 covers an area of 149 ha and allows for the creation of 23 transport related industrial lots. The development is targeted towards service-based and complementary uses such as transport, livestock, fabrication, warehousing, wholesaling and general commercial. Development of the LSP has allowed for integration of stormwater drainage and retention of existing environmental assets including waterways, wetlands and native vegetation within dedicated reserves.

Water management objectives for LSP1 are to mimic the existing hydrological regime of the site whilst protecting properties and the downstream environment from flooding and pollution. The LSP 1 design objectives seek to deliver best practice outcomes using a water sensitive urban design (WSUD) approach, including detailed management approaches for:

- Potable water consumption
- Flood mitigation
- Stormwater quality management
- Groundwater management
- Waterway management.

1.4.4 Muchea Groundwater and Soil Assessment

Urbaqua was engaged to complete a groundwater and soil investigation within the Muchea townsite to assess the capability of further development. The draft *Muchea Groundwater and Soil Assessment* (Urbaqua 2017) has been prepared to assess the current risk of existing infrastructure to public health and to inform future water and wastewater servicing. The assessment determined that:

- The ability of underlying soils to manage nutrients was very low.
- There is a lack of regional groundwater monitoring.
- The Muchea townsite exports nutrients in excess of catchment guidelines.
- A range of planning considerations would need to be addressed prior to future development.

2 Land Use and Potential Development

2.1 Historical land uses

A review of historical images available from 1965 (Landgate 2018a) onwards show the railway and many of the major roads within the site were established, and the majority of the site was cleared by 1965. Evidence of orchards, poultry sheds, horses and quarrying were observable by 1977. Muchea townsite was also evident from 1977 with the extent, number and density of rural residential lots increasing over time. Activity in relation to additional subdivisions with the townsite are evident from 2008 onwards.

2.2 Existing land uses

An overview of current land uses across the site was completed through review of the *Town Planning Scheme No. 6 (Scheme)* (SoC 2004), desktop investigation and a site visit by Emerge Associates on 10th October 2018. Land uses observed across the site are shown in **Figure 2** and include:

- Agriculture e.g. horse agistment, nurseries and cattle
- Animal husbandry (e.g. poultry farms) and establishment (e.g. kennels)
- Residential lots and hobby farms (e.g. horse agistment)
- Service stations and stores
- Storage/salvage yards, warehouse/storage, transport depot, fabrication operations
- Farm supply centres and landscape supplies
- Home business or cottage industry
- Industry e.g. quarrying and mineral sands processing plant
- Landfill or refuse centre.

The Scheme includes a number of additional uses (whereby the use is additional to the broad set of uses allowed in the zone) and special uses (where there is one use specific to the site). These include service stations, mineral sands processing plant, more intensive agriculture, some warehouse/storage and transport depots and are detailed in Schedule 3 – Additional Uses and Schedule 5 – Special Uses of the Scheme (SoC 2004).

Subdivision is restricted in the Muchea Townsite, particularly the central portion of the townsite due to shallow groundwater and the lack of reticulated water supply or wastewater servicing. Some subdivision has occurred within the Muchea Townsite over time in the western area and closer to Brand Highway.

Historically, the SoC has had no significant land areas allocated for industrial/light industrial land uses. As a result, rural land has been used for industrial uses such as transport depots and warehouse/storage uses. A number of businesses are operating within the site but beyond the townsite or industrial zoned areas (i.e. within agricultural resource zoning) and were potentially approved as home businesses, industry – rural or industry – cottage, which can be approved under the TPS in this zone. Businesses shown in **Figure 2** include earthmoving, engineering, water supply, equipment hire, logistics and transport service companies. Most industrial activities are not permitted in the agricultural resource zone, however some industrial uses have been possible and/or approved in this zone in the past.

Horse agistment and the keeping of hooved animals was observed within the townsite, where these are not permissible activities. Similarly, formal boarding kennels were noted within rural residential areas, which are not permissible. Some additional uses may have also extended into adjacent lots for which the additional use right does not apply.

Mapping from the Scheme (SoC 2004) is provided in **Appendix A**.

2.3 Potential development

Development of the MIP (previously MEN) is intended to provide economic growth and employment based on the locational advantages of the wider area, driven by freight and logistics and primary production related activities. The MIP may be the first industrial estate near Perth that provides access for triple road trains, which presents significant economic opportunities. Development across the MIP has progressed faster than anticipated over recent years, driven largely by the Northlink Road project and a number of associated development proposals.

The proposed relocation of the Road Train Assembly Area from Wubin and upgrades to Great Northern Highway between Muchea and Wubin, are likely to increase demand for freight and logistics operators in the MIP. Ingham's Sinagra operation may also be relocating into the MIP.

Since the publication of the original structure plan in 2011, LSP 1 has been rezoned for industrial use and there is a Special Control Area around the MIP to facilitate future structure planning. LSP 1 has an adopted local structure plan and preliminary subdivision approval for the first 12 lots has been issued. Landowners in Precinct 3 have recently engaged planning consultants to work toward zoning the precinct for industrial use and have submitted an LSP with the SoC for assessment.

The *SoC Local Planning Strategy* (Strategy) (SoC 2019) was endorsed by WAPC in July 2019. The Strategy supports the MIP as the focus for future industrial activity in the SoC, while retaining rural land for primary production. Recently gazetted Scheme Amendment 65 supports this approach by limiting future industrial uses in the agricultural resource zone such as transport depots and where these already exist, identify them as additional uses. Some land to the west of the MIP has been identified in the Strategy for agri-business to capitalise on rural businesses that need good access to freight and logistics.

The Strategy outlines that future development in the Muchea Townsite will only be considered where it can be demonstrated that it will not adversely affect the environment in accordance with the G*overnment Sewerage Policy* (DPLH 2019). Further subdivision across the majority of the townsite is restricted until such time that reticulated servicing is provided. As there is no reticulated sewerage and the area is sewage sensitive, subdivision of lots may be limited to a minimum of one hectare in some cases. Single dwellings can be developed on existing lots, subject to the approval of a development application. Development approval is required for all development in the townsite as it is located within the Ellen Brook Palusplain Special Control Area (SoC 2004).

3 Existing Environment

3.1 Climate

The site experiences a Mediterranean climate of hot dry summers and cool wet winters. Long term climatic averages indicate that the site is located in an area of moderate to high rainfall, receiving 654.6 mm on average annually with over half of the regions rainfall received between June and August (BoM 2018). However, this amount is predicted to reduce by 6% by 2030 (DPIRD 2019b). The region experiences rainfall (>1 mm) on 57 days annually (on average) (BoM 2018). The intensity of heavy rainfall events is likely to increase while droughts are expected to become more frequent (DPIRD 2019b).

3.2 Geotechnical conditions

3.2.1 Landform and topography

Five general physiographic landform classifications are present within the site: Bassendean Dunes, Pinjarra Plain, Piedmont Zone, Gingin Scarp, and Dandaragan Plateau (Gozzard 2011). Topographic contours and landform classifications are shown in **Figure 3**.

The Bassendean Dunes landform is present to the south-west of the site and adjacent to the western boundary, and is characterised by low undulating hills of quartz sand with sandy swamps occurring in interdunal depressions. Topography generally grades to the west.

The Pinjarra Plain landform extends from the eastern boundary of the Bassendean Dunes for 4-5 km over the majority of the site to the Piedmont Zone in the east. The plain gradually grades towards the major hydrological feature, the Ellen Brook, which itself runs from north to south through the plain and discharges at the point of lowest elevation within the site at 40 m Australian height datum (AHD). Geomorphology of the Pinjarra Plain landform consists of alluvial clays and loams associated with river floodplains and alluvial fans (hydrological features are discussed in **Section 3.5**).

The Dandaragan Plateau, Piedmont Zone and Gingin Scarp cover the eastern extent of the site. The Piedmont Zone is a series of spurs and colluvial slopes that make up the foothills of the Gingin Scarp. The Gingin Scarp is a line of hills that forms the eastern boundary of the Swan Coastal Plain within the site. The associated Dandaragan plateau consists of areas of higher elevation, undulating hills and eroded river valleys. The highest elevation within the site (166 m AHD) is reached within this landform unit towards the north-east of the site.

3.2.2 Soils and geology

3.2.2.1 Regional geological mapping

The site is situated along the boundary of the Swan Coastal Plain and the Dandaragan Plateau geomorphological units (Gozzard 2011). The physiographic landforms discussed in **Section 3.2.1** are characterised by varied regional geological classifications (Gozzard 1982).

The Bassendean Dunes landform is largely underlain by high permeability Sand (S8), with pockets of Sand over Pebbly Silt (S10) and low permeability Peaty Clay (Cps).

The Pinjarra Plain landform generally consists of low permeability Pebbly Silt (Mgs1) between the Ellen Brook and the Piedmont Zone and between Ellen Brook and the Bassendean Dunes in the southern half of the site, transitioning into S10 in the northern half. The Ellen Brook channel is underlain by S10 in the northern half of the site and Sand (S11) in the southern half. Pockets of high permeability limestone (LS5) are present in the south-west of the plain.

The Dandaragan Plateau landform is characterised largely by Sands (S6 and S5) present in the foothills (i.e. Piedmont Zone). Pockets of high permeability Gravel (G2) and low permeability Laterite (LA1) typically occur at higher elevations and steeply sloped areas within S6 classifications. Sandy Silt (Ms1) underlays Rocky Creek to the north-east of the site and several large pockets of Siltstone (ST1) are present in the south-east corner; both of which generally exhibit low permeability.

Geological mapping and unit descriptions are provided in **Figure 4**.

3.2.2.2 Northlink geotechnical investigations

Detailed geotechnical investigations have been conducted over the footprint of Stages 1-3 of the Northlink Perth to Darwin Highway development (Golder Associates 2017a), with Stage 3 (Northern Section) extending into the southern half of the site.

Subsurface conditions within the Stage 3 investigation area generally consist of a thin, variably dense layer of Guildford Formation Sand and Gnangara Sand overlaying Guildford Formation Clay (equivalent to Mgs1), transitioning to Bassendean Sand to the west of the Pinjarra Plain. The extent of the Guildford Formation and transition into Bassendean Sands (identified in the regional geological mapping discussed in **Section 3.2.2.1**), are generally consistent with the results of the geotechnical investigations. Ferricate was also observed within the bed of the Ellen Brook towards the south of the site and is considered to extend laterally beyond the channel.

Infiltration testing carried out across the Northlink geotechnical investigation area included two testing locations within the site and one immediately to the south (Golder Associates 2017a). Each of the three testing locations were situated within the Pinjarra Plain landform and underlain by Mgs1. Permeability was measured using the inverse auger hole method; the resultant 5 m/day measurement was consistent across the three locations. However, due to the occurrence of fine soil particles and shallow depth to groundwater a design infiltration rate of less than 1 m/day was recommended (Golder Associates 2017b).

Relevant figures from the geotechnical investigation are provided in **Appendix B**.

3.2.2.3 Muchea townsite soil investigations

Soil sampling was conducted by Urbaqua on the 6th of June 2017 within the Muchea townsite as part of the investigations to inform the draft *Muchea Groundwater and Soil Assessment* (Urbaqua 2017) (discussed in **Section 1.4.4**). Soil samples of 25 kg were taken by hand auger from the top 500 mm of the surface and submitted to a laboratory for testing of permeability and phosphorus retention index (PRI).

Results indicate that permeability is highly variable (ranging from 0.003 m/day to 8.64 m/day) and did not correlate well to inferred permeability values derived from regional geological mapping classifications (as shown in **Figure 4**). PRI was generally very weak (between 0 and 1.6) with the exception of one sample which was rated as moderate (8.7).

3.2.2.4 MIP LSP 1 geotechnical investigations

Geotechnical investigations conducted within the LSP 1 area within the MIP (Infra Tech Group 2015) confirmed the underlying soils to be generally consistent with the geological mapping and comprised of:

- Silty sand that ranged from 200 mm to more than 3.5 m in depth and usually covered by a 200 mm layer of topsoil, brown-dark brown coloured, angular to sub-angular, well graded sand. Bore logs show a larger depth sand layer consistent with S5 geological unit.
- Sandy clay that ranges from stiff to very stiff and generally sits below the sand layer, variable in depth but begins within 500 mm and 1 m of the surface where present. The clay layer present in bore logs is associated with the Mgs1 geological unit with the exception of TP12 and TP20.
- Granite bedrock with a variable depth across the site between 1.0 m and more than 3.5 m. Weak bedrock and pale grey to brown in colour.

Infiltration testing was also carried out across the LSP 1 area, with hydraulic conductivity varying from 1.07×10^{-4} m/s in sand to 9.89×10^{-6} m/s in the clay areas. This equates to permeability of between 0.85 m/day and 9.25 m/day.

The relevant pages from the geotechnical report are provided in **Appendix C**.

3.2.3 Summary of ground conditions

Ground conditions interpreted from geotechnical investigations and regional mapping indicate that the Guildford Formation (Mgs1) within the Pinjarra Plain is likely to act as an aquiclude following rainfall events and may lead to perched groundwater within the variably thin, overlaying layer of sand.

The depth of overlying sand within the adjacent S10 geological unit and transitional areas require site specific investigation to determine the depth of the impermeable layer and resulting likelihood of groundwater perching.

Similarly, pockets of low permeability ground conditions throughout the site (LA1, Cps, and ST1) may lead to localised perched groundwater (discussed in **Section 3.4.2**). For the remainder of the site, the sandy ground conditions within the Bassendean Dunes and Dandaragan Plateau landforms are expected to allow rainfall to freely infiltrate into the sandy soils.

3.3 Acid sulfate soils and contaminated sites

3.3.1 Acid sulfate soils

Acid sulfate soil (ASS) risk mapping classifies the eastern half of the site as having 'no known risk' of ASS occurring within 3 m of natural soil surface (DWER 2018). The western half of the site, inclusive of the Ellen Brook waterway, is categorised as having 'moderate to low' risk of ASS within 3 m of the surface. Several pockets in the western half of the site are categorised as having 'high to moderate risk' of ASS occurring within 3 m of the surface. ASS risk mapping is shown in **Figure 5**.

3.3.2 Contaminated sites

A review of the *Contaminated Sites Database* (DWER 2018a) identified five parcels of land specified as reported contaminated sites within the following categories:

- Contaminated – remediation required
- Contaminated – restricted use
- Remediated for restricted use.

Two reported contaminated sites are situated towards the north of the site (contaminated site numbers 16,495 and 16,496 respectively), as shown in **Figure 5**. Both are classified as 'Contaminated - remediation required'. Hydrocarbons, ammonium and sulfate salts are reported to be present in soil and groundwater at various locations within both sites. The abstraction of groundwater for any purpose other than remediation and analysis is restricted until further notice. Active and ongoing groundwater remediation activities have been in place since 1995.

Three adjacent reported contaminated sites encompass the existing Muchea IGA X-press and Muchea Irrigation and Rural Supplies building sites (Lot 8 on plan 50912), the Muchea Irrigation and Rural Supplies loading yards (Lot 9 on plan 50912), and the road reserve immediately to the south-east of these (site numbers 21,310, 23,311 and 23,312 respectively). These are all shown in **Figure 5**. The road reserve site is listed as "Contaminated – restricted use", while the two sites to the north are listed as "Contaminated – remediation required". Hydrocarbons are reported to be present in groundwater plumes within sections of all three sites. Groundwater abstraction is not permitted within any of the affected sites due to the nature of the groundwater contamination. Additional restrictions for Lot 8 include:

- Access to soils at the site is restricted until an assessment of the risk to site users is undertaken.
- A site-specific health and safety plan is required to address the risks to the health of any workers undertaking intrusive works until further notice.

Remediation works were carried out in 2006, however, no validation report was present on the database and it was noted that some impacted soils remain within the source site.

It should be noted that the publicly available *Contaminated Sites Database* does not identify any land parcels which may have been reported as potentially contaminated, including those awaiting classification.

A number of existing land uses within the site are identified as potentially contaminating land uses in the document *Assessment and management of contaminated sites: Contaminated sites guidelines* (DER 2014), including but not limited to:

- Biosolids application, muck spreading, organic fertiliser application
- Intensive agriculture
- Landfill sites
- Market garden, orchards, poly-tunnels, plant nurseries
- Livestock dips or spray races.

3.4 Groundwater

3.4.1 Groundwater areas

Information relating to regional groundwater obtained from the *Water Register* (DWER 2018d) indicates the groundwater beneath the site is a multi-layered system comprised of the following aquifers:

- Perth - Superficial Swan (unconfined) aquifer
- Perth - Surficial (unconfined) aquifer
- Perth - Mirrabooka (unconfined) aquifer
- Perth - Leederville Parmelia (confined) aquifer
- Perth - Leederville (confined) aquifer
- Perth - Yarragadee North (confined) aquifer.

The majority of the site is situated within the Gingin groundwater area, with the south-western corner of the site in the Gnangara groundwater area. The groundwater areas are split into the following subareas:

- Gnangara
    - Reserve
    - Gnangara Confined.
- Gingin
    - Lake Mungala
    - Eclipse Hill
    - SA 3 South
    - Chandala Confined
    - Cowalla Confined
    - Southern Scarp Semi-confined.

Mapping of groundwater areas and subareas from the current *Gingin groundwater allocation plan* (DoW 2015a) and the *Gnangara groundwater areas allocation plan* (DoW 2009a) are provided in **Appendix D.** Discussion regarding existing groundwater allocations is provided in **Section 4.1**.

3.4.2 Groundwater levels

3.4.2.1 Mapped groundwater contours

A review of the *Perth Groundwater Map* (DWER 2018b) indicates that groundwater contour mapping is limited for the site (see **Figure 6**). The historical maximum groundwater level (MGL) dataset covers a portion of the west of the site, while the minimum levels dataset covers the majority of the site at a larger interval (5 m contours), with a small portion to the south at a smaller interval (1 m contours).

Both datasets indicate that groundwater generally flows eastward from the Gnangara Mound (which is the area associated with the 'mound' of higher elevation groundwater contours to the south-west of the site) and south-westerly from the Dandaragan Plateau towards the Ellen Brook. The minimum groundwater level dataset indicates that the hydraulic gradient of eastward flowing groundwater generally increases with proximity to the Ellen Brook.

3.4.2.2 Measured groundwater contours

Groundwater data has been collated from three available sources:

- DWER groundwater monitoring bores (DWER 2018c)
- Northlink groundwater level monitoring as part of geotechnical and hydrogeological investigations (Golder Associates 2017a, b)
- MIP LSP 1 groundwater level monitoring (Emerge Associates 2017).

Groundwater monitoring data from these sources has been calibrated against a long term recorded MGL to determine the MGL at each bore location. The DWER monitoring bore "GD21" has been chosen to calibrate to due to its long historic record, central location within the site and the correlation of captured seasonal groundwater peaks compared with other available data. The measured MGL from the GD21 record was observed in October 2013. Calculated MGL contours and bore locations are shown in **Figure 7**.

MGL contours within the site range from approximately 46 m AHD towards the south of the site to 64 m AHD to the east of the site. These contours are broadly consistent with mapped groundwater contours and indicate that groundwater generally flows towards the Ellen Brook. Groundwater within the Ellen Brook channel footprint itself flows towards the south to a lesser extent.

It is noted that the data from which these contours are derived is somewhat limited. Specifically, the frequency of monitoring of DWER bores has been reduced in recent decades. This reduces confidence in the assumption that the seasonal peak has been captured. Winter monitoring was not conducted in some instances. Additionally, the spatial coverage of suitably monitored bores is limited. A greater spatial coverage of bores and more frequent winter monitoring occasions would increase confidence in derived groundwater contours (recommendations are discussed in **Section 11.5**).

For the reasons mentioned above, the displayed groundwater contours and subsequent inundation mapping (discussed in **Section 3.4.2.3**) are considered indicative and are intended to be used as a regional guide only. Detailed site-specific monitoring and assessments are required to inform any future design considerations for proposed development unless a more comprehensive regional monitoring program is progressed.

3.4.2.3 Areas of inundation

Analysis of the calibrated MGL (see **Section 3.4.2.2**) and regional topographical contours have determined the estimated depth to MGL across the site. The resulting mapping shown in **Figure 8** indicates that MGL is at or close to the existing surface through the centre of the site. This generally aligns with the Pinjarra Plain physiographic region where the topography is relatively flat and grades towards the Ellen and Chandala Brooks. This may be reflective of high surficial or superficial aquifers, which were discussed in **Section 3.4.1** and shown in **Appendix D**, and/or groundwater perching above a lower permeability layer (e.g. where sand is underlain by a pebbly silt layer). The identification of perched groundwater requires the completion of detailed geotechnical investigations.

A region to the east of the site was unable to be included in the mapping extent due to insufficient groundwater monitoring locations in this area. However, this region is expected to exhibit a depth to maximum groundwater of greater than five meters based on the elevated topography within this region and adjacent mapping.

As mentioned in **Section 3.4.2.2**, groundwater mapping is indicative only and should not be relied upon to inform future design considerations with site-specific monitoring and analysis to be completed unless a more comprehensive regional monitoring program is progressed.

3.4.3 Groundwater quality

Due to the limited availability of groundwater quality data, an existing baseline for the region was unable to be identified. Available groundwater quality data is summarised in the following sections.

3.4.3.1 Muchea townsite groundwater quality investigations

Groundwater quality samples were taken from two groundwater bores within the townsite on the 14th of June 2017 as part of groundwater and soil assessment conducted by Urbaqua (2017). Samples were analysed for nutrients and a full drinking water quality suite. With the exception of zinc concentrations at one location, major analytes complied with the *Australian Drinking Water Guidelines* (NHMRC & NRMMC 2016). From an environmental perspective, nutrients were within *Local WQIP – Ellen Brook Catchment* (SRT 2009a) guidelines with the exception of total phosphorous (TP) at one location. Additional monitoring within the townsite is required to adequately characterise groundwater quality within the townsite (for both drinking purposes and environmental considerations) given only two locations were tested.

3.4.3.2 MIP LSP 1 groundwater quality investigations

Groundwater quality monitoring was conducted by Emerge Associates to support the *MEN LSP 1 LWMS* (Emerge Associates 2017). Six bores were monitored between October 2012 and December 2013 and ten bores between August and November 2015, with groundwater quality samples taken every three months (six samples in total). Physiochemical parameters were recorded in-situ and laboratory analysis was conducted to determine nutrient concentrations.

Groundwater quality analyses indicate that the local groundwater pH is slightly acidic and exhibits high electrical conductivity. TP concentrations are moderate to high with average readings above NWQMS default trigger values (ANZECC and ARMCANZ 2000a) and *Swan Canning Water Quality Improvement Plan* (SCWQIP) target levels (SRT 2009b). Total nitrogen (TN) concentrations range from low to moderate with higher levels generally recorded at the bores located at downstream locations of groundwater flow. This is assumed to be a reflection of the historical use of the LSP1 for broad-acre agriculture and current use for cattle farming (see **Section 2.1**).

Table 1: Groundwater quality monitoring results summary

Analyte	Units	SQWIP target	NWQMS trigger value	Monitoring location								
				MB01	MB02	MB03	MB04	MB05	F2	MB07	MB08	MB09
Field parameters												
pH	pH units	-	6.5 - 8.0	5.69 (0.25)	5.38 (0.37)	5.24 (0.43)	5.79 (0.14)	6.25 (0.21)	5.53 (0.37)	5.11	5.74	5.46
Electrical conductivity (EC)	mS/cm	-	0.12 - 0.3	9.10 (0.32)	16.7 (1.21)	4.82 (0.15)	2.63 (0.16)	1.04 (0.28)	3.87 (0.15)	1.14	4.52	4.5
Dissolved oxygen (DO)	%	-	80 - 120	21.3 (11.9)	22.1 (15.2)	20.8 (13.2)	30.6 (23.6)	32.2 (17.7)	58.7 (21.8)	4.3	7.30	16.8
Laboratory analysis												
Ammonia (NH_4)	mg/L	-	0.08	0.18 (0.06)	0.09 (0.13)	0.45 (0.44)	0.14 (0.07)	0.15 (0.06)	0.18 (0.28)	0.02	0.2	0.03
Nitrates and nitrites (NO_x)	mg/L	-	0.15	0.12 (0.21)	3.09 (0.85)	0.10 (0.11)	0.46 (0.43)	0.02 (0.01)	0.09 (0.09)	2.28	0.01	<0.01
Total kjeldahl nitrogen (TKN)	mg/L	-	-	1.14 (0.48)	1.48 (2.02)	1.07 (0.78)	2.17 (2.89)	0.95 (0.99)	0.30 (0.18)	0.7	0.5	0.2
Total nitrogen (TN)	mg/L	1 - 2	1.2	1.23 (0.46)	4.58 (2.32)	1.10 (0.76)	2.63 (3.09)	0.95 (0.99)	0.35 (0.21)	3	0.5	0.2
Total phosphorous (TP)	mg/L	0.1 - 0.2	0.065	1.06 (0.54)	0.19 (0.27)	0.13 (0.11)	0.47 (0.62)	0.26 (0.29)	0.08 (0.08)	0.3	<0.01	0.01
Reactive phosphorous (RP)	mg/L	-	-	0.11 (0.06)	0.01 (0.00)	0.15 (0.00)	<0.01 (0.00)	<0.01 (0.00)	<0.01 (0.00)	<0.01	<0.01	<0.01

Detailed monitoring results are provided in the *MEN LSP 1 LWMS* (Emerge Associates 2017).

3.4.4 Public drinking water source areas

Public drinking water source areas (PDSWAs) are proclaimed areas managed by DWER in order to manage and protect WA drinking water resources. Within these areas potentially polluting activities and land uses are regulated. The extent to which these are managed and the level of acceptable risk within PDWSAs are guided by the Priority level assigned to the respective PDWSA. Gazetted PDWSAs and their protection is discussed further in various WQPNs prepared by DWER (DoW 2015c).

A section of the site to the south-west is situated within a Priority 1 (P1) PDSWA for the *Gnangara Underground Water Pollution Control Area* (Landgate 2018a), as shown in **Figure 9**. P1 areas are managed with the objective of risk avoidance. Land uses and activities are regulated to ensure that there is not degradation in quality of the drinking water source. As such, there are stringent land use capability restrictions associated with P1 areas, these are discussed in *WQPN 25: Land use compatibility tables for public drinking water source areas* (DoW 2016).

The P1 PDWSA area in the site is reflected in the TPS as a 'water supply' zone (SoC 2004), shown in **Figure 2**.

3.5 Surface water

The surface water hydrological regime within the site is a varied, interconnected system. On-site investigations by Emerge Associates hydrologists, hydrological modelling and desktop reviews of available information have identified, at a regional scale, the existing surface water regime.

3.5.1 Existing surface water features

The site is situated within the Ellen Brook sub-catchment, the largest contributing catchment of the Swan-Canning Estuary system (SRT 2009c). The Chandala Brook and Rocky Creek (two major tributaries of the Ellen Brook) enter the site to the north-west and north-east respectively and reach a confluence near the centre of the site. Approximately two kilometres downstream of this confluence the waterway is referred to as the Ellen Brook (DoW 2007a). The Ellen Brook is an ephemeral stream that discharges into the upper Swan River, contributing 8.3% of total inflows per year on average (EBICG 2015). The contributing catchment area (measured from where the Ellen Brook discharges from the site) is approximately 37,600 ha (see the modelling report in **Appendix E**).

Several other minor tributaries originating from the Dandaragan Plateau (the eastern portion of the site) as well as localised surface flowpaths within the Ellen Brook floodplain are also present across the site.

A number of surface dams are located across the site. Smaller dams are currently, or have historically been used as a water source for grazing stock. Several larger dams have been constructed to service industrial and animal agriculture requirements (e.g. the Muchea Livestock Centre). Quarrying and sand excavation activities within the site have also resulted in perennially and non-perennially inundated extraction pits (Landgate 2018b).

A number of wetlands with surface water features (ephemeral or otherwise) are located within the site, primarily along the boundary of Ellen Brook floodplain; wetlands are discussed further in **Section 3.6.5**. Surface water features and wetlands are shown in **Figure 9**.

3.5.2 Existing hydrological regime

The BUWM framework advocates for key issues and risks to be identified as early in the planning process as possible (WAPC 2008). The existing surface water regime is a key component of the total water cycle and is associated with key areas of risk requiring adequate consideration (such as floodplains and waterways). A detailed understanding of the regional surface water systems is important to determining the proper management of waterways and wetlands.

While there have been a number of independent hydrological studies covering smaller areas within and surrounding the site (see **Section 1.4**), an assessment with the level of detail and spatial coverage needed to adequately describe the surface water hydrological regime across the entire site at a regional scale has not previously been undertaken.

A 1D-2D coupled hydrological model encompassing the site and upstream contributing catchments was developed to provide a regional scale understanding of the existing surface water hydrological regime (herein referred to as "the RWMS model"). The RWMS model was constructed based on the following key assumptions and inputs:

- Upstream catchments determined from existing topographical mapping
- Topographical surface covering the site
- Land uses and loss assumptions derived from aerial photography, on-site hydrological inspection and past experience with similar hydrogeological conditions
- Details of drainage features associated with existing road and rail infrastructure, and the ongoing Perth to Darwin highway (NorthLink) development from surveys and on-site hydrological inspection and detailed designs (see **Figure 10**).

The model was run in the minor (10% AEP) and major (1% AEP) rainfall events with varying rainfall durations (2, 6 and 48 hours). The durations examined were determined following review of relevant surface water investigations including:

- The *Ellen Brook Flood Study* (WAWA 1987) - critical duration of 48 hours identified
- The *MEN LSP 1 LWMS* (Emerge Associates 2017) – critical duration of 2 hours identified
- A critical duration analysis of the 1D upstream catchments for the RWMS model - critical duration of 6 hours identified (based on peak flows entering the site).

The major event critical duration of 48 hours was determined through analysis of peak flow rates within Ellen Brook. Peak flow rates at key locations within Ellen Brook for the minor and major rainfall event are shown in **Figure 11** and **Figure 12**, respectively The model has not been formally calibrated to on-ground flows, but has been compared to other modelling studies (detailed above). Full details of the modelling methodology, assumptions (e.g. details of upstream contributing catchments and land use assumptions) and key results are provided in the modelling report (**Appendix E**).

Flood mapping over the site has been prepared for the major and minor events (**Figure 11** and **Figure 12** respectively). The flood mapping has been resolved to a suitable resolution for regional and initial development scale investigations. The intent of this mapping is to provide, in consideration of other relevant factors, early identification of key areas of risk and constraint and is not considered suitable for lot-scale or detailed design. Site-specific pre-development hydrological modelling should be completed to support any future structure planning and/or subsequent development stages.

3.5.3 Surface water quality

The Ellen Brook is understood to be a significant contributor to eutrophication within the downstream Swan-Canning Estuary system, accounting for 28% of TN and 39% TP contribution while (on average) only accounting for 8.3% of total flows (SRT 2009c; EBICG 2015). Understanding water quality parameters across the site is important for identifying existing land uses and practices that are contributing to high concentrations of nutrients (and other pollutants) within the Ellen Brook.

3.5.3.1 Ellen Brook Catchment surface water quality monitoring

Surface water quality monitoring as part of the *Ellen Brook Catchment Water Quality Monitoring* program has been conducted by the Ellen Brockman Integrated Catchment Group (EBICG). The monitoring program includes nine monitoring locations within or immediately upstream of the site in significant waterways and flowpaths. Monitoring has been conducted since 2005 and is ongoing. Emerge Associates were advised that all data associated with the monitoring program is available on the *Water Information Reporting* data repository (DWER 2018c) online.

The location of monitoring sites provides good spatial coverage of the northern inflows from Chandala Brook immediately prior to entering the site (EBN4), as well as a number of eastern flowpaths discharging into the Ellen Brook. Conversely, the western flowpaths are largely unmonitored with the exception of the Peters Road site (EBN23) near the Muchea townsite. A 'downstream' location in the Ellen Brook as flows leave the site is also absent. Surface water monitoring locations are shown in **Figure 9**.

Observed nutrient levels are highly variable throughout the site. A brief summary of key results include:

- TN and TP from Chandala Brook (EBN3 and EBN4) are significantly above NWQMS (ANZECC and ARMCANZ 2000a) guideline trigger values, as are flows at EBN21 and EBN23. TN measurements for these sites are generally 3-4 times greater than recommended trigger values, while total phosphorus is up to 18 times (EBN3).
- Nutrient levels observed at EBN8 and EBN9 are moderately higher than trigger values.
- EBN6, EBN7 and EBN10 generally exhibit nutrient concentrations within trigger values.
- pH is generally neutral and within the NWQMS guidelines (ANZECC and ARMCANZ 2000a). Flows from EBN6 are slightly acidic and flows from EBN7 and EBN10 exhibit occasionally highly acidic conditions (pH values of between 4 and 5).
- Salinity readings are significantly above NWQMS trigger values at each of the monitoring locations. Flowpaths originating from the east of the site (EBN6, EBN7, EBN8, EBN10) exhibit significantly saline flows and are the most saline sites measured throughout the wider monitoring area (EBICG 2015).

- Average concentrations of aluminium and iron are consistently high throughout the site, with measurements of up to two orders of magnitude greater than NWQMS guidelines.
- Average concentrations of chromium, copper, nickel and zinc exceed guideline trigger values to varying degrees at various locations within the site.
- One or more samples exceeding guidelines for mercury were recorded at EN4, EBN7 and EBN9.
- One or more samples exceeded lead guidelines at EBN4.
- Sites EBN6 and EBN21 were not tested for metals

High acidity in some monitoring locations has been speculated to have been caused by the disturbance of naturally acidic soils during extraction of clay, the dewatering of clay pits and subsequent alteration of the groundwater regime upstream of these locations (EBICG 2015).

Saline conditions are generally diluted as they enter the main channel of the Ellen Brook, however are a concern at a local scale for those affected areas.

A summary of EBICG surface water quality monitoring results is provided in **Appendix F**.

3.5.3.2 MIP LSP 1 surface water quality

Surface water quality monitoring was carried out by Emerge Associates on five occasions between June and October 2013 at four locations in two primary waterways within the LSP 1 area of the MIP (Emerge Associates 2017). The surface water monitoring locations are shown in **Figure 9** (SW1 – SW4) with a summary of water quality monitoring results shown in **Table 2**.

NWQMS trigger values for slightly disturbed ecosystems in South Western Australia for lowland rivers are provided for reference as well as target TN and TP loads as detailed in the SCWQIP (ANZECC and ARMCANZ 2000a; SRT 2009b).

Table 2: Surface water quality monitoring results summary

Analyte	Units	SCWQIP target	NWQMS trigger value	Monitoring location			
				SW1	SW2	SW3	SW4
Field parameters							
pH	pH units	-	6.5 - 8.0	4.02 (0.75)	5.35 (0.44)	4.05 (0.54)	5.98 (0.49)
Electrical conductivity (EC)	mS/cm	-	0.12 - 0.3	7.78 (2.26)	4.07 (0.60)	7.90 (2.46)	6.10 (1.10)
Dissolved oxygen (DO)	% saturated	-	80 - 120	97.2 (4.02)	60.4 (9.00)	89.1 (2.67)	54.4 (25.8)
Laboratory analyte							
Ammonia (NH_4)	mg/L	-	0.08	0.09 (0.05)	0.02 (0.01)	0.10 (0.05)	0.13 (0.20)
Nitrates and nitrites (NO_x)	mg/L	-	0.15	0.03 (0.01)	0.01 (0.00)	0.06 (0.04)	0.12 (0.00)

Table 2: Surface water quality monitoring results summary (continued)

Analyte	Units	SCWQIP target	NWQMS trigger value	Monitoring location			
				SW1	SW2	SW3	SW4
Laboratory analyte							
Total kjeldahl nitrogen (TKN)	mg/L	-	-	0.80 (0.50)	1.00 (0.42)	1.02 (0.77)	2.53 (1.53)
Total nitrogen (TN)	mg/L	1 - 2	1.2	0.83 (0.49)	1.00 (0.42)	1.05 (0.79)	2.55 (1.52)
Total phosphorous (TP)	mg/L	0.1 - 0.2	0.065	0.02 (0.02)	0.03 (0.02)	0.09 (0.09)	0.15 (0.13)
Reactive phosphorous (TRP)	mg/L	-	-	<0.01	<0.01	<0.01	0.03 (0.01)

Average TN and TP concentrations were generally low with all locations recording average levels below the SCWQIP target and ANZECC trigger values, except for TN at SW4 which is slightly elevated.

3.6 Environmental assets

3.6.1 Regional vegetation

Native vegetation is described and mapped at different scales in order to illustrate patterns in its distribution. At a continental scale the *Interim Biogeographic Regionalisation of Australia* (IBRA) divides the Swan Coastal Plain into two floristic subregions (Environment Australia 2000). The site is contained within the 'SWA02' or Perth subregion, which is characterised as mainly containing: *Banksia* low woodland on leached sands with *Melaleuca* swamps where ill-drained, and woodland of *Eucalyptus gomphocephala* (tuart), *E. marginata* (jarrah) and *Corymbia calophylla* (marri) on less leached soils (Beard 1990). This subregion is recognised as a biodiversity hotspot and contains a wide variety of endemic flora and vegetation types.

Variations in native vegetation within the site can be further classified based on regional vegetation associations. Beard *et al.* (2013) vegetation mapping (see **Figure 13**) shows the site as comprising five vegetation associations. These associations, along with relevant statistics from the *Statewide Vegetation Statistics* report (Government of Western Australia 2018), are summarised in **Table 3**.

Table 3: Beard et al. *(2013) vegetation association and vegetation statistics (Government of Western Australia 2018) summary.*

Vegetation association	Description	Pre-European extent remaining on the Swan Coastal Plain	Protected for conservation purposes
Bassendean_949	Low woodland or open low woodland: *Acacia* spp., *Banksia* spp., *Agonis flexuosa, Callitris* spp., *Allocasuarina* spp., *Eucalyptus loxophleba*	57.22%	13.91%
Pinjarra_1018	Mosaic: medium forest, jarrah-marri / low woodland, banksia / low forest, teatree / low woodland, and *Casuarina obesa* woodland / low woodland / low forest or woodland	17.25%	0.71%
Pinjarra_4	Medium woodland: marri & wandoo	18.89%	2.67%
Gingin_1020	Forest: mainly *Eucalyptus marginata* and *Corymbia calophylla*	28.25%	1.79%
Gingin_1027	Low forest, woodland or low woodland with scattered trees: *Eucalyptus marginata*, *Banksia* spp., *Allocasuarina* spp.	58.73%	17.57%

3.6.2 Ecological values

The native vegetation within the site has the potential to provide habitat for threatened flora and fauna species listed under the Commonwealth's *Environmental Protection and Biodiversity Conservation Act 2000* (EPBC Act) and the State's *Biodiversity Conservation Act 2016* (BC Act). The vegetation may also provide habitat for priority flora and fauna species listed by the Department of Biodiversity, Conservation and Attractions (DBCA). Threatened fauna species likely to utilise the site include three species of black cockatoo: Carnaby's black cockatoo (CBC), forest red-tailed black cockatoo (FRTBC), and Baudin's black cockatoo (BBC). CBC and BBC are listed as 'endangered' pursuant to both the Commonwealth EPBC Act and the State BC Act. FRTBC is listed as 'endangered' pursuant to the Commonwealth EPBC Act and 'vulnerable' pursuant to the State BC Act.

The vegetation present also has the potential to represent one or more threatened ecological communities (TECs) listed pursuant to the EPBC Act and the BC Act. Similarly, priority ecological communities (PEC) listed by the DBCA may also be present. TECs and PECs potentially present include (but are not limited to) the Commonwealth listed 'banksia woodlands of the Swan Coastal Plain' TEC (which is equivalent to the State listed 'banksia dominated woodlands of the Swan Coastal Plain IBRA region' PEC (P3)) and the Commonwealth listed 'assemblages of plants and invertebrate animals of tumulus (organic mound) springs of the Swan Coastal Plain' TEC (which is equivalent to the State 'Communities of Tumulus (Organic Mound) Springs, Swan Coastal Plain' TEC). TEC and PEC mapping is provided in **Figure 14**.

The vegetation also has the potential to include groundwater dependant ecosystems, which are defined as those ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson *et al.* 2011).

Known locations of TECs, PECs and groundwater dependent ecosystems are likely to be encompassed by the areas of "habitats of TECs and PECs, especially protected water-dependent fauna" taken from the *Government Sewerage Policy* (DPLH 2019) mapping (shown in **Figure 15**). Further investigation would be required to confirm the ecological values present within the site and their extent.

3.6.3 Vegetation condition

Based on a review of aerial photography, vegetation condition across the site appears to range from completely degraded to excellent condition. Completely degraded or degraded areas are likely to exist across the majority of the site, particularly throughout the central areas consisting of cleared pastures and developed lands. Vegetation in very good and excellent condition is likely to occur in the south western and north eastern portions of the site which contain larger pockets of remnant native vegetation that are less likely to have high cover by weed species and have not been subject to high levels of historical disturbance and clearing.

3.6.4 Environmentally sensitive areas

'Environmentally sensitive areas' (ESAs) are prescribed under the *Environmental Protection (Clearing of Native Vegetation) Regulations 2004* and have been identified to protect native vegetation values of areas surrounding significant, threatened or scheduled flora, vegetation communities or ecosystems. Within an ESA none of the exemptions under the *Environmental Protection (Clearing of Native Vegetation) Regulations 2004* apply. However, exemptions under Schedule 6 of the EP Act still apply, including any clearing in accordance with a subdivision approval under the *Planning and Development Act 2005* (a recognised exemption under the Schedule 6 of the EP Act).

An ESA is present over the south western quarter of the site and north western corner of the site. The location of ESAs are shown in **Figure 13**.

3.6.5 Wetlands

A review of the *Geomorphic Wetlands, Swan Coastal Plain* (DBCA 2018) dataset indicates that the majority of the Pinjarra Plain within the site is categorised as a multiple use wetland (MUW) (Ellen Brook Floodplain, UFI 15,732). Several smaller MUWs are present along the border of the Ellen Brook Floodplain and within valleys associated with the Dandaragan Plateau.

There are 17 resource enhancement wetlands (REWs) within the site. The majority of these are located along the fringes of the Ellen Brook Floodplain MUW at the upstream extent of local flowpaths.

There are 21 conservation category wetlands (CCWs) within the site. The majority of these are located within remnant bushland on the boundaries of the Ellen Brook Floodplain MUW.

Geomorphic wetlands are shown in **Figure 9** and those located partially or wholly within the site are detailed in **Table 4**.

Table 4: Geomorphic wetlands present within the site

Unique Feature Identifier (UFI)	Geomorphic classification	Management category	Total wetland area (ha)
8861	Dampland	Conservation	1.61
12407	Dampland	Conservation	1.86
8583	Sumpland	Conservation	35.7
8887	Sumpland	Conservation	1.3
8862	Dampland	Conservation	0.57
8632	Dampland	Conservation	0.73
8860	Sumpland	Conservation	2.01
8483	Sumpland	Conservation	1.61
8865	Dampland	Conservation	0.84
8630	Sumpland	Conservation	3.99
8628	Dampland	Conservation	0.87
15064	Sumpland	Conservation	4.54
8886	Sumpland	Conservation	1.83
8631	Dampland	Conservation	0.3
8866	Dampland	Conservation	0.26
8484	Dampland	Conservation	0.87
8879	Sumpland	Conservation	0.57
8593	Dampland	Conservation	2.96
8867	Dampland	Conservation	0.23
8586	Sumpland	Conservation	9.5
8888	Sumpland	Conservation	3.69
8486	Sumpland	Multiple Use	1.04
12251	Palusplain	Multiple Use	25.43
8498	Sumpland	Multiple Use	21.2
8629	Dampland	Multiple Use	0.39
8884	Sumpland	Multiple Use	6.71
8584	Sumpland	Multiple Use	3.17
8588	Sumpland	Multiple Use	1.62
8608	Palusplain	Multiple Use	14.75
8885	Sumpland	Multiple Use	6.72
8878	Sumpland	Multiple Use	0.83
8883	Sumpland	Multiple Use	1.29

Table 4: Geomorphic wetlands present within the site (continued)

Unique Feature Identifier (UFI)	Geomorphic classification	Management category	Total wetland area (ha)
8766	Sumpland	Multiple Use	0.33
8864	Sumpland	Multiple Use	2.59
8881	Not Assessed	Multiple Use	2.75
12257	Palusplain	Multiple Use	5.23
15732 (Ellen Brook Floodplain)	Palusplain	Multiple Use	19003.24
8587	Sumpland	Resource Enhancement	17.7
9173	Sumpland	Resource Enhancement	8.9
8582	Sumpland	Resource Enhancement	2.15
12405	Palusplain	Resource Enhancement	18.81
8589	Dampland	Resource Enhancement	2.04
8591	Dampland	Resource Enhancement	1.52
9174	Sumpland	Resource Enhancement	4.12
8590	Dampland	Resource Enhancement	18.1
8772	Sumpland	Resource Enhancement	11.15
8880	Sumpland	Resource Enhancement	1.95
8771	Sumpland	Resource Enhancement	75.31
8606	Dampland	Resource Enhancement	54.52
8592	Sumpland	Resource Enhancement	1.57
8882	Sumpland	Resource Enhancement	8.5
12258	Palusplain	Resource Enhancement	4.92
8607	Sumpland	Resource Enhancement	22.36
8485	Sumpland	Resource Enhancement	38.87

3.6.6 Sewage sensitive areas

The majority of the site is classified as a sewage sensitive area by the *Government Sewerage Policy* (DPLH 2019). The policy defines sewage sensitive areas geographically based on proximity to a variety of environmental assets and sensitivity to on-site sewage disposal. The three classifications of relevance to the site (see **Figure 15**) define a sewage sensitive area as:

a) Estuary catchments on the Swan and Scott Coastal Plains.
f) The area within a boundary, which is 1 km up-groundwater-gradient and 250 m down-gradient of a significant wetland; or where the groundwater gradient is unknown within 1 km of the significant wetland.
g) Habitats of TECs and PECs, especially protected water-dependent fauna.

The site is located within the Ellen Brook sub-catchment, with the Ellen Brook ultimately discharging into the Swan-Canning Estuary (as described in **Section 3.5**). With the exception of the north-eastern corner and eastern boundary, the majority of the site is mapped as a sewage sensitive area due to the proximity to the Ellen Brook (i.e. classification 'a').

There are multiple CCWs within and surrounding the site (see **Section 3.6.5**). Mapping has identified the area within a 1 km radius of these wetlands as sewage sensitive areas (i.e. classification 'f'). The sewage sensitive areas surrounding wetlands may be adjusted as per the definition in the policy to take into consideration local groundwater gradient should further site investigations and assessments confirm this is appropriate.

Sewage sensitive areas have been classified within a 1 km radius of three identified water dependent fauna or ecological communities (i.e. classification 'g') located within and nearby the Muchea townsite. The sewage sensitive areas surrounding these environmental assets may be adjusted as per the definition in the policy should further site investigations and assessments confirm this is appropriate.

3.7 Summary of existing environment

In summary, the environmental investigations and desktop assessment conducted indicate that:

- The site receives 654.6 mm on average annually with over half of the regions rainfall received between June and August.
- Five general physiographic landform classifications are present within the site – Bassendean Dunes, Pinjarra Plain, Piedmont Zone, Gingin Scarp ad Dandaragan Plateau.
- The Pinjarra Plain landform generally consists a variably thick layer of Bassendean sand (S8) underlain by low permeability Pebbly Silt (Mgs1) of the Guildford Formation.
- The Bassendean Dunes landform generally consists of Bassendean sand (S8).
- The Dandaragan Plateau landform is characterised largely by Sand (S6), with pockets of laterite (LA1) with Sand (S5) present in the foothills (i.e. the Piedmont Zone).
- The western half of the site is categorised as having 'moderate to low' risk of ASS within 3 m of the surface. Several pockets in the western half of the site are categorised as having 'high to moderate risk' of ASS occurring within 3 m of the surface.
- There are five reported contaminated sites within the site.
- There is limited available regional groundwater level data within the site.
- Measured groundwater contours and depth to groundwater mapping indicates that MGL is at or close to the existing surface through the centre of the site.
- There is insufficient groundwater quality data available within the site to determine a baseline.
- A portion of the site to the south-west is situated within a P1-PDWSA area.
- The site is situated within the Ellen Brook sub-catchment, the largest contributing catchment of the Swan-Canning Estuary system.
- Two major tributaries, the Chandala Brook and Rocky Creek, enter the site to the north-west and north-east respectively and reach a confluence near the centre of the site. Downstream of this confluence the waterway is referred to as the Ellen Brook.
- Several other minor tributaries of the Ellen Brook are present within the site.
- Flood mapping across the site identifies flow paths, waterways and associated flood plains.

- Surface water quality monitoring has determined that several surface water flows within the site exhibit elevated nutrient (and some other pollutants) concentrations, as compared to guideline values.
- Pockets of remnant native vegetation are present in the south-western and north-eastern portions of the site. Otherwise, the majority of the site is largely cleared pastures and developed land.
- TECs and PECs are likely to occur within the site.
- A large number of geomorphic wetlands are situated within the site, including 21 CCWs and 17 REWs.
- The majority of the site is classified as a sewage sensitive area.

4 Existing Servicing

There are a number of existing water supply and wastewater servicing measures utilised across the site, though the full extent of each measure used is unclear due to poor records. Below is a summary of the measures identified across the site to date.

4.1 Water supply

Water for potable and non-potable uses across the site are currently supplied from rainwater, groundwater or stormwater sources (SoC 2004, 2008, 2018) utilising:

- Dams to capture stormwater runoff
- Rainwater tanks to capture rainwater from roofs
- Production bores to abstract groundwater from various aquifers.

There are currently no reticulated water supply systems implemented across the site, though investigations into potable water supply conducted by Urbaqua (2017) indicate that some residents may be reliant on bottled water as a drinking water source. It is understood that two water service providers have begun the approval process to provide reticulated water supply within the MIP (P Stuart [SoC] 2018, *pers. comm.*, 30 October). Both service providers are proposing to utilise groundwater as a supply source. Specific details of the proposed supply schemes have not been made publicly available at the time of the drafting of this report however it is understood that these are not yet implemented.

Buildings for residential use in rural residential zones are required to install rainwater tank(s) at least 120 kL in size and have a water recycling system (e.g. greywater) (SoC 2004). Smaller rainwater tanks are permitted if another water source (such as a reticulated supply or a domestic groundwater bore) is available and of potable quality. Other requirements regarding water supply (e.g. permitted locations, required setbacks) are outlined in the *Town Planning Scheme* (TPS) *No. 6: Local Planning Policy* (LPP) *No. 6 - Water Supply and Drainage* (LPP No. 6) (SoC 2008).

A review of the *Water Register* (DWER 2018d) found that there are currently 85 water licenses allocated within the RWMS area totaling 4,936,356 kL/year with allocations ranging from 1,340,000 kL/year to 650 kL/year. Of these licenses, 28 are located within the Muchea townsite with allocations totaling 338,918 kL/year. An additional 22 licenses are allocated to rural residential lots immediately to the east of the townsite, with allocations totaling 396,625 kL/year. The balance of groundwater allocation (which constitute a vast majority of the total) is predominantly used for industrial and agricultural purposes. All allocation license details are publicly available on the online *Water Register* (DWER 2018d).

The site is wholly situated within the proclaimed *Swan River and Tributaries, Ellen Brook* Surface Water Area (DWER 2018d). There are three existing water licences within this surface water area, which are located beyond the site.

It is expected that groundwater bores used for domestic and stock watering purposes contribute significantly to water supply within the site. The actual extent of this contribution is unknown as both DWER and SoC generally exempt any licencing and planning consent requirements for bores of this type. Groundwater licencing and regulation is discussed further in **Section 5.2.4**.

4.2 Wastewater servicing

There are currently no reticulated wastewater services available within the site and wastewater is disposed of via on-site treatment systems. Traditionally this would involve septic tanks and leach drains however newer or re-developed lots (that have been subject to a development application (DA)) are required to utilise aerobic treatment units (ATU) (SoC 2018).

Industrial lots are required to avoid and/or minimise the discharge of pollutants, contaminants and/or trade wastes (SoC 2004) specific to the industrial use (i.e. above the general building waste requirements).

All on-site wastewater treatment systems require provision of adequate nutrient removal capability, clearance to groundwater and ongoing maintenance by lot owners to ensure they are working correctly and providing the necessary level of treatment before discharging wastewater to the local environment. All systems should meet the requirements of the SoC and Department of Health (DoH) (SoC 2004) as part of approvals processes however ongoing maintenance of systems is not currently tracked.

It has not been possible to determine the specific treatment systems and design configurations in place across the site as there is no single database that records this information and it is not possible to determine via site visits.

An investigation into current disposal systems across the Muchea townsite and adjacent rural and rural residential lots completed by Urbaqua (2017) indicated that there are a small number of lots with septic tanks and roughly half of the area with unknown disposal systems (which are likely to be septic tanks).

5 Water Resource and Supply Options

Water supply is constrained throughout the majority of the site (as discussed in **Section 4.1**). Alternative water supply options (such as stormwater harvesting, wastewater recycling and managed aquifer recharge (MAR)) may be required to provide potable and/or non-potable water supply where traditional methods (i.e. rainwater harvesting and groundwater abstraction) are insufficient or unavailable.

5.1 Approval framework, relevant policies, and risk considerations

Lot-scale systems (where the source and end use of water occurs within a single lot boundary) currently supply all water requirements within the site (see **Section 4.1**). Lot-scale systems that provide water as a service (i.e. not self-supply; such as bathroom water used by employees) are considered reticulated systems in terms of relevant policies and approvals (discussed below in **Section 5.1.2**).

5.1.1 Lot-scale systems

Lot-scale self-supply systems are regulated and approved by SoC, which requires compliance to relevant policies such as LPP No. 6 (SoC 2008). However, ongoing compliance and the suitable operation and maintenance of lot-scale supply options is the responsibility of the lot owner. Lot-scale systems are difficult to audit, which introduces a level of uncertainty as to the actual risks occurring across the site. The level of risk and potential impacts vary significantly depending on a range of factors such as the source (e.g. rainfall or groundwater) and end use of the water (potable or non-potable). These risks, the manner and extent of which they are mitigated, the residual risk and therefore the suitability of supply options are discussed in **Section 5.2**.

5.1.2 Reticulated systems

Reticulated systems supply water via pipe networks as a service to others. These systems can supply potable or fit-for-purpose non-potable water (via a third pipe network) to multiple lots or for non-self-supply purposes within individual lots (e.g. to employees).

Reticulated supply schemes must be implemented and managed by a registered ‘service provider’ that is licensed by the Economic Regulation Authority (ERA), unless specifically exempted by the Minister for Water. The approval of reticulated supply schemes is contingent on compliance with Federal, State and Local Government agency regulation and policies, discussed below.

- Reticulated water supplies should be considered as early as possible in the planning process; the appropriate timing and level of planning is discussed in *BUWM* (WAPC 2008) and in the *Guideline for the approval of non-drinking water systems in Western Australia - Urban developments* (DoW 2013b) for non-potable systems specifically.
- Potable water supply is regulated by DoH and must be provided in accordance with *Australian Drinking Water Guidelines* (NHMRC and NRMMC 2017).

- The relevant regulatory bodies and policies for non-potable water supply vary depending on the water source and supply process. This is detailed in the *Guideline for the approval of non-drinking water systems in Western Australia - Urban developments* (DoW 2013b) along with guidance on planning, implementing and obtaining approvals for reticulated non-potable water systems.
- Approvals, design, implementation and operation of reticulated non-potable systems sourced from recycled water (including stormwater harvesting, wastewater recycling and MAR; discussed in **Sections 5.2.2**, **5.2.5** and **5.2.6** respectively) are detailed in *Guidelines for the non-potable uses of recycled water in Western Australia* (DoH 2011b). A recycled water quality management plan (RWQMP) is a prerequisite for DoH approval of water recycling systems. Guidance on the development of a RWQMP and a template are also provided in the *Guidelines for the non-potable uses of recycled water in Western Australia* (DoH 2011b).

The supply of reticulated water is generally well regulated by the relevant authorities through the approval processes. The risk to public health or the environment from an approved and appropriately operated reticulated system is considered low.

As discussed in **Section 4.1**, the site is not currently serviced by reticulated supply of either potable or non-potable water. The Water Corporation has no plans to supply reticulated potable water to the site, which is spatially removed from Water Corporation's existing services (P Howard [Water Corporation] 2018, *pers. comm.*, 25 October). A reticulated potable and/or non-potable water supply scheme could be supplied by an alternative licensed service provider with access to at least one suitable water supply source (see **Section 5.2**). The suitability of, and manner in which reticulated systems may supply water is discussed in **Section 5.2**.

5.2 Water resourcing and supply options

A number of water resources are present across the site. These water resources have the potential to provide potable or non-potable water supply at the lot-scale or as part of larger reticulated schemes servicing multiple lots. Each resource has associated risks and considerations inherent with its use as a source for water supply and these should be appropriately planned for and managed.

5.2.1 Rainwater harvesting

Runoff of rainfall from roof areas can provide a seasonal source of water of a magnitude directly proportional to the area of roof catchment. As rainfall is intermittent and seasonal (climate is discussed in **Section 3.1**), storage of rainwater in rainwater tanks (RWTs) is generally required to adequately utilise this resource as a primary supply option.

Rainwater runoff from roofs is generally of a high quality as exposure to pollutants is limited. The risk of illness by ingestion from a well-designed and maintained rainfall capture and storage system is low, but increases without maintenance and/or when the system does not have a first flush diverter (DoH 2018a). While unlikely, emissions from major industrial land uses and overspray of pesticides can present a chemical risk to vulnerable individuals (e.g. children) and may result in the rainwater not being suitable for drinking (DoH 2018a).

Rainwater harvesting is widely utilised as a water supply method throughout the site. Rainwater for both potable and non-potable uses will continue to be an important lot-scale water source for many land uses across the site. As the quality of rainwater is high, relatively little treatment is needed to provide a fit-for-purpose water supply. As such, costs associated with rainwater harvesting is typically low and infrastructure requirements generally consist of a storage tank, pump system and filtration system (DoW 2011d).

5.2.1.1 Lot-scale supply

All lot-scale rainwater tanks should be designed, installed and maintained following relevant guidelines by the lot owner/lot developer to ensure the risks identified in **Section 5.2.1** are mitigated (DoH 2018a, 2018b). Rainwater tanks of at least 120 kL capacity are currently required for all residential buildings without a reticulated water supply (SoC 2008).

The *Draft LPS* (SoC 2018) indicates changing climate conditions may restrict the viability of rainwater harvesting as a sustainable water source for lots within the site. The long-term climatic conditions should be considered when designing water supply systems that incorporate rainwater harvesting. The efficacy of rainwater harvesting can be improved by increasing the rainwater catchment areas (i.e. connected roof areas), such as shed roofs.

5.2.1.2 Reticulated supply

Rainwater could also be utilised as part of a community-based reticulated potable or non-potable water supply scheme. The feasibility of such a system would need to be investigated, but it is anticipated that it would only be relevant to the MIP or new urban areas (should these be considered in future planning) with relatively large proportions of roof area.

5.2.2 Stormwater harvesting

Stormwater is runoff generated from rainwater that flows over ground surfaces or on the surface as a concentrated flow. Prior to entering receiving environments (watercourses, wetlands or aquifers) stormwater runoff can be harvested as a fit-for-purpose water supply, provided that it is demonstrated that receiving environments are not adversely impacted.

It is important to note that when water (from any source including stormwater) enters or is expressed in a natural watercourse or wetland, that water would therein be distinctly considered as surface water in terms of water resourcing and licencing. Surface water and the definition of a natural watercourse and wetland in terms of water licensing is discussed in **Section 5.2.3**.

In general, a greater volume of stormwater is generated from impervious surfaces and hardstand (e.g. road surfaces and pavement) than pervious surfaces (e.g. pasture). Land uses associated with higher proportions of impervious area (such as urban and industrial) may therefore provide greater potential for stormwater harvesting. Pervious areas also produce stormwater, generally to a lesser extent and at a scale dependent on a range of geophysical parameters (e.g. soil infiltration capacity, slope, etc.).

Similar to rainwater, stormwater availability can be intermittent and seasonal. Captured stormwater is typically stored in sumps/ponds/dams or manufactured storages (surface or sub-surface). Consideration should also be given to infrastructure requirements relating to stormwater drainage diversion and collection, fit-for-purpose treatment, pumping and discharge systems (generally sub-surface or spray irrigation).

Runoff from impervious surfaces can mobilise a wide range of pollutants including hydrocarbons, nutrients and metals and may contain chemicals and pathogens; common stormwater pollutants are detailed in Table 4 of the *NWQMS – Australian Guidelines for Urban Stormwater Management* (ANZECC and ARMCANZ 2000b). In comparison to rainfall captured from roofs, stormwater is generally more exposed to these pollutants and can exhibit increased variability of pollutant concentrations depending on a range of factors such as land use, and timing and intensity of rainfall events. The health and environmental risks associated with stormwater capture and reuse are relatively high owing to this uncertainty. Consequently, harvested stormwater is generally utilised for lower risk non-potable uses (such as irrigation or industrial processes).

Where implemented, stormwater harvesting should be considered in the context of the stormwater management plan, adhering to the relevant policy and guidelines and should be designed such that environmental flows are maintained (stormwater management is discussed in **Section 8**). Appropriately designed and constructed stormwater harvesting systems can reduce or wholly negate the need for dedicated stormwater drainage and/or treatment infrastructure. Further guidance on implementing stormwater harvesting systems can be found in *Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse* (NRMMC *et al.* 2009).

5.2.2.1 Lot-scale supply

Lot-scale stormwater harvesting systems are generally not considered where inexpensive supply options such as groundwater abstraction or rainwater harvesting are available. However, it may be appropriate for larger commercial or industrial lots with a large area of impervious surface and a demand for non-potable water, or where other resources are not accessible. Potable on-lot stormwater harvesting systems are currently considered less feasible due to the infrastructure and treatment costs associated with the required reliability and level of treatment.

5.2.2.2 Reticulated supply

Stormwater harvesting is generally considered more feasible at a larger scale as part of a reticulated scheme. A greater connected impervious catchment area provides greater volume of stormwater and economies of scale reducing the relative cost of infrastructure (e.g. storage).

The *Guidelines for the non-potable uses of recycled water in Western Australia* (DoH 2011b) indicates that stormwater harvesting is most likely available from:

- High density development and commercial areas.
- Areas with limited infiltration potential (due to high groundwater levels or less permeable soils).

Stormwater harvesting may therefore be appropriate within urban or industrial areas such as the Muchea townsite and the MIP, both of which are underlain by low permeability soils associated with the Pinjarra Plain (see **Section 3.2**) and are expected to constitute significant areas of hardstand.

Stormwater harvesting for non-potable purposes has been successfully implemented in several regional centres in Western Australia as part of the *Stormwater Management, Harvesting and Reuse Efficiency Project* implemented by Department of Agriculture and Food, Western Australia (DAFWA) and Wheatbelt Natural Resource Management (NRM) (Wheatbelt NRM 2015). This initiative was wholly funded as part of Royalties for Regions. Systems implemented within regional shires generally harvested stormwater to irrigate recreational areas, which was commonly the town oval.

Stormwater harvesting as a source of potable water is not commonly implemented due to a range of factors including cost, lack of supporting regulation and guidance, and uncertainty regarding the implementation and operation of a relatively new supply concept. Indirect potable supply of stormwater may be an option, however this requires the discharge of treated stormwater into an existing reticulated potable supply scheme, which is not currently available (see **Section 4.1**). Stormwater harvesting as a direct potable supply is not currently considered to be a financially viable option for the site.

The suitability of stormwater harvesting will ultimately be determined through on-site investigations, consultation with relevant authorities and stakeholders and in consideration of financial feasibility. As outlined in the *Guideline for the approval of non-drinking water systems in Western Australia* (DoW 2013b), preliminary design and source assessment should occur at the local planning stage.

5.2.3 Surface water extraction

Surface water broadly refers to any water that flows or rests on land and is open to the atmosphere. In terms of resource management, DWER (the regulatory agency) considers surface water to be water flowing or held in watercourses or wetlands on the surface of the landscape (DWER 2019c). Runoff, overland flow, drainage or any surface flow of water not within a watercourse or wetland is therefore not considered to be surface water in terms of water resourcing and licencing. This would be considered as stormwater, discussed in **Section 5.2.2**.

In terms of licensing, a watercourse is defined as a river, stream or creek in which water flows in a natural channel, whether permanently or intermittently (DWER 2019c). In the same regard, a wetland is defined as a natural collection of water, whether permanent or temporary, on the surface of any land and includes:

- Any lake, lagoon, swamp or marsh.
- A natural collection of water that has been artificially altered.

A wetland is distinct from and does not include watercourses.

A licence to take surface water may be required where the surface water is to be taken or diverted from a watercourse, wetland or spring within a proclaimed Surface Water Area. To 'take' means to remove water from, or reduce the flow of water in, a watercourse, wetland or underground water source (see **Section 5.2.4**), as defined in the *Rights in Water and irrigation Act* 1914 (RIWI Act).

This can include:

- Pumping or siphoning water
- Stopping, impeding or diverting the flow of water
- Releasing water from a wetland
- Permitting water to flow under natural pressure from a well
- Permitting stock to drink from a watercourse or wetland
- Storing water during, or ancillary to, any of those processes or activities.

The site is wholly situated within the proclaimed *Swan River and Tributaries, Ellen Brook* Surface Water Area. Taking of any surface water therefore requires approval from DWER (any queries should be made to Swan Avon Region Water Licencing Program). This would involve application for a licence to take water and would also likely involve works (e.g. pump installation) that would require a bed and banks permit. However, the *Water Register* (DWER 2018d) classes this resource as limited information (i.e. neither fully allocated nor having allocation available) and therefore approval of a surface water license (without considerable investigations) is considered unlikely. Exemptions for licence approval apply when the water is to be used for domestic purposes, firefighting or non-intensive watering of stock, and given that the water resource will not noticeably diminish (DWER 2019b).

It is noted that SoC may refuse an application to take water (including surface water and groundwater) to maintain environmental flows and conserve water resources (even if approved by DWER) (SoC 2008).

The risks relating to the supply and use of surface water will be dependent on the origin of the surface water and the proposed end use. Upland surface water bodies are, in general, fed predominantly by rainwater (as stormwater runoff) and/or groundwater. The risks and considerations associated with stormwater and groundwater are discussed in **Sections 5.2.2** and **5.2.4** respectively.

Seasonal variability and reliability of the water source should be taken into account (i.e. a streamline may be ephemeral). Water storage such as dams may be required if the water source is to be relied upon throughout the year. It is noted that DWER do not support on-stream dams for water extraction and off-stream dams are preferred in accordance with *WQPN 53: Dam construction and operation in rural areas* (DWER 2018b). Any proposed surface water scheme should consider the impact to the resource and any affected environment (this should be addressed during the licence application process and/or in consultation with DWER).

Potable use of surface waters is generally not advised as the water quality can be highly variable and is largely dependent on upstream factors often out of the control of the licensee or governing agency. Reticulated schemes are unlikely to be viable due to the aforementioned considerations. Furthermore, the volume of water required for a medium to large scale scheme is unlikely to be available from the resources within the site (see **Section 3.5**).

Surface water could be utilised in lot scale, reticulated supply or as part of a managed aquifer recharge (MAR) scheme (detailed in **Section 5.2.6**).

5.2.4 Groundwater abstraction

Groundwater is water located under the surface in soil pore spaces and rock fractures. Groundwater can be abstracted from aquifers through drilled bores via pumped flow. Aquifers have a limited volume of water available for sustainable abstraction, which is largely dependent on the local hydrogeological regime and aquifer recharge rates. Groundwater abstraction is a major water supply method throughout the site. Groundwater for both potable and non-potable uses will continue to be an important lot-scale water source for many land uses across the site and is a proposed reticulated source (see **Section 4.1**).

Management of proclaimed groundwater resources is regulated by DWER in WA, including the licencing of groundwater abstraction allocations (licence to take water) and bore construction, under the RIWI Act. Queries regarding taking of groundwater should be made to Swan Avon Region Water Licencing Program. Construction of groundwater abstraction bores is also regulated by SoC through the *LPP No. 6: Water Supply and Drainage* and *LPP No. 18: Setbacks* (SoC 2007b, 2008). Exemptions to approval requirements for taking water and bore construction from DWER and SoC apply and generally include domestic and stock watering uses. For exemptions see: *Do I need a licence? – Groundwater* (DWER 2019a) and LPP No. 6 (SoC 2008).

The *Water Register* (DWER 2018d) illustrates that the majority of groundwater resources beneath the site are over-allocated. There are some allocations remaining in the following groundwater sub-areas:

- Perth – Surficial in the Gingin area (Eclipse Hill sub-area)
- Perth – Leederville in the Gingin area (Chandala subarea)
- Perth - Yarragadee North.

Additional allocation of groundwater for potable or non-potable uses is therefore unlikely. The exception to this is the surficial aquifer in the Eclipse Hill subarea, located to the east of the Great Northern Highway and Old Gingin Road within the site. An allocation report obtained from DWER in October 2018 indicates that the aquifer has approximately 1.9 GL of unallocated volume per annum. The groundwater quality is largely unknown within this area and throughout the site in general. This may impact on the suitability of this as a water supply source option (see **Section 3.4.3**).

Groundwater quality is dependent on the upgradient groundwater catchment and sub-soil conditions and can therefore be geographically variable. The main concerns for groundwater quality in Australia are salinity, acidity, trace elements, nutrients and pesticides (Geoscience Australia 2009). These issues are attributable to specific land uses (diffuse sources), activities (point sources) and operation (i.e. over-abstraction). Site-specific monitoring of groundwater quality should be conducted to determine the viability of a proposed groundwater supply. Additional hydrogeological assessment and/or an operating strategy may be required. The need for these, and the specified level of detail, will be determined by DWER based on *Operational policy 5.12 - Hydrogeological reporting associated with a groundwater well licence* (DoW 2011c) and *Operational policy 5.08 - Use of operating strategies in the water licencing process* (DoW 2011b).

Given the current and proposed land uses associated with the site (see **Section 2**), nutrients and pesticides (associated with agricultural areas) and trace elements (associated with industrial areas) are considered to be a key concern and should be included in any proposed monitoring plan (discussed in **Section 11.5**). Proximity to potential pollutant sources such as contaminated sites and wastewater disposal locations should also be considered (see **Section 3.3.2** and **4.2** respectively).

5.2.4.1 Lot-scale

Lot-scale self-use of groundwater is not regulated by DoH or SoC and is generally exempt from DWER licencing or approvals (see **Section 5.2.4**), regardless of the end use of the water. Therefore, the lot owner is generally responsible for the management of groundwater self-supply. This includes installation of the bore and any measures to manage the inherent risks associated with groundwater supply and usage (i.e. quality) (see **Section 5.2.4**). General guidelines regarding the use of groundwater for non-potable and potable use (including treatment, testing of water quality and maintenance) is provided by DoH (2019c). One such recommendation is to have groundwater quality tested once per year where this is the main supply. However, this is up to the discretion of the lot owner, who may not be aware of risks associated with the water source.

There exists uncertainty associated with the transparency, suitability and compliance of current on-site wastewater disposal methods within the Muchea townsite (see **Section 4.2**). Consequently, there is an ongoing risk that groundwater abstracted for lot-scale uses may not be acceptable for non-potable or potable uses, without additional treatment, given the high likelihood that current on-site wastewater disposal systems may be utilised in close vicinity of water supply bores. This is particularly pertinent where the end use of the water is considered high risk (i.e. drinking water).

5.2.4.2 Reticulated

A third party with a suitable existing licence, or the ability to obtain a suitable allocation amount through trading, may be able to supply potable and/or non-potable water through a local reticulated system. Groundwater licence trading is dependent on DWER approval and is guided by *Operational policy 5.13 - Water entitlement transactions for Western Australia* (DWER 2010). Reticulated supply of groundwater may necessitate the involvement of DoH, depending on the end use of the water. Low exposure end uses (i.e. early morning irrigation of open spaces) would be considered low risk, whereas essential household services (such as toilet flushing) would be considered higher risk. In these cases DWER may require DoH assessment of the application at the licencing stage.

Where any potable scheme is proposed for potable water, the water resource and abstraction bores should be protected by an appropriate PDSWA (detailed in **Section 3.4.4**) and/or well head protection zone (WHPZ) detailed within a drinking water supply protection plan (DWSPP). The DWSPP is a requirement of the memorandum of understanding that an ERA licensed water service provider will enter into with the DoH and is approved by the DoH on advice from DWER.

5.2.5 Wastewater recycling

Wastewater (discussed in **Section 6**) is 'used' water disposed of through household or business processes (stormwater is dealt with as a separate resource). Water accounts for 99.97% of the content of wastewater and represents a significant water resource if separated from the remaining 0.03% which can include potentially harmful pollutants (DWER 2019d). Pollutants can include nutrients, metals, salts, endocrine (or hormone) disrupting chemicals, bacteria, viruses and other pathogens (DPLH 2019). The quality of wastewater varies significantly depending on the previous use of the water (e.g. residential vs industrial process). Some sources of wastewater are therefore more viable than others, requiring less stringent treatment for a given end use.

Direct potable re-use (of wastewater) is not currently supported in Western Australia therefore non-potable uses are the only opportunity for wastewater recycling as a resource.

Wastewater recycling would generally involve the collection of wastewater, treatment, distribution and subsequent reuse of the recycled wastewater. Wastewater recycling sources can include sewage, greywater and/or trade waste (see **Section 6**), either separately or collectively. Recycled wastewater can provide a consistent and reliable source of fit-for-purpose water as wastewater supply generally remains relatively constant. This can reduce or negate the need for storage infrastructure. However, the uptake of treated wastewater (e.g. by irrigation areas) may be seasonally limited, therefore some degree of storage may be required. Re-use of treated wastewater where discharge to the environment or open space occurs (e.g. irrigation) will need to demonstrate that receiving environments are not adversely impacted in line with guidance discussed in **Section 6.2**. Irrigation with treated agricultural or food processing industry wastewater (fertigation) must be conducted in accordance with *WQPN 22: Irrigation with nutrient rich wastewater* (DoW 2008b), however considering the constraints of the site (discussed in **Section 3**) this is not recommended at the site.

5.2.5.1 Lot-scale

On-lot domestic wastewater disposal systems, such as ATUs and greywater reuse systems, can provide a fit-for-purpose non-potable water supply for irrigation or household uses. ATUs are discussed further in **Section 6.2**.

Greywater (household wastewater from bathroom washing, the laundry and the kitchen) can be reused for non-potable purposes such as irrigation and toilet flushing. Greywater treatment or diversion systems are designed to treat and/or directly re-use greywater, predominantly as a water conservation and non-potable water supply measure. The *Code of Practice for the Reuse of Greywater in Western Australia* (DoH 2010) provides guidance on the use of household greywater systems in WA.

Greywater is generally considered 'clean'. While this may be true in comparison to blackwater (water from toilet flushing), greywater can contain high levels of pathogens, pollutants and chemicals attributable to laundry, bathroom and kitchen uses. The *Code of Practice for the Reuse of Greywater in Western Australia* (DoH 2010) details requirements and guidance which, when implemented, mitigate these risks and allow for safe use of approved greywater systems. Approved greywater systems are detailed online in *Approved greywater systems* (DoH 2019b), however, may not include recent additions (last updated May 2016 at the time of writing).

Trade waste (discussed in **Section 6.3**) may contain pollutants that are present at higher concentrations or of a different type to common wastewater pollutants and may therefore be incompatible with standard on-lot treatment processes and reuse. The viability of treating and recycling trade waste on-lot will be dependent on the quality of the trade waste, and ability to provide sufficient treatment for the intended end use of the recycled water. The suitability of trade waste reuse will need to be determined on a case by case basis in consultation with relevant authorities (i.e. DoH and SoC) and in accordance with *WQPN 51: Industrial wastewater management and disposal* (DoW 2009c).

5.2.5.2 Reticulated

Decentralised reticulated wastewater treatment systems can manage wastewater produced from multiple lots up to a development scale within a wastewater treatment plant (WWTP) and are discussed further in **Section 6.1.2**. These systems can also facilitate the reuse of treated wastewater. Recycled wastewater is typically used for irrigation due to the lower treatment requirements and therefore reduced treatment costs. Irrigated treated wastewater also provides nutrients for plants, which reduces the amount of fertiliser application.

The viability of treating and recycling trade waste as part of a decentralised system will be dependent on the quality of the wastewater, the ability of the WWTP to provide sufficient treatment and the intended end use of the recycled water, and the constraints of the site over which it covers.

5.2.6 Managed aquifer recharge

MAR involves the intentional and controlled recharge of water (from any source) into an underlying groundwater aquifer. This recharged water may be abstracted later when needed. Storing water that would have otherwise been disposed of (i.e. treated stormwater and/or wastewater) can provide a valuable water resource as well as a range of additional environmental, social and economic benefits; see Table 1 of *Operational Policy 1.01 - Managed Aquifer Recharge in Western Australia* (DoW 2011a).

The *Operational Policy 1.01* (DoW 2011a) indicates that potential water sources for MAR can include:

- Groundwater drawn from other aquifers (including interception by sub-soil drainage)
- Water from streams, lakes or dams
- Treated wastewater sourced from industrial sites or sewerage treatment plants
- Dewatering excess from mine sites or construction sites
- Excess stormwater or stormwater redirected from existing drainage systems
- Excess agricultural runoff.

A licence to take water from DWER is required to abstract recharged water and is conditional on the continued environmental integrity and regulatory compliance of the MAR scheme (details of the licensing process is provided in Section 6.4 of the *Operational Policy 1.01* (DoW 2011a)).

The viability of MAR schemes are largely dependent on site-specific characteristics and may be constrained by hydrogeological conditions, source water availability, environmental considerations and financial feasibility. It must be demonstrated that the scheme provides an appropriate recharge pathway (injection or infiltration) and water is recharged at an acceptable rate, quantity and quality to ensure that the aquifer is not adversely impacted. The *Operational Policy 1.01 - Managed Aquifer Recharge in Western Australia* (DoW 2011a) provides guidance on the implementation of MAR in regards to health, environmental and regulatory considerations. Applications will be assessed by DWER on a case-by-case basis following a risk management approach involving a risk assessment, hydrogeological investigations and consultation with government authorities (e.g. DWER, DoH, DBCA and Environmental Protection Authority (EPA) where relevant).

5.3 Potential water resource and supply options

As discussed in previous sections, there are a number of water resources that can be utilised for supply of non-potable and/or potable water. A summary of these options is provided in **Table 5** and includes a high-level assessment of whether each option is feasible/suitable for non-potable and/or potable supply at the site.

Ongoing management and maintenance of each water supply option is generally the responsibility of either the operator or the landholder, depending on whether the measure is considered a reticulated or lot-scale system.

The suitability of each management measure, along with specific design configurations, needs to be determined based on the proposed development, individual site constraints and opportunities, and project objectives.

Table 5: Water resource and supply options for the site

Supply potential	Potable		Non-potable		Section detailed	Responsibility	
Water resource	Potential source	Treatment requirements	Potential source	Treatment requirements		Government stakeholders*	Ongoing management
Rainwater harvesting	Yes	Minor	Yes	Minor	See **Section 5.2.1**	SoC, DoH, DPLH, ERA	Owner/operator
Stormwater harvesting	Dependent	Variable, likely to be significant.	Yes	Variable, likely to be minor.	See **Section 5.2.2**	SoC, DoH, DPLH, ERA	Owner/operator
Surface water extraction	Yes, subject to demonstration of viability	Minor to significant	Yes, subject to demonstration of viability	Variable, likely to be minor or none.	See **Section 5.2.3**	SoC, DoH, DWER* (licencing only), DPLH, ERA	Owner/operator
Groundwater abstraction	Yes, subject to demonstration of viability	Variable, likely to be minor.	Yes, subject to demonstration of viability	Variable, likely to be minor.	See **Section 5.2.4**	SoC, DoH, DWER* (licencing only), DPLH, ERA	Owner/operator
Domestic wastewater	Currently infeasible	Inhibitively stringent, constrained by available technology.	Unlikely, subject to feasibility	Significant	See **Section 5.2.5**	SoC, DoH, DPLH, ERA	Owner/operator
Trade waste	Currently infeasible	Variable, likely to be inhibitively stringent.	Unlikely, largely dependent on wastewater quality	Variable, likely to be significant	See **Section 5.2.5**	SoC, DoH, DPLH, ERA	Owner/operator
Grey water	Currently infeasible	Inhibitively stringent	Yes	Minor	See **Section 5.2.5**	SoC, DoH, DPLH, ERA	Owner/operator
MAR	Yes (following abstraction)	Significant treatment prior to injection, minor treatment following abstraction	Yes	Significant prior to injection, minor to none following abstraction	See **Section 5.2.6**	SoC, DoH, DWER, DPLH, ERA	Owner/operator

** Local and state government agencies who may provide advice or approval(s) for the proposed water supply option. Their involvement is highly dependent on the site context, the proposed water resource and uses, and the water supply option itself.*

***DWER do not recommend the consumption of surface water or groundwater unless it is suitably treated and meets DoH requirements*

6 Wastewater Servicing

Wastewater is defined under the *Water Service Act 2012* as sewage and does not include stormwater, surface water or groundwater of a type that is ordinarily drained from land as part of the provision of a drainage service. Sewage is defined in the *Government Sewerage Policy* (DPLH 2019) as any waste composed wholly or partly of liquid. Sewage then includes any wastewater discharged from households and businesses attributable to domestic use (i.e. toilet, bathroom, laundry and kitchen) and may include trade waste. Trade waste is defined under the *Water Service Act 2012* as wastewater other than wastewater of the kind and volume ordinarily discharged from an ordinary dwelling used solely or primarily as the dwelling of the occupants.

Existing wastewater servicing is discussed in **Section 4.2**, future wastewater management options are outlined in the following sections. The suitability of any of the options detailed below will need to be determined through appropriate on-site investigations, risk assessment, consultation with regulatory authorities and to demonstration of compliance with the relevant guidelines and policies. Many WQPNs (see **Section 1.3**) may be relevant in certain scenarios, these should be reviewed to ensure compliance (DoW 2015c).

6.1 Reticulated sewerage

Reticulated sewerage systems consist of a closed network of sewers that convey wastewater from a development to an off-site location for treatment and disposal. The *Government Sewerage Policy* (DPLH 2019) states that the State Government's preference is for provision of reticulated sewerage systems to all developments. The policy adopts a risk-based approach to determine where reticulated networks are required and provides guidance where reticulated networks are not feasible and on-site disposal is appropriate.

6.1.1 Centralised reticulated sewerage

Large scale reticulated sewerage systems (such as those operated by the Water Corporation) treat and dispose of wastewater from multiple developments via large centralised treatment plants. As discussed in **Section 4.2**, the site is currently not serviced by reticulated sewerage. Consultation with the Water Corporation has indicated that there are currently no plans for areas within or adjacent to the site to be serviced by centralised sewerage (P. Howard [Water Corporation] 2018, pers. comm., 25th October). The *Draft Local Planning Strategy* (LPS) (SoC 2018) notes that there is no plan to provide a reticulated water or sewerage service to the Muchea townsite within the foreseeable future. It is therefore unlikely that centralised reticulated sewerage can be considered as a viable option currently or in the near future.

6.1.2 Decentralised reticulated sewerage

Smaller scale decentralised (or 'local') reticulated sewerage systems can service wastewater from multiple lots, up to the development scale, within local treatment facilities. The implementation of decentralised systems can provide reticulated sewer where connection to centralised sewer systems is unavailable or impractical.

Sewerage infrastructure and services must be provided under licence issued by the ERA as stipulated by the *Water Services Act 2012*, unless an exemption is granted by the Minister for Water.

The feasibility of local reticulated sewerage will be determined by the service provider and is dependent on the density of development, the required quality of effluent that is appropriate for the receiving environment, financial feasibility etc.; all of which is required to be demonstrated as part of the ERA licencing process.

The implementation of decentralised reticulated sewerage can facilitate the re-use of treated wastewater via a 'third pipe' to irrigation systems or other end users (see **Section 5.2.5**). Where treated wastewater is proposed as a water supply, the quality of treated water will reflect the requirements of the intended usage (i.e. fit for purpose).

The Muchea townsite is unlikely to be serviced by reticulated sewerage, as this is currently cost prohibitive. While, it is the only location across the RWMS where increased development has the potential to have density of sewage (i.e. load) suitable for reticulated sewerage, the townsite would require retrofitting of a piped sewer network. The higher cost of sewer installation is a financial barrier for service providers.

Local reticulated sewerage is unlikely to be feasible for many rural areas due to the lower population density and resulting low sewage production.

The ultimate feasibility of reticulated sewage for industrial areas is largely dependent on the final use of lots, which influences the quantity and quality of trade waste (defined in **Section 6.3**). This can only be reliably determined during the final development and planning stages (i.e. DA). Due to the timeliness and coordinated planning required to implement reticulated wastewater services prospectively it is considered unlikely that this would eventuate prior to development completion. Suitable options for trade waste disposal is discussed in **Section 6.3**.

6.2 On-site disposal

On-site disposal systems contain, treat, dispose of and potentially reuse (see **Section 5.2.5**) wastewater at source within the lot.

While the State's preferred position is to provide reticulated sewerage, this approach may be impractical in some instances. Remote and rural areas are often constrained by proximity to available services, in these cases on-site disposal can present a practical solution to wastewater management.

The implementation and suitability of on-site sewage disposal is currently guided by the *Government Sewerage Policy* (DPLH 2019) and should be determined in consideration of the:

- Sensitivity of the receiving environment (i.e. sewage sensitive areas, PDWSAs, water bodies or areas prone to flooding).
- Appropriate clearance to groundwater and flood levels.
- Proximity to superficial groundwater bores used for household/drinking water.
- Soil conditions, type and structure (and associated treatment potential).
- Density of development (i.e. lot sizes and spatial layout) and resulting nutrient loading.
- Rainfall and stormwater loading.

On-site disposal systems are discussed in the following sections.

6.2.1 Primary treatment systems

Primary treatment systems (such as septic tanks) separate suspended material within sewage before discharging the remaining liquid to a dispersion system (such as a leach drain) or a secondary treatment system (see section below). Amended soils that remove nutrients and microbes are required to underlay dispersion systems and will need to be replaced when soils become saturated with nutrients. The availability of amended soil replacement will need to be determined prior to installation.

The *Government Sewerage Policy* (DPLH 2019) stipulates that secondary treatment systems with nutrient removal should be used in sewage sensitive areas (see **Section 3.6.6** and **Figure 15**). Therefore, primary treatment systems alone are not considered suitable for use within the majority of the site.

6.2.2 Secondary treatment systems

Secondary treatment systems produce a significantly higher quality of effluent than primary treatment alone through biochemical and physical processes such as decomposition, microbial digestion, filtration and settling. Secondary treatment systems can be in addition to septic tanks or can be standalone systems that provide both primary and secondary treatment (e.g. ATUs).

The G*overnment Sewerage Policy* (DPLH 2019) defines effluent of a secondary standard as consisting of no more than:

- 20 mg/L of Biochemical Oxygen Demand (BOD)
- 30 mg/L of Total suspended solids (TSS)
- 10 cfu/100 mL of *Escherichia* (E) *coli*.

Where additional nutrient removal is required (i.e. sewage sensitive areas), secondary treatment systems must ensure that discharged effluent contains TP and TN concentrations of less than 1 mg/L and 10 mg/L respectively.

6.2.2.1 Aerobic treatment systems

DoH provides an online repository of pre-approved ATUs suitable for single houses in WA, with associated discharge methods (DoH 2019a). These pre-approved systems are suitable where wastewater loads are within specified capacities (see **Table 6**).

Higher specification secondary treatment systems may be required in instances where wastewater loads exceed those of DoH pre-approved systems (detailed in **Table 6**), or where development is for buildings other than single houses.

Design specifications of ATUs, including the proposed location and discharge mechanisms (i.e. irrigation areas or discharge outlets) must be determined in consideration of the specific site constraints present on lot, including soil types, clearances from groundwater etc.).

Treated wastewater can be used as a non-potable water source for irrigation if appropriately sized irrigation areas are provided. ATUs without a disinfection system however must be discharged below the surface (where appropriate to do so).

Approved ATU models that remove nutrients consistent with the maximum allowable concentrations for discharge into a sewage sensitive area or PDWSA are summarised in **Table 6**. These should be verified against the full list of approved ATUs are available online, as these are updated when approvals expire (DoH 2019a).

Table 6: Approved ATUs with nutrient removal summary (DoH 2019a).

Manufacturer	Model	Capacity	Nutrient removal	Approved discharge
Aquarius Wastewater Systems Pty Ltd	Aquarius O–3	1,800L/day	TP: <1 mg/L (98.5 % removal) TN: <10 mg/L (97.8 % removal)	Sub-surface or sub-strata or above ground spray irrigation.
	Aquarius O–2 NR	1,800L/day	TP: <1 mg/L (98.5 % removal) TN: <10 mg/L (97.8 % removal)	Below ground disposal only via sub-surface irrigation, leach drains, soak wells or AquaSafe Drains.

6.2.2.2 Implementation and maintenance of ATUs

The *Code of Practice for the Design, Manufacture, Installation and Operation of Aerobic Treatment Units* (The ATU Code) (DoH 2001) details minimum standards for the design, manufacture, installation and operation of ATUs, and provides guidance to local government as to how to assess the installation and ongoing operation of ATUs. Adherence to the ATU Code is considered to be sufficient to ensure the risks associated with ATUs are mitigated.

The Policy notes that the State adopts a 'cautious approach' to the use of secondary treatment systems (DPLH 2019). A small number of studies and surveys have identified difficulties associated with the somewhat rigorous installation, maintenance, auditing and education requirements associated with secondary treatment system implementation (McGrath *et al.* 2015). If unchecked, these difficulties can increase the risk of system failure and subsequent health and environmental hazards. An appropriate auditing procedure should be implemented to ensure maintenance is occurring as required if development is approved with secondary treatment systems used (see **Section 12.4**). ATU manufacture and installation companies typically offer an annual maintenance service with a certificate of completion that can be provided to demonstrate compliance. ATU systems are also available with inbuilt alarm systems that provide visual and audio warnings should systems stop working, thus minimising the risk of untreated wastewater discharging directly to the environment.

Specific consideration should be given to the location of ATUs, both in relation to environmental assets and any local groundwater abstraction bores used for supply purposes. This is considered to be a significant risk in the Muchea Townsite area, as well as other areas across the site but is not well understood due to a lack of information on system and bore locations (discussed further in **Section 12.3**).

6.3 Trade waste

Trade waste is any wastewater other than wastewater produced from domestic uses (i.e. municipal wastewater) and includes industrial wastewater (e.g. runoff from wash down areas, animal storage etc.). Stormwater runoff that mobilises hazardous materials (e.g. pesticides, herbicides) or other pollutants should also be considered trade waste as per the *Water Services Act 2012* as the stormwater is not of a type that is ordinarily drained from the land. Contaminated stormwater will require treatment prior to discharge from a site in accordance with Environmental Protection (Unauthorised Discharges) Regulations 2004.

6.3.1 On-site treatment

Industrial on-site systems could include high specification ATUs or extend to individual wastewater treatment plants, depending on the needs of the lot.

Any on-site industrial wastewater treatment plants associated with specific lot uses should be designed and constructed in accordance with *WQPN 51: Industrial wastewater management and disposal* (DoW 2009c). Proposed industrial wastewater systems will need to be independently assessed and approved by DoH and DWER on a case by case basis.

6.3.2 Hazardous materials

A risk assessment is required to decide the appropriate level of containment required for hazardous materials that will be held on lots. The lot developer/operator should consider the hazardous materials on-site, the risks posed by accidents, the likely failure mode of the primary containment, the sensitivity of receiving environments and the potential pathways for any resultant discharge to enter the stormwater system or downstream environments (DoW 2007b).

Primary containment includes the tanks in which hazardous materials are contained and must be fit for purpose (e.g. fuel tanks in service stations). Secondary containment devices and practices are related to the capture of spills for treatment should they occur and can be local or remote (DoW 2007b). Local containment devices are preferred with remote containment (such as floating booms installed on the inlets to ponds or wetlands) considered a short-term emergency response to spills only (DoW 2007b).

6.3.2.1 Service stations

Service stations provide a specific risk to the environment through the storage of significant volumes of fuels on site, specifically hydrocarbons. The design and management of service stations should consider the guidelines presented in the following WQPNs:

- *WQPN 49: Service stations* (DoW 2013d)
- *WQPN 56: Tanks for fuel and chemical storage near sensitive water resources* (DWER 2018a)
- *WQPN 65: Toxic and hazardous substances - storage and use* (DoW 2015b)
- *WQPN 10: Contaminant spills - emergency response* (DoW 2013e).

6.3.2.2 Wash down areas

Equipment wash down areas present a high risk to downstream environments due to high sediment loads, hydrocarbon and nutrient content. Depending on the use of vehicles on site, additional contaminants may also be present. All areas used for wash down must be designed to ensure capture of all wastewater for treatment prior to discharge from lot (or removal where necessary) in accordance with *WQPN 68: Mechanical equipment wash down* (DoW 2013e).

Collection of wash down wastewater can be achieved through grading and diversion of flows from washdown areas to a single collection point/sump. Keeping runoff from wash down areas separate from the stormwater system (discussed in **Section 8**) will need to occur in order to reduce the risk of spills to the environment.

As with other industrial wastewater the treatment required is dependent on the likely contaminants within the washdown water. There are a number of technologies and methods that can remove sediment loads, hydrocarbons and provide a measure of nutrient treatment, detailed further in **Section 8.2**.

6.3.3 Off-site treatment

Some land uses produce wastewater that is not suitable for on-site treatment due to the chemical content being unable to be treated in such systems (e.g. certain industrial process waters). It is not envisaged that the MIP (based on current land uses proposed) or any existing land uses will result in wastewater of this type. However, should future planning consider such land uses on-site storage and removal of waste would need to be considered to allow approval of these land uses considering the sensitive nature of the site.

A Sewage Holding Tank (SHT) is an alternative to a conventional on-site sewage system with special and limited applications. A SHT provides a means to collect and temporarily store sewage from a facility, for subsequent removal and transport to an approved treatment and disposal site thus no on-site wastewater disposal should occur. Depending upon the facility served or the particular set of circumstances surrounding the use of a SHT, the expense of sewage pumping, hauling, and disposal at an approved facility can be very costly. In addition, the potential for operational/management problems with resulting public exposure to raw sewage is significant. For this reason, a SHT is only approved for commercial and temporary use, with usage limited to a maximum of 12 months.

The use of the SHT must be approved by the DoH or the SoC in accordance with Regulation 4 or 4A of the *Health (Treatment of Sewage and Disposal of Effluent and Liquid Waste) Regulations 1974* (DoH 2019d).

This approach is consistent with industrial sites across WA, even where a reticulated sewer connection is provided. Standard wastewater treatment facilities (such as those provided by Water Corporation) are not suited to the chemical components of many industrial processes and therefore this wastewater is unable to be discharged to sewer networks.

6.4 Potential wastewater servicing options

Future wastewater servicing options for the site have been outlined in the previous sections. A summary of these options is provided in **Table 7** and includes a high-level assessment of whether each option is feasible/suitable for residential or industrial land uses.

The summary is built upon a strategic on-site wastewater treatment risk assessment (shown in **Figure 16**). This risk assessment illustrates areas that are not capable of supporting on-site wastewater treatment (i.e. incompatible) and areas that may be capable of supporting on-site wastewater treatment subject to compliance with guidelines and policies (i.e. restricted). These categories are based upon the *Government Sewerage Policy* (DPLH 2019) and includes the following factors:

- Incompatible area:
  - Flooded in the minor rainfall event (see **Figure 11**)
  - Within the indicative Ellen Brook / Chandalla Brook floodplain (see **Figure 17**)
  - Within 50 m of an indicative waterway centreline (see **Figure 17**)
  - Within 100 m of the edge of a mapped CCW (see **Figure 9**).
- Restricted area:
  - Within 100 m of an indicative waterway centreline (see **Figure 17**)
  - Within a sewage sensitive area (see **Figure 15**)
  - Where depth to groundwater is within 2.5 m of the existing surface (see **Figure 8**).

The *Government Sewerage Policy* (DPLH 2019) states that on-site systems should be setback 100 m from a waterway, but also notes that setbacks from 100 m to 30 m can be considered in lower risk proposals in consultation with DWER. A 50 m buffer from indicative waterway centerlines has been utilised as part of the incompatible area determination to be consistent with the indicative foreshore areas described in **Section 9.1.1.2**. Foreshore areas and their buffers should be determined through site-specific investigations and may result in a less than, or greater than 50 m buffer distance being required.

The risk mapping shown in **Figure 16** is indicative and should not be relied upon to determine whether on-site systems can or cannot be utilised for a proposed development. It is expected that the above factors will be refined through on-site investigations (e.g. identification of waterways, wetlands and their buffers are discussed in **Section 9.1**). Other considerations discussed within the *Government Sewerage Policy* (DPLH 2019) will need to be addressed for each proposed development, such as setbacks to surface or subsurface drainage systems that discharge into downstream waterways or waterbodies.

Whether on-site wastewater treatment or removal of waste from site is proposed, appropriate risk management and contingency plans will be required to support applications to ensure the surrounding sensitive environments are protected should spills or storage failures occur, in accordance with *WQPN 10: Contaminant spills - emergency response* (DoW 2006). These plans are to be submitted and approved as part of the building approvals process along with the proposed plant designs.

Ultimately, the suitability of any of the options, along with specific design configurations, will need to be determined through appropriate on-site investigations (including a land capability assessment), based on the proposed development, consultation with regulatory authorities, and demonstration of compliance to the relevant guidelines and policies.

Table 7: Wastewater servicing options for the site

Treatment options	Incompatible			Restricted			Unconstrained			Section	Responsibility	
	Residential wastewater	Industrial wastewater	Trade waste	Residential wastewater	Industrial wastewater	Trade waste	Residential wastewater	Industrial wastewater	Trade waste		Government stakeholders*	Ongoing management
Centralised reticulated sewer	Yes	Yes, subject to WWTP facilities	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	**Section 6.1.1**	DWER, SoC, DPLH, ERA	Licenced service provider
Decentralised reticulated sewer	Yes	Yes, subject to WWTP facilities	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	Yes	Yes	Yes, subject to WWTP facilities	**Section 6.1.2**	DWER, SoC, DPLH, ERA	Licenced service provider
Primary treatment - septic tanks/leach drains	No	No	No	No	No	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	No	**Section 6.2.1**	DoH, SoC, DWER	Lot owner
Secondary treatment - pre-approved ATUs	No	No	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	No	**Section 6.2.2**	DoH, SoC, DWER	Lot owner
Secondary treatment - site specific ATUs/treatment plants	No	No	No	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	Yes, subject to demonstration of suitable site conditions and compliance to guidelines and policies	**Section 6.2.2** and **6.3.1**	DoH, SoC, DWER	Lot owner
Containment devices and practices	No	No	Yes	No	No	Yes	No	No	Yes	See **Section 6.3.2**	SoC, DWER	Lot owner
Treatment WSUD measures	No	No	Yes	No	No	Yes	No	No	Yes	See **Table 8**.	SoC, DWER	Lot owner or SoC
Off-site treatment storage	No	No	Yes	No	No	Yes	No	No	Yes	See 6.3.3	SoC, DWER	Lot owner

** Local and state government agencies who may provide advice or approval(s) for the proposed wastewater servicing option. Their involvement is highly dependent on the site context and the wastewater servicing option itself.*

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7 Groundwater Management

The groundwater regime forms an integral part of the total water cycle and its management has implications to development of the site through impacts on proposed infrastructure, the environment and public health, and safety and amenity.

Groundwater management should aim to protect the public and infrastructure from groundwater inundation whilst also preventing adverse environmental impacts. Groundwater management strategies are developed to manage the impact and risk of development primarily through consideration of groundwater levels and quality.

7.1 Groundwater management planning

Groundwater management should be considered at each stage of the planning process. The approach to groundwater management should be based on key guiding documentation including:

- *BUWM* framework (WAPC 2008)
- *Water resource considerations when controlling groundwater levels in urban development* (DoW 2013f)
- *Government Sewerage Policy* (DPLH 2019)
- *Specification: separation distances for groundwater controlled urban development* (IPWEA 2016)
- *Decision process for stormwater management in WA* (DWER 2017)
- WQPNs, where relevant (see **Section 1.3**).

In order to appropriately identify groundwater management strategies a strong understanding of the existing groundwater characteristics of each site is required, ensuring that consideration is given to the relevant key areas of risk. It is also important to identify gaps in understanding as early as possible and enable additional investigations to be completed to support each level of planning.

7.2 Groundwater data

A review of available groundwater data in the Muchea region (discussed in **Section 3.4**) has identified an absence of available and reliable groundwater data for the site; both spatially and temporally. Assessment of the available groundwater data has been used to produce high-level, regional depth to groundwater mapping (**Figure 8**). However, this mapping should be used as an indicative guide only; detailed site-specific investigations are required to determine appropriate groundwater management strategies associated with future land use change or development approvals.

Alternatively, a regional monitoring program could be implemented to provide a more comprehensive data coverage of the site (see **Section 11.5**).

Site-specific investigations will need to sufficiently describe the existing groundwater levels and quality. Geotechnical investigations should also be completed to confirm underlying soil conditions (including soil profile configuration, PRI and permeability) and identify whether the underlying groundwater regime is a perched system (see **Section 3.4**).

7.3 Groundwater level management

Groundwater level management should aim to maintain the existing regime where possible, and ensure proposed development design (layout and construction) appropriately considers the groundwater constraints of the associated site.

Improper consideration of groundwater levels can lead to groundwater encroachment or prolonged inundation, which can result in:

- Undermining the integrity of infrastructure
- Inhibiting the operation of drainage structures
- Creating breeding habitat for mosquitoes
- Exacerbating flooding
- Reducing amenity of backyards and open space
- Impacting groundwater sensitive environments
- Mobilising legacy nutrients/contaminants
- Increasing ASS risk and resulting acidity
- Increasing salinity
- Inhibiting the effectiveness and suitability of on-site wastewater disposal systems.

These concerns are expected to be relevant primarily to those areas identified as having a high risk of groundwater inundation (**Figure 8** – groundwater at surface) or immediately surrounding areas. Mitigation of these risks can be achieved through the implementation of the strategies discussed in the following sections.

7.3.1 Regulations and management measures

The scale and extent of groundwater level management will depend on the proposed land use(s) and associated needs (e.g. wastewater management, water supply etc.) and the level of risk posed by the site conditions.

A number of existing policies and guidelines are available to inform the design process in relation to consideration of groundwater including:

- *Specification: Separation distances for groundwater controlled urban development* (IPWEA Guidelines) (IPWEA 2016) - specifies clearance criteria for drainage infrastructure, private space and public open space (POS) where a controlled groundwater level is proposed (see **Section 7.3.1.2**).
- *Water resource considerations when controlling groundwater levels in urban development* (DoW 2013f).
- *Government Sewerage Policy* (DPLH 2019) - Section 6.4 of the policy discusses clearances required where wastewater is disposed of on-site (see **Section 6**).
- *Decision Process for Stormwater Management in Western Australia* (DWER 2017) – outlines how groundwater and stormwater management considerations interface.
- *Stormwater Management Manual for Western Australia* (DoW 2007b) – Chapter 9 describes how WSUD measures should be designed in response to groundwater levels.
- *Australian Rainfall and Runoff (*Engineers Australia 2016) – Describes how WSUD measures should be designed in response to groundwater levels.

- Some WQPNs (DoW 2015c) which are relevant to the management of groundwater and groundwater dependent ecosystems.

Management of groundwater levels can include:

- Only developing areas with existing separation to groundwater already provided.
- Importing fill to provide adequate separation to groundwater.
- Utilising surface or subsoil drainage networks to locally control groundwater.

The manner in which groundwater levels are managed should be determined in consultation with SoC and/or state authorities (DWER and DBCA) as early as possible to ensure all factors have been appropriately considered. Identification of the appropriate clearances should occur at all planning stages, or solely at DA and/or building licence where individual lots are not to be subdivided.

7.3.1.1 Imported fill

Imported fill can provide clearances from groundwater (whether perched, superficial or controlled) through elevation of the finished surface level and any associated wastewater discharge areas (which may be below surface).

Fill may be utilised where groundwater levels are expected to be close to the natural surface thereby necessitating an appropriate separation clearance from infrastructure, drainage features, private or public open space. Fill can be used in conjunction with subsoil drainage (discussed below in **Section 7.3.1.2**) to achieve required separation clearances or to ensure compliance to building code specifications. Fill may also be required for grading, other services (e.g. a reticulated sewer network), and lot classification based on geotechnical conditions.

Use of fill may be localised (e.g. for housing pads) or development-wide. The use of fill should not create a barrier to existing upstream surface flows, should determine how any existing runoff from upstream areas will be conveyed through the site, and will need to respond to the presence of any environmental assets (e.g. wetlands).

The use of fill should be appropriately documented at each stage of the planning process. Fill within lots can be used at the lot owner's discretion given compliance to the relevant policies and guidelines are achieved and SoC approval (through DA or building licence) is gained.

7.3.1.2 Controlled groundwater

Open drains/swales and/or subsoil drains can be used to control groundwater, either existing levels or the potential rise following development (into existing soils or imported fill). The invert of swales/drains/pipes and resulting phreatic surface is referred to as the controlled groundwater level (CGL). Considerations for assessing the need for, and setting of a CGL, are discussed in the *Water resource considerations when controlling groundwater levels in urban development* (DoW 2013f).

The appropriateness for control of groundwater should consider impacts to environmental and water resources (including quality and quantity). The extent of control measures will be dependent on any proposed land uses, both in relation to impact and spatial coverage.

For example, the existing groundwater regime within the vicinity of sensitive environments should be maintained to preclude any impact. It is common for groundwater control measures to be installed within road verges to control the rise of groundwater beneath adjacent lots. Where groundwater control measure inverts are placed on a low permeability layer within the soil profile, this layer may need to be graded to ensure an appropriate flowpath is provided. Control measures can also be used within lots at the lot owner's discretion given compliance to the relevant policies and guidelines are achieved and SoC approval (of DA and/or building licence) is gained. Within the site, both swales and sub-soil drains are likely to be utilised as part of proposed development due to high groundwater in many areas.

7.3.1.3 Building and construction

The above policies and guidelines do not specify a groundwater separation requirement from the MGL or CGL for individual buildings, road pavement or services. It is common for these to be protected by earth working (e.g. grading of any low permeability layers), controlling groundwater and/or importing fill. However, alternative construction methods and materials can provide sufficient protection and should be investigated against the sustainability and feasibility of fill importation and/or groundwater level controls.

For example, buildings are required to meet performance requirements in accordance with the *Building Code of Australia (BCA) Volume 2 – Class 1 and 10 buildings* (ABCB 1996). Achievement of the BCA can be met with moisture barriers, damp-proofing systems or other building controls with or without the groundwater level management methods discussed above. Likewise, roads and pavement can be susceptible to water damage. Advances in material technologies and construction methods have significantly improved the lifespan and resistance to moisture for surfaces and should be considered where appropriate (IPWEA 2016).

7.4 Groundwater quality management

The overarching principle of maintaining or improving groundwater quality can be achieved by managing the load of pollutants being applied to the site and conveyed into underlying groundwater, and through ensuring appropriate development practices are adhered to (e.g. ASS management, stormwater treatment, groundwater controls).

As discussed in **Section 3.2.3**, groundwater beneath the majority of the site flows towards the Ellen Brook and other sensitive receiving environments (defined by the EPA (2008) in *Guidance statement no. 33: Environmental guidance for planning and development*). The management of groundwater quality is therefore essential for the protection of the surrounding waterways and wetlands (see **Section 9**).

7.4.1 Pollutant sources

Pollutants may be conveyed into groundwater through:

- Landuse practices (e.g. use of fertilisers or pesticides).
- Infiltration of stormwater (**Section 8**)
- On-site disposal of wastewater (**Section 6.2**)

- Recharge of water (generally recycled water) as part of a MAR scheme (**Section 5.2.6**).
- Interception of existing groundwater (e.g. subsoil drains, constructions practices) mobilising legacy pollutants (including nutrients and ASS) (**Section 7.3**).

7.4.2 Groundwater quality management measures

All potential pollutant sources should be managed such that the underlying groundwater, and any sensitive receiving environments are not impacted. This can be achieved through a number of measures, including:

- Ensure that development approval is obtained for land uses and development where groundwater is close to the surface and will potentially be impacted by development (discussed in **Section 3.4**).
- Lot owners should be encouraged to minimise fertiliser and pesticide use and be provided relevant educational material to understand their potential impact on groundwater.
- Developers should minimise fertiliser use to establish and maintain vegetation within any proposed open space areas.
- Agricultural land uses should be operated in accordance with relevant guidelines to manage wastes and the application of other pollutant sources, such as pesticides. These guidelines may include some WQPNs (DoW 2015c), codes of practice for livestock (DPIRD 2019a), small landholder responsibilities (DPIRD 2019c), and other requirements of the SoC.
- Industrial land uses (warehouses, farm supply centres, refuse centre, service stations etc.) should be operated in accordance with relevant guidelines (e.g. some WQPNs will be relevant, as noted in **Section 1.3**, and guidelines and measures discussed in **Sections 6** through **9**).
- Treating the small rainfall event stormwater runoff within WSUD features such as swales, bio-retention areas (BRA) or constructed wetlands, as discussed in **Section 8.2**.
- Ensure on-site wastewater treatment and disposal systems are appropriately implemented and maintained, and adhere to the relevant codes, policy and recommendations discussed in **Section 6**.
- Ensure any MAR schemes do not adversely impact the water quality within the aquifer to which it relates (see **Section 5.2.6**).
- Ensure construction practices adequately protect the groundwater system through preparation of Construction Management Plans (or equivalent) demonstrating how activities will be carried out and confirming mitigation measures in place in line with *A guide for managing the impacts of dust and associated contaminants from land development sites, contaminated sites remediation and other related activities* (DEC 2011).
- ASS investigations may be required where groundwater control is proposed, or works intersect groundwater (temporarily or permanently), in accordance with *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015a).
- Groundwater that is intercepted by an open drain/swale or subsoil drain may require treatment prior to discharging off-site (DoW 2013f). This can be achieved through a number of measures such as treatment within a WSUD structure or by surrounding the open drain/swale or subsoil drain invert with appropriate filter media (Payne *et al.* 2015).
- The creation of open drains that intercept groundwater is generally not supported by DWER and may require a Notice of Intent to Drain under the *Soil and Land Conservation Act 1945*.

Any structural treatment measures proposed should be designed appropriately for the level of treatment required which will be dependent on the input water quality (for stormwater and wastewater) or the existing groundwater quality. An understanding of existing groundwater quality on each site proposed for development is essential for identifying management needs and measures, as well as for monitoring impacts over time.

7.5 Potential groundwater management options

As discussed in previous sections, there are a number of measures that can be implemented to achieve the groundwater level and groundwater quality management objectives for a specific site or proposed development.

Groundwater management should be addressed at all levels of the planning process by documentation of water management plans and approved from relevant approval agencies (see **Section 10**, **Table 9**). Ongoing maintenance of these measures is generally the responsibility of either the SoC or the landholder, depending on whether the measure is located within a public road reserve / POS area etc or private lot.

Ultimately, the suitability of any of the options, along with specific design configurations, will need to be determined through appropriate on-site investigations, based on the proposed development, consultation with regulatory authorities, and demonstration of compliance to the relevant guidelines and policies.

8 Stormwater Management

Stormwater is a key consideration for any future development or change in land use as well as existing practices. An understanding of the site-specific risks associated with the existing hydrological regime (see **Section 3.5**) as well as risks associated with land use should be addressed in a stormwater management strategy/plan. In order to prevent or mitigate these risks in a holistic manner, stormwater management strategies should broadly aim to mimic, as closely as practicable, the natural hydrological regime relative to the pre-development condition. This approach has been shown to provide the best economic, social and ecological outcomes (DWER 2017).

8.1 Regulations and guidance

The specific objectives of, and principles behind stormwater management plans should be formed in response to site-specific conditions and should be based on guiding documentation including the *Stormwater Management Manual for Western Australia* (DoW 2007b), which comprehensively describes the stormwater management approach in a Western Australian context. The *Decision Process for Stormwater Management in Western Australia* (DWER 2017) compliments this approach and integrates stormwater management into the water planning process; this is detailed in Figure 1 of the report itself.

Stormwater management should be considered at each stage of the planning process and documented within water planning reports. The appropriate level of detail regarding stormwater management strategies at each stage of the planning and water planning process is detailed in *BUWM* (WAPC 2008).

Based on the aforementioned guidelines, stormwater management strategies should specifically aim to:

- Mitigate the risk to public health and safety and infrastructure from flooding.
- Mitigate the risk to receiving environments from poor water quality (pollutants), excessive runoff or biodiversity and habitat loss.
- Maximise the reuse of stormwater (discussed in **Section 5.2.2**).
- Achieve the above objectives through means which are economically viable, sustainable and provide good amenity and social value.

The impacts of stormwater on public health and safety and the environment are considered primarily through management of stormwater quantity and quality prior to discharge offsite or towards an environmental asset (e.g. waterway, wetland etc). The *Decision Process for Stormwater Management in Western Australia* (DWER 2017) advocates for this to be achieved through the:

- Management of runoff from small rainfall events for ecological protection.
- Management of runoff from minor rainfall events for serviceability, amenity and road safety.
- Management of runoff from major rainfall events for flood protection.

The objectives discussed above will ultimately be achieved through the implementation of appropriate best management practices (BMPs) and WSUD measures, the use of which should be approved by the relevant approval authorities (e.g. SoC, DPLH) on a case-by-case basis with advice from relevant referral authorities (e.g. SoC, DWER and DBCA).

The manner in which these strategies achieve the desired outcomes in relation to stormwater quantity and quality management are discussed in **Sections 8.2** and **8.3**.

8.2 Stormwater quality management

Stormwater is runoff generated from rainwater that flows over ground surfaces or on the surface as a concentrated flow. Runoff from impervious surfaces can mobilise a wide range of pollutants including gross-pollutants, sediment, hydrocarbons, nutrients and metals, and may contain chemicals and pathogens (ANZECC and ARMCANZ 2000b). Similarly, runoff from pervious surfaces (e.g. pasture) also has the potential to mobilise pollutants (ANZECC and ARMCANZ 2000b) including pesticides and insecticides. Pollutant type and concentration within stormwater is dependent on the rainfall event (i.e. intensity and volume) as well as site characteristics (e.g. soils and vegetation) and land uses.

The site is located within the Ellen Brook sub-catchment, which has been identified as a major contributor to nutrient (and other pollutant) loading in the downstream Swan-Canning Estuary system (see **Section 3.5**). Management of stormwater quality is therefore important to minimising water quality issues both within the site and downstream receiving environments.

8.2.1 Objectives and management measures

The *Decision Process for Stormwater Management in Western Australia* (DWER 2017) advocates for stormwater quality to be managed primarily through two approaches:

- Management of runoff from small rainfall events prior to discharge from the site or towards sensitive receiving environment.
- Reduce water pollution loading through non-structural controls.

Management of small event runoff should be provided through methods that respond to site-specific conditions. This will involve the retention and/or detention, and appropriate treatment of runoff from the small rainfall event (currently defined as the first 15 mm of rainfall) as close to the source as possible, where it is practicable to do so. Any flows that discharge from a development area in the 1 EY event will also need to be maintained relative to the existing peak flows and total discharge volume (where possible). Examples of WSUD measures that can be utilised to achieve these are summarised in **Table 8** (provided at the end of the Section).

Non-structural controls include institutional and pollution-prevention practices designed to prevent or minimise pollutants from entering stormwater runoff and/or reduce the volume of stormwater requiring management (DoW 2007b). These can include:

- Street sweeping.
- Maintenance of structural WSUD features.
- Minimising fertiliser use.
- Utilising drought tolerant plant species that require minimal water and nutrients.

- Education of lot owners, residents and tenants regarding fertiliser application and the use of nutrient absorbing vegetation.
- Appropriate storage of hazardous and dangerous goods.
- Erosion and sediment control during construction.
- Maintenance of waterways and riparian vegetation.

Commonly applied non-structural measures are outlined in Appendix A of Section 7 of the *Stormwater Management Manual for Western Australia* (DoW 2007b).

8.3 Stormwater quantity management

Built form and hardstand associated with development generally increases the amount of impervious area on any given site, thereby altering the existing surface water hydrological regime, generally leading to increasing the volume and velocity of stormwater runoff. If unmanaged, this can increase risk of flooding, habitat loss, erosion and stream bed alteration, and lead to adverse impacts on sensitive receiving environments (DoW 2007b). Conversely, improper management may lead to an alteration (e.g. a reduction, diversion or temporal change) in environmental flows, which can result in negative impacts to environmentally sensitive assets downstream that depend on these flows. It is therefore important to identify the existing hydrological regime and manage stormwater quantity appropriately. This is achieved primarily through management of runoff from the minor and major rainfall events (DWER 2017).

8.3.1 Objectives and management measures

Runoff from minor rainfall events is managed to provide serviceability, amenity and road safety. This is achieved by designing stormwater management systems in consideration of transport networks, POS and drainage networks. Specific criteria for achieving these outcomes should be determined in consultation with the party ultimately responsible for the infrastructure assets to be constructed (e.g. SoC, Main Roads WA, Public Transport Authority).

Management of runoff from major rainfall events provides flood protection for people and infrastructure. Appropriate management of the major event should be determined in response to site-specific conditions.

The primary guideline relating to stormwater management in developments is the *Decision Process for Stormwater Management in Western Australia* (DWER 2017). Any stormwater management strategy supporting development within the site should consider:

- Maintenance of existing peak flow rates entering and leaving the site.
- Maintenance of existing floodplain storage.
- Maintenance of flows entering waterways and wetlands within the site.
- Provision of clearance from the major event flood levels to habitable floor levels.
- Provision of safe conveyance pathways for major event runoff (i.e. through waterbodies, drainage infrastructure, overland flow paths etc.).
- Maintaining serviceability of roads and infrastructure for minor events:
    - Minor event is the 20% AEP (5-year ARI event) in residential/rural residential areas.
    - Minor event is the 10% AEP (10-year ARI event) in commercial/industrial areas.

The specification and relevance of the above criteria should be determined in consultation with the relevant agencies (i.e. DWER, SoC) and in consideration of existing site constraints. Identification of site constraints relating to stormwater management (flow paths, storage requirements, peak flow rates etc.) should consider the surface water modelling completed for the site (detailed in **Section 3.5.2**) and any additional site-specific investigations that will be required to support future development (discussed in **Section 11.5**).

There are a number of WSUD measures that can be implemented to meet the objectives and criteria detailed above, examples of which are summarised in **Table 8**.

8.4 Potential stormwater management options

As discussed in previous sections, there are a number of WSUD measures that can be implemented to achieve the stormwater management objectives (both quality and quantity) for a specific site or proposed development. A summary of these measures is provided in **Table 8**, along with the objectives they help to achieve.

Stormwater management should be addressed at all levels of the planning process by documentation of water management plans and approved from relevant approval agencies (see **Table 9**). Retrofitting of appropriate stormwater management measures for existing land uses should also be considered where the need is identified (discussed further in **Section 11.5**). Ongoing maintenance of WSUD measures is generally the responsibility of either the SoC or the landholder, depending on whether the measure is located within a public road reserve / POS area or private lot.

The suitability of each WSUD measure, along with specific design configurations, needs to be determined based on the proposed development, individual site constraints and opportunities, and project objectives (beyond stormwater management) etc.

Table 8: Structural stormwater management options for the site

Stormwater management category	Management response examples	Description	Primary objective achieved	Secondary objective achieved	Rainfall event managed
Retention and detention	End of pipe (i.e. basins, sub-surface storage, RWTs)	• Retain stormwater (infiltrated or evaporated) or detain stormwater to meet pre-development flow rates (controlled discharge). • Typically located at the catchment low point. • A large variety of solutions in many forms are available. Can provide water reuse storage.	Quantity	Quality	Minor and major
	Pond/urban lake	• Ponds or urban lakes can be integrated into the stormwater management system to provide detention storage. • Can provide amenity and reuse storage.	Quantity / social value	Quality	Varies
	Constructed/rehabilitated wetland	• Stormwater runoff is treated within wetlands through a number of biochemical and physical processes, which are primarily facilitated by submerged and emergent vegetation (Śarmā 2018). Runoff is also detained and/or retained. • A high flow or bypass should be configured to circumvent major event flows.	Quality	Quantity / social value	All
Infiltration	Soakwell, pervious pavement, swale	• Infiltrates runoff at source and reduces pollutant mobilisation. • Decreases effective imperviousness across a catchment.	Quality	Quantity	Small
Treatment	BRA, rain gardens, tree pits, vegetated swale	• WSUD features that treat stormwater within a vegetated area underlain by nutrient removing soils/media. • A large variety of solutions in many forms are available.	Quality	Quantity / social value	Small
Conveyance	Living stream	• A living stream is a vegetated, meandering stream that mimics the characteristics of natural waterways. Living stream can be constructed, rehabilitated from degraded streamlines or retrofitted to an existing stormwater conveyance system (e.g. a drain). • When implemented correctly they can provide greatly improved water quality, promote biodiversity and create an attractive landscape feature, while maintaining the safe conveyance of stormwater.	Quantity / quality	Social value	All
	Drain/swale	• Vegetated channel to convey runoff that decreases the effective imperviousness across a catchment. Runoff is also detained and/or retained. • Can convey runoff at a shallower grade than pit and pipe networks, and be utilised to control groundwater rise.	Quantity	Quality / serviceability	All

Table 8: Structural stormwater management options for the site (continued)

Stormwater management category	Management response examples	Description	Primary objective achieved	Secondary objective achieved	Rainfall event managed
Conveyance	Pit and pipe network	Convey runoff from road reserves and ensure required serviceability of road bitumen is achieved.	Quantity	Serviceability	Small and minor
Pollution mitigation	GPT, sediment trap, gully baskets	• Structural controls can intercept and remove pollutants from urban stormwater. Pollutants can be particulates, gross pollutants and particulate-bound pollutants. • There is a wide range of pollutant removal devices and they are generally designed to capture and remove a specified type of pollutant (i.e. GPTs typically remove particles that are larger than 5 mm)	Quality	Ease of maintenance	All
	Non-structural measures	Discussed in **Section 8.2**	Quality	Community engagement	All
Reuse	RWTs, stormwater harvesting	Discussed in **Section 5.2.1** and **5.2.2**.	Water reuse and conservation	Quantity / quality	All/varies
	Green wall, green/blue roof	• Vertical gardens or roof gardens that use greywater or stormwater for irrigation. • Reduce potable water use, provide amenity, insulate buildings and provide cooling.	Social value	Water reuse and conservation / quantity / quality	All/varies
	MAR	Discussed in **Section 5.2.6**.	Water reuse and conservation	Quantity / quality	All/varies

9 Waterway and Wetland Management

Protection of the sensitive receiving environments present across the site can be accomplished through ensuring inflows (surface and groundwater) are appropriately managed (as discussed in **Sections 6**, **7** and **8**) as well as through direct protection and management of the assets themselves.

This section details the identification process of wetlands and waterways across the site, and presents management measures that can be utilised to protect these assets.

9.1 Identification

Formal identification of the environmental assets located across the site is important to then understand the required protection and management measures suitable, and implications of proposed land uses in the area that may impact them.

Identification of waterways and wetlands involve different processes and are managed by different agencies (DWER and DBCA respectively) though many of the principles are similar.

9.1.1 Waterway assessment

9.1.1.1 Existing datasets

The DWER maintains the *Hydrography, Linear (hierarchy)* dataset which includes major streamlines across WA; **Figure 9** illustrates the watercourses and drains identified in this layer across the site.

The dataset currently includes information from 1995 through to 2007. Experience with the dataset (including within the RWMS area for LSP1) has been that not all identified watercourses exist in the current landscape (potentially from historical land use change), or actually represent overland flow paths with no on-ground characteristics of a 'waterway' present (i.e. defined channel, riparian vegetation etc.).

As such, site specific investigations are required to identify foreshore areas to confirm the presence of waterways, including an associated floodplain (see **Section 9.1.1.2**).

9.1.1.2 Foreshore areas

A foreshore area is defined by the DWER as '*the land that adjoins or directly influences a waterway. It is the area of transition between the edge of the waterway and the furthest extent of riparian vegetation, the floodplain and riverine landforms, or a negotiated area endorsed by the*' DWER (DoW 2012a).

There are a number of policies and guidelines that provide direction on the identification of foreshore areas including:

- *Operational policy 4.3: Identifying and establishing waterways foreshore areas* (DoW 2012a).
- *Water Note 23: Determining foreshore reserves* (WRC 2001c).
- *Foreshore condition assessment in urban and semi-rural areas of south-west Western Australia* (WRC 1999).

- *River Restoration: Determining Foreshore Reserves* (WRC 2001a).

In order to confirm the presence of a waterway and extent of associated foreshore area a biophysical assessment is required, which includes consideration of the following factors (WRC 2001c):

- Waterways and surface flow paths
- Remnant vegetation, including floristic composition, condition and spatial extent
- Soils, including those associated with riparian vegetation and those prone to erosion
- Landforms important to watercourse function
- Aquatic and riparian fauna habitat
- Adjacent land use pressures
- Adjacent archaeological and ethnographic sites.

The outcomes of foreshore area assessments should be presented in a Foreshore Area Report and submitted to DWER for review and approval and to DBCA for review and comment. Where possible, it is DWER's preference that this report be included as part of an LWMS document, which supports a proposed structure plan.

9.1.1.3 Muchea RWMS waterways

A high-level initial biophysical assessment has been completed to identify waterways present across the site which has included:

- Desktop assessment of
  - Soils and geology
  - Topography
  - Vegetation
  - Fauna habitat.
- Aerial imagery analysis
- Groundwater conditions
- Surface runoff modelling (see **Section 3.5**).

The 'potential waterways' and 'indicative foreshore areas' identified by the assessment are illustrated in **Figure 17**. These are indicative as the level of assessment completed to date is not sufficient to fully confirm foreshore areas across the site, therefore more detailed site-specific assessments will be required to determine the full extent of any foreshore areas.

For the purposes of this report the indicative foreshore areas have incorporated the following:

- Ellen and Chandala Brooks
  - 1% AEP flooded area.
- Other waterways
  - 10% AEP flooded area.
  - 50 m buffer from waterway (as indicated in Hydrography linear layer) centre line (J. Mackintosh [DWER] 2019, *pers. comm.* 16th August).

These distinctions were chosen to include significant flow paths identified from surface water modelling, the hydrography linear layer (major and minor watercourses), and on-ground conditions visible in aerial imagery.

The Ellen and Chandala Brooks are major watercourses with significant tributaries and riparian zones (the extent of which is not easily identifiable from aerial imagery), therefore the full floodplain (1% AEP) has been allowed for in the 'indicative foreshore area' assessment. A full floodway/flood fringe assessment has not been completed to delineate where development could occur within the floodplain (i.e. outside of floodway) as this would require more detailed modelling of the entire Ellen Brook catchment which is outside of the scope of this study. Should development be proposed within the Ellen and Chandal Brook floodplain identified a more detailed study to delineate the floodway/flood fringe would be required and approved by DWER.

The 10% AEP has been used to define 'floodway' in other waterways as the extent of flows is more easily delineated in minor watercourses. While only 10% AEP has been considered for other waterways, this does not remove the need to maintain the major event (1% AEP) peak flows across a site (discussed in **Section 8**) should amendments in the vicinity of the waterway occur.

This mapping should not be used to inform development approvals without further site-specific assessment being considered and presence of waterways and extent of foreshore areas confirmed with DWER.

9.1.2 Wetland assessment

9.1.2.1 Existing datasets

DBCA maintains the *Geomorphic Wetland of the Swan Coastal Plain* dataset (DBCA 2018), which identifies individual wetlands, classifies them according to their geomorphology, and categorises them into one of three management categories:

- Conservation (CCW)
- Resource enhancement (REW)
- Multiple use (MUW).

As detailed in **Section 3.6.5** and shown in **Figure 9**, there are a number of mapped wetlands present across the site. No assessment of the suitability of the wetland dataset to on-ground conditions across the site has been completed as part of this study.

9.1.2.2 Modifications to wetland classifications

The management categories of wetland features are determined based on hydrological, biological and human use features. *A methodology for the evaluation of specific wetland types on the Swan Coastal Plain, Western Australia* (DBCA 2017) details the methodology by which wetlands on the Swan Coastal Plain are assigned management categories, which uses a two-tiered evaluation system comprising preliminary and secondary evaluation stages.

The preliminary evaluation aims to identify any features of conservation significance that would immediately place the wetland within the CCW management category, for example:

- Presence of significant wetland lists (e.g. Ramsar wetlands).
- Presence of threatened or priority (priority 1 and 2) ecological communities.
- Presence of threatened flora.
- Over 90% of vegetation in good or better condition based on the (Keighery 1994) scale.

If such environmental values are identified the wetland would be categorised as CCW without further evaluation. Should the preliminary evaluation indicate that no such features occur, the secondary evaluation and site assessment are then applied. In the secondary evaluation, an appropriate management category is determined through the assessment of a range of environmental attributes, functions and values.

Should the location, extent or condition of a wetland across the site need to be reviewed, the *Protocol for proposing modifications to the Geomorphic Wetlands Swan Coastal Plain dataset* (DBCA 2018) details what is required to propose changes to the boundaries and/or management categories of an existing wetland within the geomorphic wetland dataset, or to add a new wetland to the dataset. The procedure involves a wetland desktop evaluation and site assessment to determine the recommended management category. Relevant information should be obtained in the optimal season for vegetation condition and water levels, which is usually spring. In the case of larger wetlands that have undergone a degree of disturbance, a separate management category may be assigned to parts of the wetland in order to reflect the current values.

9.1.2.3 Environmental asset water balance assessment

Following the identification of waterways and wetlands present on site (see **Section 9.1**), water balance assessments should be completed to determine the hydrologic/hydrogeologic regime of the asset and demonstrate that changes to the regime have been avoided or minimised post development (Eamus and Froend 2006; DoW 2007b, 2013f; DWER 2017; EPA 2018). *Guidance note 7: Managing the hydrology and hydrogeology of water dependent ecosystems in urban development* (DoW 2013a) provides direction on the process, from identifying assets to considerations to be included within the water balance.

As outlined in *BUWM* (WAPC 2008), varying levels of detail should be provided across the planning approvals process. The outcomes of water balance assessments should be presented within LWMSs, UWMPs or equivalent technical documentation, consistent with other reports and management plans produced for the asset.

9.2 Wetland and waterway protection

Once foreshore areas and wetland boundaries are identified, they need to be protected to ensure assets are sustained at their current condition, or improved where possible/appropriate. There are a number of measures that can be used to protect these assets with mechanisms for these dependent on a number of factors including proposed development.

9.2.1 Planning

Protection of wetlands and waterways can be progressed through implementation and appropriate monitoring of planning controls that limit existing and proposed land uses in areas associated with these assets, as well as the assets themselves.

9.2.1.1 Land use planning and implementation

Appropriate zoning and reservation of land within contributing catchment areas for wetlands and waterways should be incorporated in all land planning schemes. Land-uses considered to be high-risk in relation to wetland and waterway protection include heavy industry, broadscale agriculture, and extractive industry. However, all land uses pose a level of risk that will require specific water management measures to help protect surrounding and downstream receiving environments. Specific measures that should be considered are detailed in the following sections of this report:

- Wastewater management – **Section 6**
- Groundwater management – **Section 7**
- Stormwater management – **Section 8**.

Existing and future proposed land uses require ongoing monitoring to ensure that only approved uses are occurring, along with appropriate water management practices being implemented (as applicable for the land use). As discussed in **Section 2**, a desktop study and site visit has highlighted that there are existing practices within the site that are not consistent with approved land uses (e.g. horse and other animal agistment within the Muchea Townsite). There are also potentially high-risk practices occurring directly adjacent to the Ellen Brook (e.g. significant scale poultry farming) which while allowable under the identified zoning for the site (agricultural resource) on the scale it appears to have been implemented requires significant water management measures (specifically waste and stormwater) be implemented and monitored. It is unclear if appropriate water management measures have been implemented or are being maintained, which poses a risk to the adjacent waterway and downstream environment.

Approval of development applications should only be provided where sufficient technical support and planning has been completed, with ongoing monitoring and maintenance committed to, to demonstrate that the land use can be supported considering the lot specific constraints (even when it is an approved land use under the planning scheme).

Recommendations for potential land use planning responses to the water management constraints of the site are discussed in **Section 11.5**.

9.2.1.2 Reserves

Identification of 'Reserves' to incorporate wetlands and waterways should be implemented through the planning process as early as possible to protect the associated assets. Reserves should encompass:

- Wetlands, waterways and foreshore areas confirmed to be present on site (see **Section 9.1**).
- Minimum buffers from CCW and REW boundaries (see **Section 9.1.2**); a 50 m buffer is generally considered to be an appropriate indicative buffer for CCW and REWs but final buffer requirements will need to be confirmed and approved by DBCA.

Land can be reserved in the Local Planning Scheme. Types of reserves can include 'Public Open Space, 'Environmental Conservation' or 'Drainage/Waterway', however the appropriate reserve classification will need to be confirmed in consideration of other needs and constraints in the area as part of the planning process. Existing 'Parks and Recreation' reserves are indicated in the LPS, located along sections of the Ellen Brook (shown in **Figure 2**).

Land can be designated as Crown Reserve. All reserves incorporating wetlands and waterways will ultimately be ceded to an appropriate agency for ongoing management and maintenance. Identification of the appropriate agency should occur as early in the planning process as possible to ensure any management plans and remediation works (where appropriate) are prepared consistent with the expectations of the relevant agency (discussed in **Section 9.2.2**). Appropriate agencies for the site include DPLH, DBCA or Shire of Chittering.

9.2.2 Management plans and licencing

Preparation of management plans demonstrating how wetlands and waterways, and associated reserves will be managed and maintained (including any potential remediation requirements) into the future are required through the planning approvals process, with varying documentation required at each stage. A number of additional licences are also required to support construction works associated with wetlands and waterways that need to be obtained prior to construction occurring. All plans and licences are the responsibility of the proponent (i.e. lot owner, developer) to prepare and secure approval for. Potential management plans and licencing required to support development impacting waterways and wetlands is summarised in **Section 10** (**Table 9**).

9.2.3 Monitoring

Monitoring of waterways and wetlands is required to ensure that their condition is maintained and any damage (e.g. erosion, sedimentation, pollution) from adjacent or upstream practices are identified early and negative impacts minimised or removed. Ongoing monitoring should include general condition assessments and water quality testing. The specific monitoring associated with each asset should be identified within overarching management plans prepared for each proposed development (discussed in **Section 9.2.2** and detailed in **Section 10**, **Table 9**), with reporting and responsibilities also confirmed.

10 Development Implementation

Should development be proposed anywhere within the site, demonstration that the proposal can adequately respond to the constraints of the site (discussed throughout this document) will be required. The scale and detail of any proposed development will determine what documentation and technical works will be required to support the proposal. This document is a high level strategic RWMS, and does not replace the requirement for more detailed documentation to support the planning approval process. Any future district structure plans or local planning schemes will need to be supported by a DWMS.

Table 9 below provides a summary of the potential management plans and/or licences that may need to be considered to support any development proposals within the site, and identifies agencies that should be engaged as part of the preparation and approvals process. This table is not exhaustive and each proposal should be reviewed and appropriate supporting documentation identified according to the site-specific constraints and development proposed, and in consideration of current policies and guidelines. It should be noted that not all items indicated in the table may be required and not all levels of planning may be relevant.

A number of technical assessments may be required to support the necessary management plans/licences depending on the level of detail available for each proposed development at the time of submission. Additional technical assessments required can be determined based on the relevant sections of this document and recommendations provided in **Section 11.5**.

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Table 9: Management plans and licencing requirements associated with water management

Planning stage	Documentation	Relevant water management component(s)	Requirements	Approval and referral agencies
Zoning (i.e. local planning schemes)	District water management strategy (DWMS)	Water resource and supply options, wastewater servicing, groundwater management, stormwater management, waterway and wetland management	Determine likely areas for land use change and any impacts on water use and management consistent with BUWM framework (WAPC 2008).	DPLH on advice from DWER, SoC and/or DBCA
	Non-drinking water supply option evaluation and concept design study	Water resource and supply options	Consider options and suitability for the source, treatment, storage and distribution of non-potable water supplies consistent with the *Guideline for the approval of non-drinking water systems in WA* (DoW 2013b). This can be summarised within DWMS.	Depending on proposal: DWER, DoH, DBCA, ERA, EPA, DPLH and/or SoC
Local structure planning	Local water management strategy (LWMS)	Water resource and supply options, wastewater servicing, groundwater management, stormwater management, waterway and wetland management	Consistent with BUWM framework (WAPC 2008), determined whether the area is capable of supporting the proposed development and what areas are required for water management.	DPLH on advice from DWER, SoC and/or DBCA
	Foreshore area report	Waterway identification and management	See **Section 9.1.1**	DWER in consultation with DBCA
	Wetland assessment report	Wetland identification and management	See **Section 9.1.2**	DBCA in consultation with DWER
	Non-drinking water preliminary design study	Water resource and supply options	Consistent with *Guideline for the approval of non-drinking water systems in WA* (DoW 2013b), determine the preferred source option, further develop the proposal and obtain advice from agencies. Can be summarised within LWMS.	DWER, DoH, DBCA, ERA, EPA, DPLH and/or SoC
	Potable drinking water supply protection plan (PDWSPP)	Water resource and reticulated supply proposal and demonstrated provider	Demonstrate feasibility of reticulated potable supply	ERA and DoH on advice from DWER
	Hydrogeological assessment	Water resource and supply options if reticulated supply proposed (in conjunction with PDWSPP).	Relevant where MAR is proposed or groundwater is the resource utilised. Demonstrate the availability of water quality and quantity including impacts of taking water in accordance with *Operational policy no. 5.12 – Hydrogeological reporting associated with a groundwater well licence* (DoW 2009b).	DWER
	Risk assessment and proposed management	Water resource and supply options	For MAR proposals in accordance with the *Australian guidelines for water recycling: managed aquifer recharge* (NRMMC *et al.* 2006).	DWER
	Site and soil evaluation	Wastewater servicing	Examine aspects of site in relation to sewerage collection, treatment and on-site disposal (DoH 2018) in accordance with *Government Sewerage Policy* (DPLH 2019) and can be summarised within DWMS.	DoH on advice from DPLH, SoC, DWER and/or DBCA
	Land capability assessment	Land use intensification	Examine site conditions in relation to soil nutrient retention capability and sustainable use of site in accordance with *evaluation standards for land resource mapping: assessing land qualities and determining land capability in south-western Australia* (van Gool *et al.* 2005).	SoC and/or DPLH on advice from DWER and/or DBCA

Table 9: Management plans and licencing requirements associated with water management (continued)

Planning stage	Documentation	Relevant water management component(s)	Requirements	Approval and referral agencies
Subdivision/development application	Urban water management plan (UWMP) or equivalent	Water resource and supply options, wastewater servicing, groundwater management, stormwater management, waterway and wetland management	Consistent with BUWM framework (WAPC 2008), demonstrate that proposed works are able to respond to the water management constraints of the site (discussed throughout this document) abd present detailed designs.	SoC on advice from DWER (if needed)
	Non-drinking water detailed design study	Water resource and supply options	Develop detailed design and required applications for approval directly to each agency as described in *Guideline for the approval of non-drinking water systems in WA* (DoW 2013b). Can be summarised within UWMP.	DWER, DoH, DBCA, ERA, EPA, DPLH and/or SoC
	Hydrogeological assessment (if not completed at structure planning)	Water resource and supply options	Relevant where MAR is proposed or groundwater is the resource utilised. Demonstrate the availability of water quality and quantity including impacts of taking water in accordance with *Operational policy no. 5.12 – Hydrogeological reporting associated with a groundwater well licence* (DoW 2011c).	DWER
	Operating strategy	Water resource and supply options	Relevant for MAR proposals, if groundwater is the proposed resource and/or if stated as a license condition, in accordance with *Operational policy 5.08 – Use of operating strategies in the water licensing process* (DoW 2011b).	DWER
	Recycled water quality management plan	Water resource and supply options, wastewater servicing	Relevant where wastewater is the proposed non-potable resource	DoH on advice from DWER (if needed)
	Site and soil evaluation	Wastewater servicing	Examine aspects of site in relation to sewerage collection, treatment and on-site disposal in accordance with *Government Sewerage Policy* (DPLH 2019) and can be summarised within DWMS.	DoH on advice from DPLH, SoC, DWER and/or DBCA
	Land capability assessment (if not completed at structure planning)	Land use intensification	Examine site conditions in relation to soil nutrient retention capability and sustainable use of site in accordance with *evaluation standards for land resource mapping: assessing land qualities and determining land capability in south-western Australia* (van Gool *et al.* 2005).	SoC and/or DPLH on advice from DWER and/or DBCA
	Foreshore, wetland and waterway management plans	Waterway and wetland management	Relevant where wetlands or waterways are identified and appropriate management and remediation measures are established	SoC in consultation with DWER and DBCA
	Works approval	Water resource and supply options, wastewater servicing	Relevant where wastewater treatment systems are proposed (above pre-approved units)	DWER, DoH
	Water quality management plan	Water resource and supply options	Relevant where rainwater or stormwater harvesting proposed as either potable or non-potable source	DoH on advice from DWER (if needed)
	Water services operating licence	Water resource and supply options, wastewater servicing	Relevant where a reticulated water supply or wastewater service is proposed	ERA
	ASS investigations/management plans	Groundwater management	Investigations may be required where groundwater is proposed to be controlled, in accordance with *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015a) and *Treatment and management of soil and water in ASS landscapes* (DER 2015b).	DWER

Table 9: Management plans and licencing requirements associated with water management (continued)

Planning stage	Documentation	Relevant water management component(s)	Requirements	Approval and referral agencies
Subdivision/development application	Construction management plans	Groundwater management, stormwater management, waterway and wetland management as pertinent to on-site construction practices	Detail proposed practices during earthworks and civil workss, lot build out etc. that will ensure no pollution of downstream receiving environment will occur prior to completion of ultimate water management measures. See *A guide for managing the impacts of dust and associated contaminants from land development sites, contaminated sites remediation and other related activities* (DEC 2011).	SoC
Construction/operation	Bed and banks permits	Waterway and wetland management	To support any works that will interfere or obstruct the bed and banks of a watercourse or wetland. Permits are granted under the Rights in *Water and Irrigation Act 1914*.	DWER
	Wastewater treatment systems	Wastewater servicing	Design and implementation of systems to be supported by relevant approvals of systems and works.	SoC and/or DoH on advice from DWER (if needed)
	Groundwater licence	Water resource and supply options	To take groundwater from proclaimed areas, recharge water for MAR, support exploratory drilling, test pumping and/or to construct a bore in accordance with DWER guidelines and policies.	DWER
	Surface water licence	Water resource and supply options	To take surface water from a proclaimed watercourse in accordance with DWER guidelines and policies.	DWER
	Building licence	Water resource and supply options, wastewater servicing, groundwater management, stormwater management, waterway and wetland management	Design and construction to be in accordance with requirements of water management documentation (minimum of subdivision/DA required).	SoC
	Licence / registration to operate premises	Water resource and supply options, wastewater servicing	Required to operate a proposed treatment plant.	DWER, ERA
	Recycled water quality management plan	Water resource and supply options, wastewater servicing	Relevant if wastewater is the resource proposed to be used. In order to use the recycled water, the final plan should verify that the system operates in accordance with agency requirements. See with *Guideline for the approval of non-drinking water systems in WA* (DoW 2013b).	DoH

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11 Muchea Industrial Precinct

This document forms a key input into the update of the MIP-SP. Consistent with the requirements of a DWMS (see **Table 9**), this section highlights the key existing environmental considerations to inform the MIP-SP layout and provides design objectives that should be met by future development within the MIP. Post-development surface runoff modelling is detailed to provide an estimate of the detention volume needed to achieve stormwater management (both quality and quantity), and a broadscale water balance for environmental assets within the MIP has been completed. These environmental considerations should be refined through further investigations and detailed in any future LWMS and UWMP documents (see **Table 9**) supporting proposed development in the MIP.

11.1 MIP structure plan

The DPLH in consultation with the MIP-SP Stakeholder Working Group are progressing an update to the MIP-SP, the layout of which will be informed by the existing environment described in **Section 3** and illustrated in **Figure 3** through **Figure 15**. Though the key constraints and opportunities that inform future structure planning (i.e. the layout) within the MIP are discussed below, additional investigations are required to confirm what environmental values are present within the MIP, their extent, any appropriate buffer requirements, and implications for structure planning.

11.1.1 Waterways

Waterways are discussed in **Sections 3.5** and **9**. There are three potential waterways within the MIP flowing from east to west, along with the Ellen Brook in the south-western portion of the site (see **Figure 18**). It should be noted that future assessments may conclude that some existing flowpaths (as shown in **Figure 11** and **Figure 12**) may also be defined as waterways. Indicative foreshore areas can be applied to waterways, as discussed in **Section 9.1.1**, until site specific investigations are completed.

11.1.2 Vegetation, ecological values and ESAs

Regional vegetation mapping, potential ecological values and ESAs are discussed in **Section 3.6**. Known locations of TECs, PECs and groundwater dependent ecosystems are likely to be encompassed by the sewage sensitive areas in **Figure 14**. An ESA is present in the south-eastern portion and along the western boundary of the MIP (shown in **Figure 18**).

11.1.3 Wetlands

Wetlands are discussed in **Sections 3.6.5** and **9**. There are two wetlands located within the MIP, a REW within the MEN LSP1 area and a CCW to the south-east (see **Figure 18**). An indicative 50 m buffer can be applied to these wetlands, as discussed in **Section 9.1.2**, unless site specific investigations are completed that demonstrate alternative buffers are required.

11.2 Design objectives and criteria

BUWM (WAPC 2008) promotes total water cycle management, which addresses not only physical and environmental aspects of water resource use, planning and management, but also integrates other social and economic concerns. The key principles of total water cycle management include:

- Considering all water sources, including wastewater, stormwater and groundwater.
- Integrating water and land use planning.
- Allocating and using water sustainably and equitably.
- Integrating water use with natural water processes.
- Adopting a whole of catchment integration of natural resource use and management.

Design criteria should therefore seek to deliver best practice outcomes in terms of the following broader objectives:

- Supply of fit-for-purpose water servicing
- Appropriate treatment of wastewater
- Maintenance of the groundwater regime
- Maintenance of surface water flows
- Maintenance of and, where possible, enhanced water quality
- Protection of environmental assets.

The design criteria of relevance to the MIP are proposed in the following sections based upon the policies and guidelines provided in **Section 1.3**.

11.2.1 Water supply conservation and wastewater servicing

Criteria WC1 Ensure the efficient use of all water resources.

Criteria WC2 Ensure appropriate treatment of wastewater from lots is provided in consideration of ultimate lot use.

Criteria WC3 Use appropriate fit-for-purpose water supply sources for the proposed land use.

11.2.2 Groundwater management

Criteria GW1 Finished floor levels of building areas will have clearance to MGL of at least 500 mm.

Criteria GW2 Inverts of WSUD measures, surface and/or subsoil drains will be set in accordance with relevant guidelines (DoW 2013f) and SoC requirements.

Criteria GW3 Where utilised, subsoil drains should have a free draining outlet and be treated prior to discharge offsite.

Criteria GW4 Groundwater quality leaving the site should be the same, or better, than the groundwater entering the site.

11.2.3 Stormwater management

Criteria SW1 Treat small rainfall event runoff from constructed impervious surfaces within lots, where practical.

Criteria SW2 Treat small rainfall event runoff from constructed impervious surfaces within road reserves, where practical.

Criteria SW3 Detain flows from major rainfall events within the boundary of each lot to maintain the existing peak flow rates leaving the site.

Criteria SW4 Detain flows from major storm events from road reserves within the development boundary to maintain the existing peak flow rates across the site.

Criteria SW5 Convey existing arterial flows through the site at existing peak flow rates.

Criteria SW6 Maintain existing inflow and outflow locations (i.e. culverts and waterways).

Criteria SW7 Minor roads must remain passable in the minor rainfall event.

Criteria SW8 Finished floor levels to have a 500 mm clearance from the top water level of the major drainage system, waterways and terminal retention or detention areas with no overflow relief in major rainfall events.

Criteria SW9 Finished floor levels to have a 300 mm clearance from the road drainage system during major rainfall events.

Criteria SW10 Design WSUD measures to avoid creating mosquito habitat.

Criteria SW11 Apply appropriate non-structural measures to reduce pollutant loads.

11.2.4 Waterway and wetland management

The principles behind wetland and waterway management are to maintain the existing hydrological regime and ensure protection of water quality. Therefore, design criteria listed above are also relevant to the successful management of these environmental values. As the 1 exceedance per year (EY) event is important to maintaining the form and hydrology of receiving water bodies, an additional design criteria that should be considered if a waterway or wetland is located within or downstream of the site is:

Criteria WW1 Maintain existing peak flow rates and total volume runoff discharging from the site in the critical 1 EY event.

However, this criteria will not be applicable to all waterways and wetlands, which will be determined by the waterway and/or wetland assessment (outlined in **Section 9**). For example, detention of runoff within waterways (above the small rainfall event) is a common stormwater management approach when the waterway has low ecological values and would not be required to meet criteria WW1.

The design criteria proposed for the MIP can be achieved by applying the appropriate management measures already detailed in **Sections 5** through **9**.

11.3 Surface runoff modelling

A post-development surface runoff model for the MIP has been completed to estimate requirements for structural stormwater management measures, in addition to the waterways, foreshore areas, wetlands and wetland buffers already discussed. This demonstrates how implementation of a WSUD strategy can maintain the existing hydrological regime and protect downstream infrastructure and environments from flooding.

The MIP has been divided into a number of post-development catchments based upon the location of existing inflows and outflows, waterways, wetlands, flowpaths and MEN LSP 1 (development of which has commenced prior to drafting of this document). It is assumed that the waterways, wetlands, and their associated foreshore areas and buffers (as discussed in **Section 11.1**) will not be developable for industrial purposes. Given an update to the MIP-SP is being progressed and an internal road reserve layout is still to be determined, the remainder of the MIP is assumed to be industrial (see **Figure 18**). The MEN LSP 1 area has not been included in this assessment, as this has already been completed for this area (see **Section 11.5** below). Upstream catchments, post-development catchments and existing environmental values are shown in **Figure 18**. Post-development catchment land use assumptions are discussed in **Appendix E**.

The allowable peak flow from each catchment in the major rainfall event are assumed to be the cumulative peak flow along the boundary, that is the sum of: peak flows within culverts, over road reserves, discharging into a waterway or floodplain, and/or across the MEN LSP1 boundary. These allowable peak flows have been taken from the critical duration major rainfall event (i.e. the 48 hour duration that is critical to the Ellen Brook, which was discussed in **Section 3.5.2**) and are shown in **Figure 18** and **Appendix E**.

The detention volumes required to be provided within each catchment to achieve allowable peak flow rates are shown in **Figure 18** and **Appendix E**. The detention volumes are in addition to treatment of the small rainfall event, which is required to occur as close to source as possible (e.g. within a lot boundary) to manage stormwater quality (see **Section 8.2**).

The post-development surface runoff model has assumed that runoff within Ct-08 and Ct-11 will be fully retained to be consistent with the existing environment. For runoff from these catchments to be allowable, detailed investigations would need to demonstrate that additional runoff will not significantly impact downstream environmental values and/or infrastructure.

Site-specific post-development hydrological modelling should be completed to support any future structure planning and/or subsequent development stages. It is expected that the waterways, wetlands, and their associated foreshore areas and buffers will be refined as part of future assessments (see **Section 9**). It is also anticipated that the broad catchment assumptions outlined in **Appendix E** will be refined when local scale modelling is completed. This would account for the final MIP-SP layout (i.e. more detailed land uses) and other additional technical assessments (e.g. vegetation, geotechnical). It is likely that the critical duration rainfall event for local scale models will differ from the critical duration event applicable to Ellen Brook (i.e. the 48 hour). Nevertheless, it is the responsibility of the proponent to demonstrate that site-specific post-development hydrological modelling is comparable to the modelling presented within this RWMS.

11.4 Environmental asset water balance assessment

The environmental assets within the MIP most likely to be protected from development (subject to site specific investigations) are the three east-west waterways, the two wetlands and Ellen Brook indicated in **Figure 18**. A broadscale water balance for the MIP has been completed in **Table 10** to '*inform the determination of hydrologic regimes of water dependent ecosystems to be protected*', as outlined in BUWM (WAPC 2008) and *Guidelines for DWMS* (DoW 2013c).

Table 10 highlights the key existing environmental considerations, potential impacts that may occur due to the proposed change in land use from agricultural to industrial, and outlines management / mitigation options to be considered (note this is not an exhaustive list). At structure planning, a more detailed water balance should be completed for any identified asset (DoW 2008a) to demonstrate that changes to the regime have been avoided or minimised post development.

This water balance should include:

- Existing water balance considering all elements highlighted in **Table 10** based upon site specific investigations (see **Section 3** and **4**).
- Outline of proposed design approaches, and management and mitigation measures relevant to the asset.
- Mass water balance to estimate any changes to the existing hydrologic/hydrogeologic regime and assessment of any residual impacts.

Table 10: MIP broadscale water balance

Element	Existing environmental considerations	Potential impacts	Potential management / mitigation options
Rainfall	• Direct rainfall on environmental asset (e.g. conservation category or resource enhancement wetland) • Rainfall on upstream surface water / groundwater catchments	• Direct rainfall may reduce commensurate with reduction in asset area • Climate change may change rainfall patterns, but no other potential impacts due to land use change	• Maintain asset area (e.g. do not clear area identified as asset)
Evapotranspiration	• Direct evapotranspiration from asset • Evapotranspiration within upstream surface water / groundwater catchments	• Direct evapotranspiration may reduce commensurate with reduction in asset area • Clearing of existing pasture / trees within upstream surface water / groundwater catchments may decrease evapotranspiration from these areas	• Maintain asset area (e.g. do not clear area identified as asset)
Recharge	• Direct recharge to groundwater • Recharge within upstream surface water / groundwater catchments based upon local geology, soil, vegetation etc.	• Direct recharge may reduce commensurate with reduction in asset area • Recharge within upstream surface water / groundwater catchments may decrease due to increase in impervious area • Recharge within upstream surface water / groundwater catchments may increase due to implementation of infiltration systems • Water supply using rainwater or stormwater harvesting within upstream surface water / groundwater catchments may reduce recharge • On site disposal of wastewater may increase recharge	• Maintain asset area (e.g. do not clear area identified as asset). • Mimic existing infiltration processes (e.g. use detention and conveyance stormwater management measures where infiltration is low, and wastewater discharge onsite is proposed). • Consider the requirement for environmental flows if using rainwater or stormwater harvesting for water supply.

Table 10: MIP broadscale water balance (continued)

Element	Existing environmental considerations	Potential impacts	Potential management / mitigation options
Surface water inflows	• Inflows from upstream surface water catchments within waterways and through culverts informed by surface runoff model • Overland inflows from upstream surface water catchments informed by surface runoff model	• Development (e.g. layout, use of sand fill etc.) can reduce or prevent existing inflows from entering the asset • Runoff entering asset can increase due to increase in impervious area • Water supply using rainwater harvesting, stormwater harvesting or surface water extraction within upstream surface water / groundwater catchments may reduce inflows	• Maintain existing culverts • Maintain waterways within a foreshore reserve and wetlands within a buffer • Ensure existing flow paths are able to enter asset (e.g. avoid diverting upstream flows away from asset) • Meet stormwater quality and quantity management requirements (e.g. treat runoff prior to entering an asset) • Consider the requirement for environmental flows if using rainwater or stormwater harvesting for water supply.
Surface water outflows	• Outflows within waterways and downstream culverts informed by surface runoff model • Overland outflows informed by surface runoff model	• Development (e.g. layout, use of sand fill etc) can reduce or prevent existing outflows discharging from the asset	• Maintain existing culverts • Maintain waterways within a foreshore reserve and wetlands within a buffer • Ensure existing outflows are able to discharge from asset (e.g. allow outflows from asset to enter downstream stormwater management measures)
Groundwater inflows	• Inflows from upstream groundwater catchments	• Development (e.g. low permeability grading etc.) can reduce or prevent existing upstream inflows towards the asset • Water supply using groundwater abstraction within upstream groundwater catchments may reduce inflows to asset	• Meet groundwater quality and quantity management requirements (e.g. avoid diverting groundwater inflows away from the asset) • Ensure groundwater abstraction allocations and bore construction are approved by relevant authority
Groundwater through-flow and outflows	• Groundwater through-flow beneath asset or discharging from the asset	• Development (e.g. use of subsoil drains etc.) can alter groundwater levels and through-flow beneath the asset • Water supply using groundwater abstraction may alter groundwater levels within/beneath the asset	• Meet groundwater quality and quantity management requirements (e.g. ensure subsoil drainage inverts do not lower groundwater within assets) • Ensure drawdown from abstraction bores minimises the impact on groundwater levels within the asset

11.5 MEN Local Structure Plan 1

The MEN LSP 1 area is shown in **Figure 18**. LSP 1 has progressed through structure planning with additional detailed site-specific investigations completed to support the process, including:

- Site specific pre-development groundwater and surface water monitoring.
- Calibrated localised pre-development surface runoff modelling, which included a critical duration analysis based on upstream inflows into LSP 1.
- A comprehensive waterway and wetland assessment.
- Other technical assessments (e.g. geotechnical investigations) to characterise the pre-development environment.

The key constraints and opportunities shown in **Figure 18** within the MEN LSP 1 area are based upon the regional scale assessments outlined throughout this document. For LSP 1, the regional assessments have been superseded by the more detailed investigations completed for LSP 1.

12 Recommendations and Considerations

Broad land use management, monitoring and ongoing maintenance recommendations for the site are outlined below based upon the assessment of the existing land uses and environment, potential development within the MIP and wider site area, and the servicing and water management measures outlined within this document. The recommendations summarised in the following sections are in addition to (not in place of) the approvals and design considerations typically applied to developments proposed throughout the planning process (detailed in **Section 10**, **Table 9**). The below recommendations have been assigned to the agency that would typically undertake the work however, these are subject to resource allocation and capacity.

12.1 Further investigations

12.1.1 Monitoring

As discussed in **Section 3.4.3** and **3.5.3**, data relating to water quality and levels (groundwater and surface water) is limited across the site. The lack of data means a clear baseline for existing water quality, levels and flows is not available and the true impacts of development occurring is difficult to understand.

12.1.1.1 Regional monitoring program

Ideally, a regional monitoring program should be progressed that allows the identification of regional-scale changes between existing and post-development parameters. Ongoing monitoring with sufficient spatial coverage would enable identification of water quality changes and potential point sources for further investigation.

While large scale development will be concentrated within the MIP, smaller development or land use change is likely to occur across the site. Therefore it is recommended that any monitoring program should be extended across the Muchea RWMS site area.

It is acknowledged that any regional monitoring program would require significant funding and need to be managed by a single agency/group, with a single database maintained and accessible to support development proposals at all scales, which may not be feasible at this time. However, the benefit of progressing a regional program would be significant in supporting ongoing land use change and development across the Muchea RWMS site area.

Given the current and proposed land uses associated with the site (see **Section 2**), nutrients and pesticides (associated with agricultural areas) and trace elements (associated with industrial areas) are considered to be a key concern and should be included in any proposed monitoring program. Proximity to potential pollutant sources such as contaminated sites and wastewater disposal locations should also be considered (see **Section 3.3.2** and **4.2** respectively).

Any monitoring progressed for the site should aim to include the elements identified in **Table 111**.

Table 11: Monitoring requirements

Monitoring type	Monitoring element	Key data	Frequency	Location
Groundwater	Levels	Winter peaks and seasonal variability	Monthly	Across the site, specifically within areas mapped as < 5 m to groundwater (**Figure 8**).
	Quality	Ongoing quality concentrations and variability: nutrients, trace metals, pesticides, alkalinity, standard field chemistry	Quarterly	
Surface water	Levels	Winter peaks and seasonal variability	Monthly/Quarterly	Significant waterways (upstream and downstream locations) and wetlands (CCW and REW)
	Quality	Ongoing concentrations and variability	Quarterly	
	Peak flows	Base flows and peak flows in response to significant rainfall events	Quarterly and in response to rainfall events	Key control points within significant waterways (including Ellen and Chandala Brooks).
Environmental assets	Condition	Base line and ongoing condition: vegetation, sedimentation, pollution	Annually	Significant waterways (Ellen and Chandala Brooks at minimum) and wetlands (REW and CCW)

The inclusions and frequency of monitoring can be refined dependent on funding and resourcing available.

12.1.1.2 Localised monitoring

Should a regional monitoring program not be progressed (or additional, more detailed spatial coverage of individual lots be deemed to be required) localised monitoring needs to be conducted by the proponent to support any development proposals.

The DWER guidelines (DoW 2012b) relating to the monitoring required to support development include:

- A minimum of 18 months existing (prior to development) site monitoring including two winter periods.
- Post-development monitoring over 24 months, prior to handover of assets to appropriate agencies.
- Monitoring elements and frequency consistent with details provided in **Table 111**.
- Additional monitoring may be required dependent on works proposed e.g. monitoring during construction itself (i.e. ASS), to be identified as part of CMP (discussed in **Table 9**).

Proposal specific monitoring should be detailed in the appropriate management plans supporting planning and development applications (detailed in **Section 10**, **Table 9**), and used to inform development design and identify required management measures. Funding and completion of localised monitoring to support development is the responsibility of the proponent.

Smaller development applications relating to minor works within existing land uses may not require such significant monitoring to support proposals, depending on the extent of works proposed and constraints of the lot in question. Applications should be reviewed on a case by case basis utilising design constraints identified in this document to determine the need for site specific monitoring.

12.1.2 Surface runoff modelling and flood mapping

As discussed in **Section 3.5.3**, surface runoff modelling has been completed to identify the current surface runoff flowpaths and flooded areas across the site. The modelling completed to date has not been formally calibrated to site-specific conditions (i.e. measured flow rates and levels at key control points), though it has been compared to historical data and flood modelling where available.

12.1.2.1 Regional modelling

It is recommended that the regional model (prepared to inform this document) be calibrated through inclusion of measured flow rates at key control points associated with specific rainfall events (i.e. 20% AEP or greater if possible) and the flood mapping and peak flow information (provided in the modelling summary report, **Appendix E**) updated accordingly.

12.1.2.2 Localised modelling

Future development proposals will need to appropriately consider surface flowpaths and flooding on their property and appropriate management of the associated risks (discussed in **Section 8**). Additional surface runoff modelling may be required to demonstrate existing conditions at a finer lot scale. Post-development runoff modelling may also be needed to identify the necessary stormwater management measures to maintain the existing hydrological regime (specifically within the MIP). The responsibility for lot scale modelling rests with the proponent.

12.1.3 Additional technical assessments

As discussed throughout this document, the risk of development is dependent on the specific proposals and constraints of the area in which the proposed development lies. In addition to the investigations discussed above, other investigations required may include:

- Geotechnical investigations (of an appropriate scale) to understand soil and geological conditions within the proposed development area to inform proposed wastewater, groundwater and stormwater management approaches.
- Lot/site-specific flora and fauna surveys may need to be considered where potential environmental assets (discussed in **Section 3.6**) are located within or adjacent to the proposed development.
- Wetland and waterway assessments (as discussed in **Section 9.1**) will need to be completed if such assets are present within the development to inform the proposed design.

- A land capability assessment may be required to support land use change or intensification of agricultural practices (specifically where direct nutrient loading to soils and groundwater can occur e.g. crop production, cattle farming) (van Gool *et al.* 2005). Where animals are present (i.e. horses, cows, sheep etc.) a stocking rate assessment should be provided to demonstrate the number of proposed animals the land can sustainably support through a 'dry sheep equivalent' assessment (van Gool *et al.* 2000).

All of these investigations would be the responsibility of the proponent as required following consultation with DPLH and/or SoC on advice from DWER and/or DBCA.

12.2 Land use management

There are a number of existing land uses, as well as proposed land use changes, that pose a risk to the environmental assets and water quality across the site. In order to minimise the ongoing risk and impact of land uses within the Muchea RWMS site area the following land use management considerations are recommended:

- Non-compliant land uses should be identified through review against *TPS No. 6* (SoC 2004) (some of which are discussed in **Section 2.2** and shown on **Figure 2**), and reassessed in consideration of the site constraints and risks posed by the land use activities detailed throughout this document. Seek to remove land uses that are determined to be incapable of responding to land use constraints through appropriate water management measures. It is recognised that implementation of such a review will be dependent on practical limitations and resourcing capacity of the Shire and practicalities of implementing systems.
- Intensification of agriculture (including broadscale agriculture and intensive farming) should not be approved within the incompatible and restricted on-site wastewater risk areas shown in **Figure 16** due to increased nutrient loading from fertiliser application and/or stock access. Exceptions should only be considered where a detailed land capability assessment is provided that demonstrates that the land is capable of sustainably supporting the proposed intensification/practice.
- Minimum residential lot sizes should be compliant with the *Government Sewerage Policy* (DPLH 2019) where on-site wastewater disposal is proposed (i.e. a minimum of 1 ha lot size in sewage sensitive areas, shown in **Figure 15**), and TPS 6 (SoC 2004) and LPP 2 (SoC 2005) updated accordingly.

12.3 Water supply and wastewater servicing

As discussed in **Sections 5** and **6**, the risks associated with a reticulated water supply or wastewater servicing solution are significantly lower than lot-scale and/or on-site systems. The feasibility of these occurring across the Muchea RWMS site area is low given the need for a licenced provider to construct and operate reticulated solutions. Therefore, it is anticipated that lot-scale water supply solutions and on-site wastewater disposal systems will continue to be utilised across the site until such time as a reticulated option may become available.

With the exception of groundwater abstraction, lot-scale water supply systems are generally regulated and approved by SoC (see **Section 5.1.1**). It is recommended that the location of all groundwater abstraction bores proposed for potable water supply be assessed and approved by the SoC. Similarly, on-site wastewater disposal systems are also generally approved by SoC (e.g. within a building licence application). The assessment of all lot-scale water supply options and on-site wastewater solutions needs to consider the constraints outlined throughout this document in a holistic manner (e.g. to ensure abstraction bores are located away from any ATU).

12.4 Record keeping and auditing

As discussed throughout **Sections 5** through **9**, there are a number of management measures and technologies that can help to respond to site constraints and risks posed by development whilst still allowing development to occur. All of the measures and technologies detailed require a measure of ongoing maintenance to ensure they continue to perform as needed.

One issue highlighted as part of the desktop and site assessment for the Muchea RWMS area is a lack of understanding of management measures (including infrastructure and technologies) currently being used across the site and no process for tracking newly approved systems. On this basis, the following auditing and compliance practices are recommended.

12.4.1 Approved systems database

An auditing and compliance database should be implemented by the SoC (as primary approval authority of DAs and building licences) to track the technologies and infrastructure approved and constructed across the site in response to water management (specifically water quality). The database should include details relating to:

- Wastewater systems – ATUs, septic systems, bespoke on-site wastewater treatment systems, detention/treatment basins.
- Potable water supply – groundwater bores, rainwater tanks, treatment units (where required).
- Stormwater management – GPTs, detention basins, treatment basins/swales, conveyance swales.
- Groundwater management – subsoil networks, groundwater control/treatment swales.

All systems should have the necessary management and maintenance requirements indicated including frequency of review.

It is acknowledged that set-up of a database will involve funding however the improved tracking and auditing of systems will better facilitate development across the Muchea region. All newly approved systems should be included within the database. Where existing approved land uses are in place, an understanding of existing systems/technologies/practices should be obtained and incorporated within the database and compliance system accordingly.

12.4.2 Compliance auditing

Once systems are identified within the database a compliance auditing system should be utilised to ensure ongoing compliance of approved systems is being demonstrated by proponents. Demonstration of compliance could be in the form of certification by qualified technicians (e.g. ATU maintenance), provision of reports detailing the maintenance tasks completed and/or photographic evidence of condition (e.g. treatment basins).

A compliance system should put the onus on the proponents/lot owners to provide the required information consistent with approvals with a reminder notification provided by the SoC where information is outstanding. As with the system database, a compliance system would require funding (both to set-up, and to manage notifications and follow-ups) but would allow for more targeted policing of proponents that do not provide appropriate demonstration of compliance, and better identification of point sources of pollution. High risk areas that should be prioritised are detailed in the following sections.

12.4.2.1 Lot-scale rainwater harvesting and/or groundwater abstraction

Where potable water is proposed to be supplied by rainwater harvesting and/or groundwater abstraction, annual monitoring of water quality is recommended (DoH 2019c). This should include chemical quality and microbiological tests (usually included within a standard drinking water laboratory analysis suite). Comparison should be made against the *Australian Drinking Water Guidelines* (NHMRC and NRMMC 2017).

12.4.2.2 On site wastewater systems

Without an appropriate tracking and compliance audit system, approving on-site wastewater systems within restricted areas (shown in **Figure 16**) adds significant risk.

DoH and the University of Western Australia (UWA) have produced a report outlining the current maintenance requirements for ATUs and greywater treatment systems in WA. The report, *Review of the Regulatory Requirements for the Maintenance of Aerobic Treatment Units and Greywater Treatment Systems in Western Australia* (the ATU Review) (McGrath *et al.* 2015) provides recommendations that, when implemented, are expected to ensure effluent quality standards are reliably and consistently met. The ATU Review found that the existing guidelines were generally satisfactory and when followed, the current maintenance program works well. However, a significant proportion of surveyed responses from Local Government environmental health officers, manufacturers and service technicians indicated inadequate monitoring, maintenance and reporting was occurring for various reasons including: inconsistent and out of date procedure, lack of funding and resources, or lack of education for owner/operators. As ATUs are electrical and mechanical systems, they require consistent servicing to maintain a sufficient treatment standard. The most common cause of ATU failure was cited to be incorrectly installed and/or maintained irrigation systems.

Not implementing regular audit and compliance procedures may ultimately drive a recommendation for not allowing onsite wastewater systems to be approved across the site (specifically in incompatible and restricted areas shown in **Figure 16**) due to the detrimental impacts of such systems not being maintained and discharging to the environment. This would be a significant restriction to any future development/land use change across the site, including in the MIP.

12.4.2.3 Existing systems

Where existing systems are found to be inadequate for the risk they pose (based on the details presented in this document) retrofitting of appropriate measures and implementation of management practices is recommended, with ongoing maintenance records provided to SoC as part of compliance procedures (pending implementation of an appropriate auditing system, subject to practical limitations and resource capacity of the Shire). This includes demonstrating the land is capable of sustainably supporting the land use through a land capability assessment (discussed in **Table 9**) and/or stocking rate assessment (discussed in **Section 12.1.3**) where animals are kept.

13 Conclusion

High level investigations over the site have identified existing constraints and issues across the site including:

- High groundwater levels and seasonal inundation occur across the majority of the site.
- A number of significant waterways and wetlands are located across the site, along with other environmental assets including TECs and PECs.
- Large surface water flooded areas occur following minor and major rainfall events.
- Limited water supply and wastewater servicing options exist due to the location and constraints of population/land uses across the site.
- A significant gap in monitoring data exists both spatially and temporally, in levels and quality of surface water and groundwater.

Development within the Muchea RWMS site area needs to address the data gap and consider the environmental constraints and risk posed by potential water management measures, especially in relation to water quality (groundwater and surface water).

Most risks can be managed through implementation of appropriate management measures however ongoing maintenance of systems is key to ensuring the protection of water quality and environmental assets into the future. Development of the MIP can be supported subject to appropriate design and ongoing maintenance of water management measures (as discussed throughout this document).

Ongoing compliance auditing of land use practices, management systems and technologies is required to adequately address the long-term risks of both existing and proposed development in the area. Implementation of compliance auditing will be subject to resourcing capacity within the Shire and practicalities of implementing systems.

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Figures

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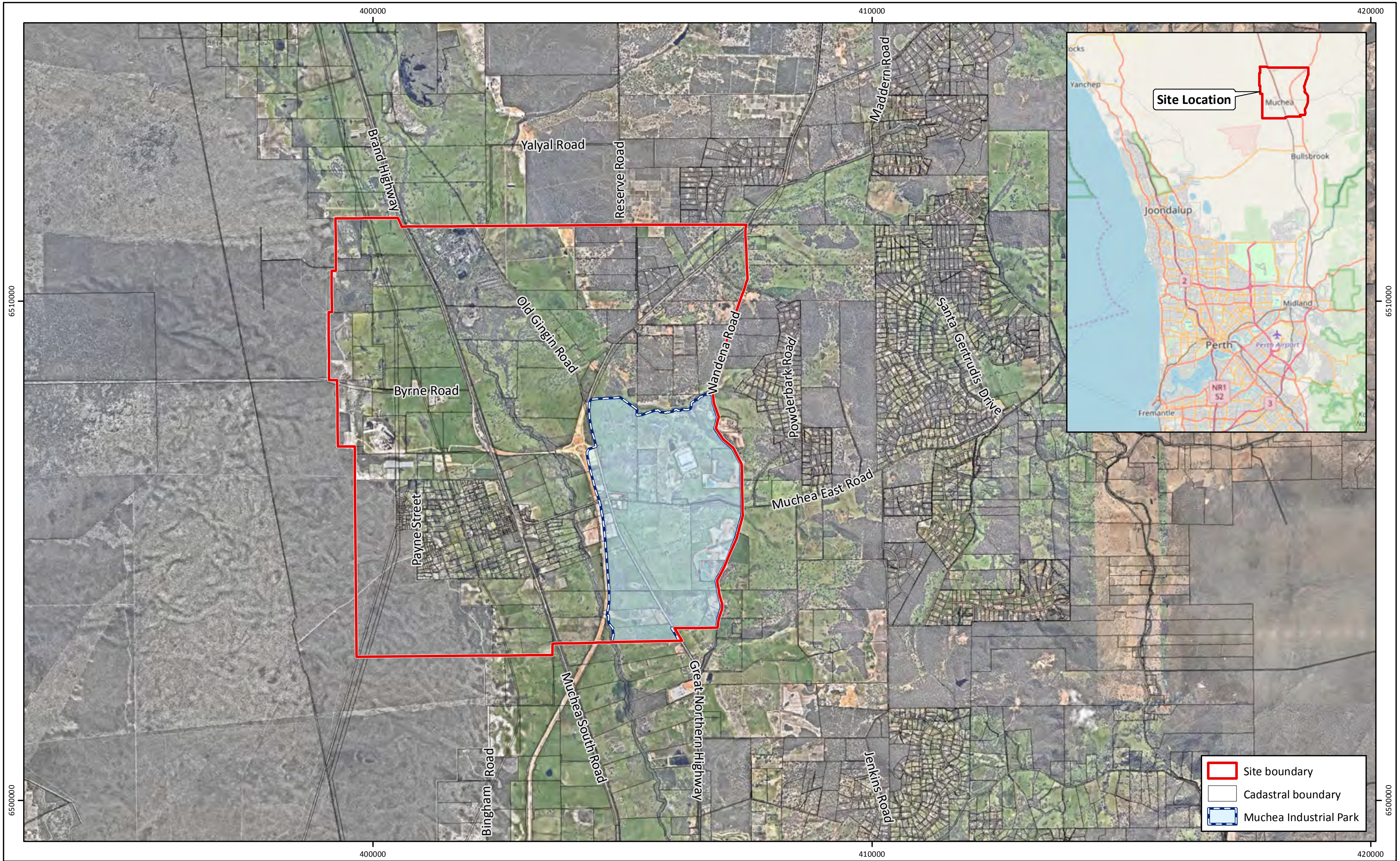

Figure 1: Location Plan

Project: Regional Water Management Strategy
Muchea

Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F02
Drawn: MGB
Date: 06/12/2018
Checked: ASC
Approved: RLE
Date: 06/06/2019

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Kilometres
Scale: 1:100,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

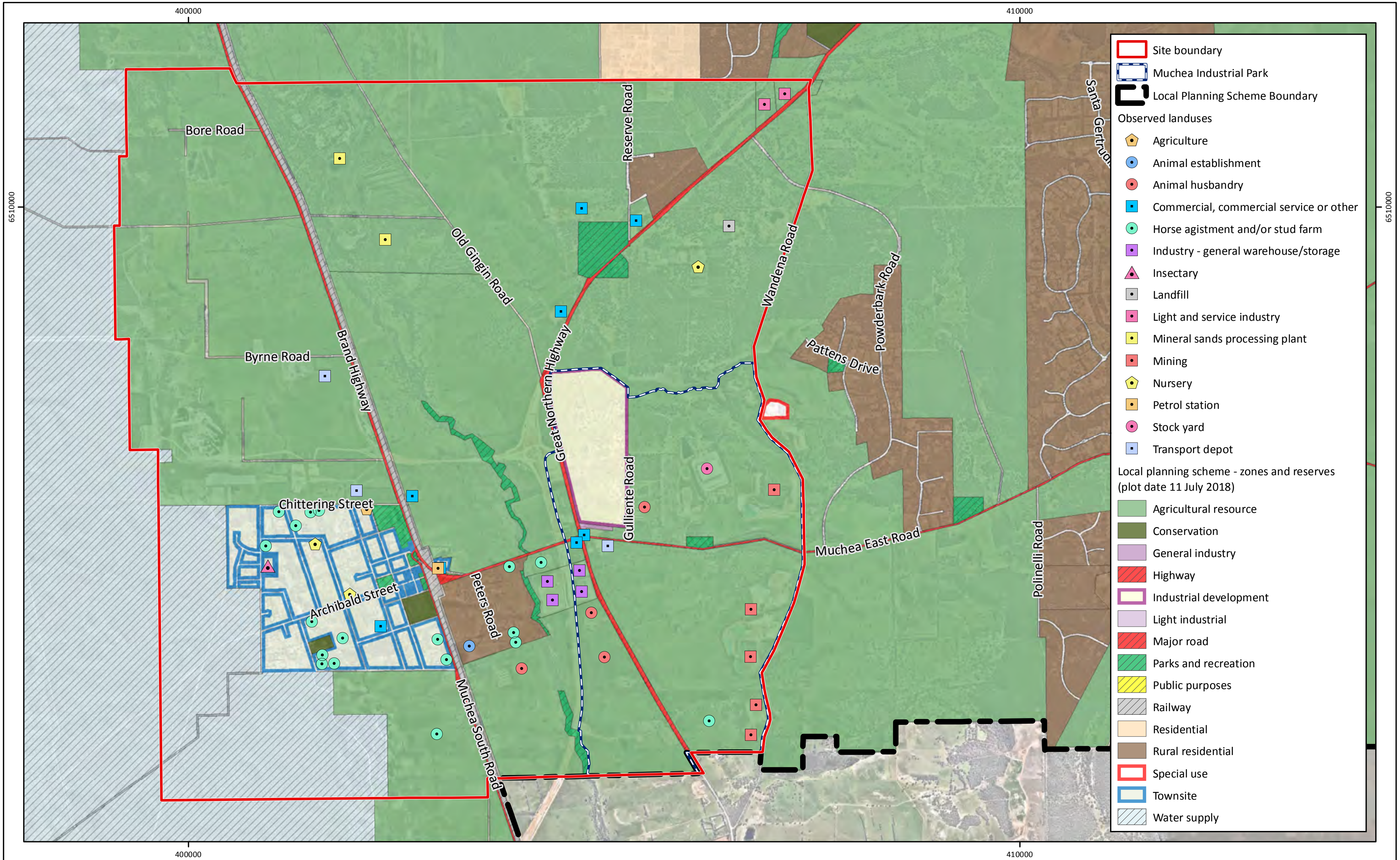

Figure 2: **Local Planning Scheme Zones and Reserves and Observed Landuses**

Project: Regional Water Management Strategy Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: EP18-104(02)--F03a
Drawn: GAR
Date: 19/07/2019
Checked: ASC
Approved: RLE
Date: 30/07/2019

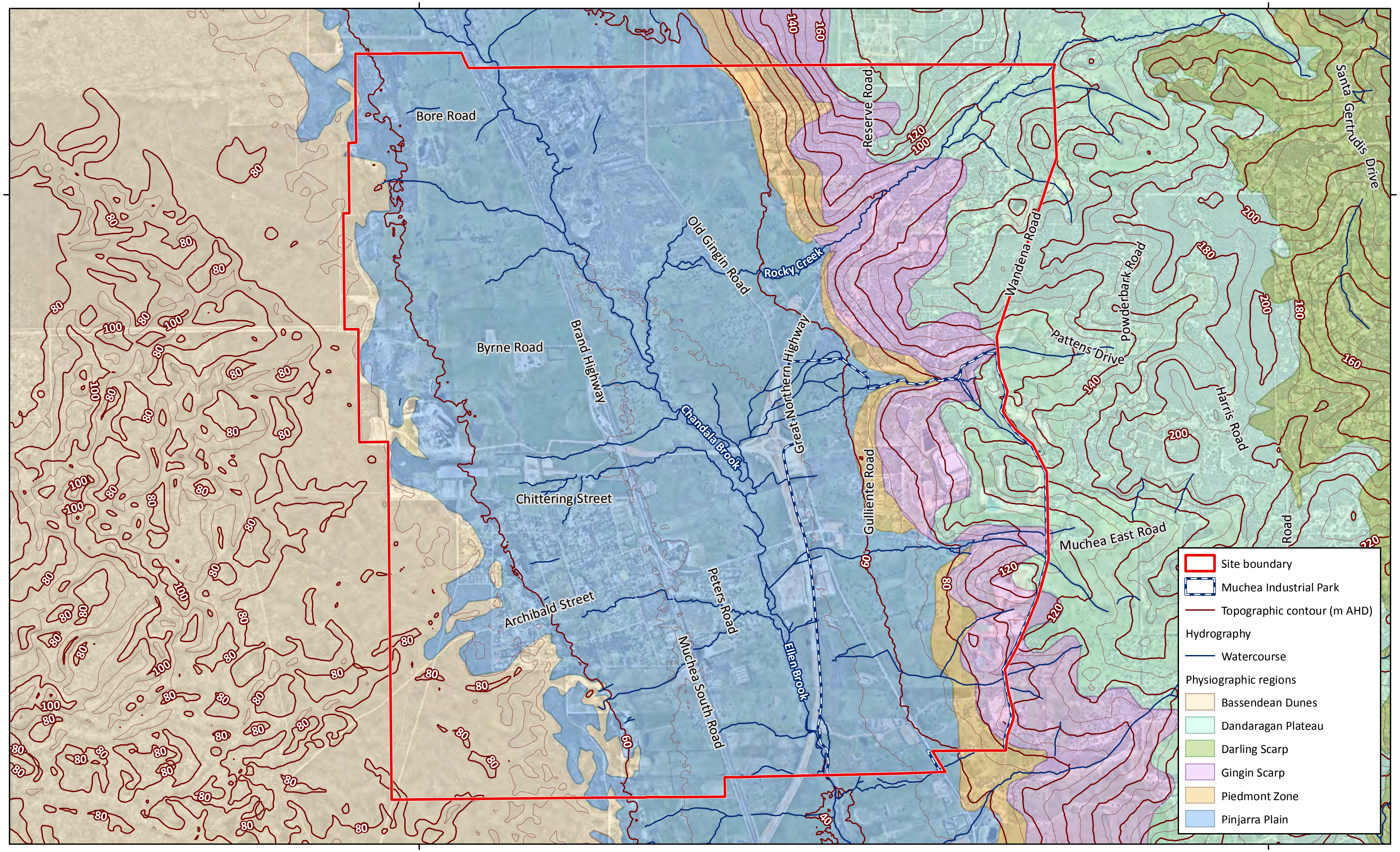

Figure 3: **Landform and Topography**

Project: Regional Water Management Strategy Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: **EP18-104(02)--F04**
Drawn: MGB
Date: 06/12/2018
Checked: ASC
Approved: RLE
Date: 06/06/2019

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Kilometres
Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

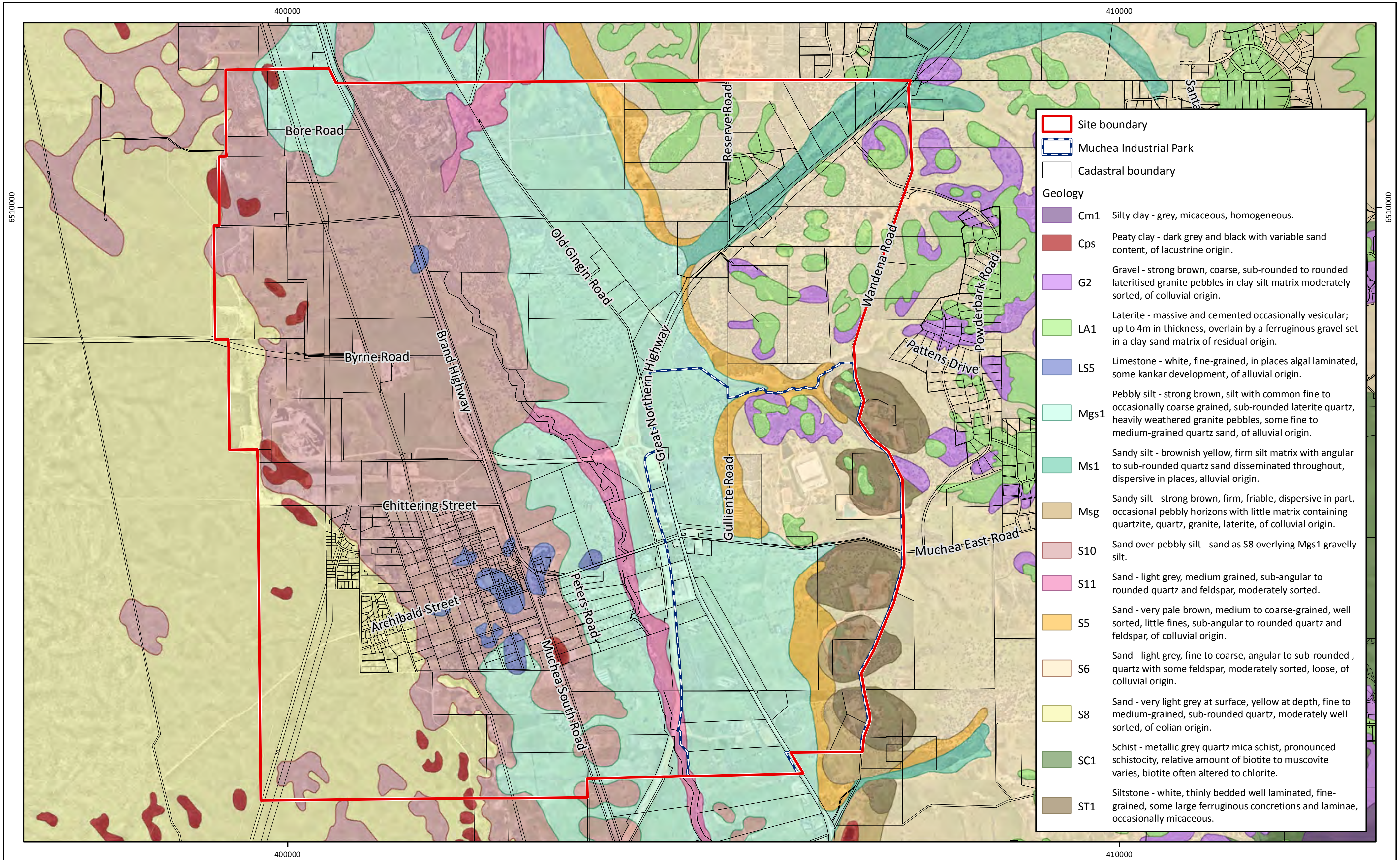

Figure 4: Geological Mapping

Project: Regional Water Management Strategy
Muchea

Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F05
Drawn: MGB
Date: 06/12/2018
Checked: ASC
Approved: RLE
Date: 06/06/2019

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Kilometres
Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

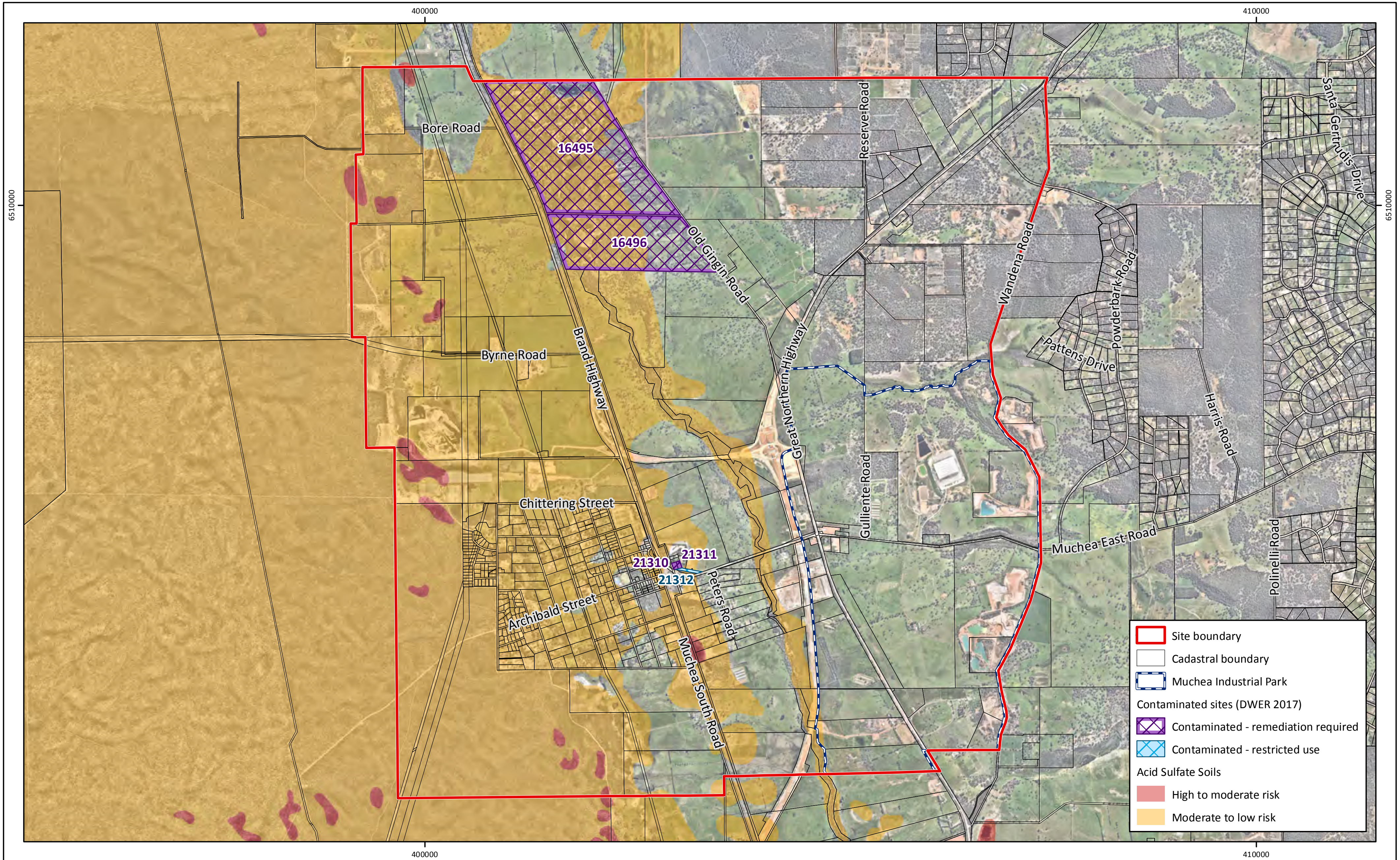

Figure 5: **Acid Sulfate Soil Risk Mapping and Contaminated Sites**

Project:	Regional Water Management Strategy Muchea
Client:	Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F07

Drawn:	KNM
Date:	07/12/2018
Checked:	ASC
Approved:	RLE
Date:	06/06/2019

Scale: 1:60,000@A4

GDA 1994 MGA Zone 50

emerge ASSOCIATES

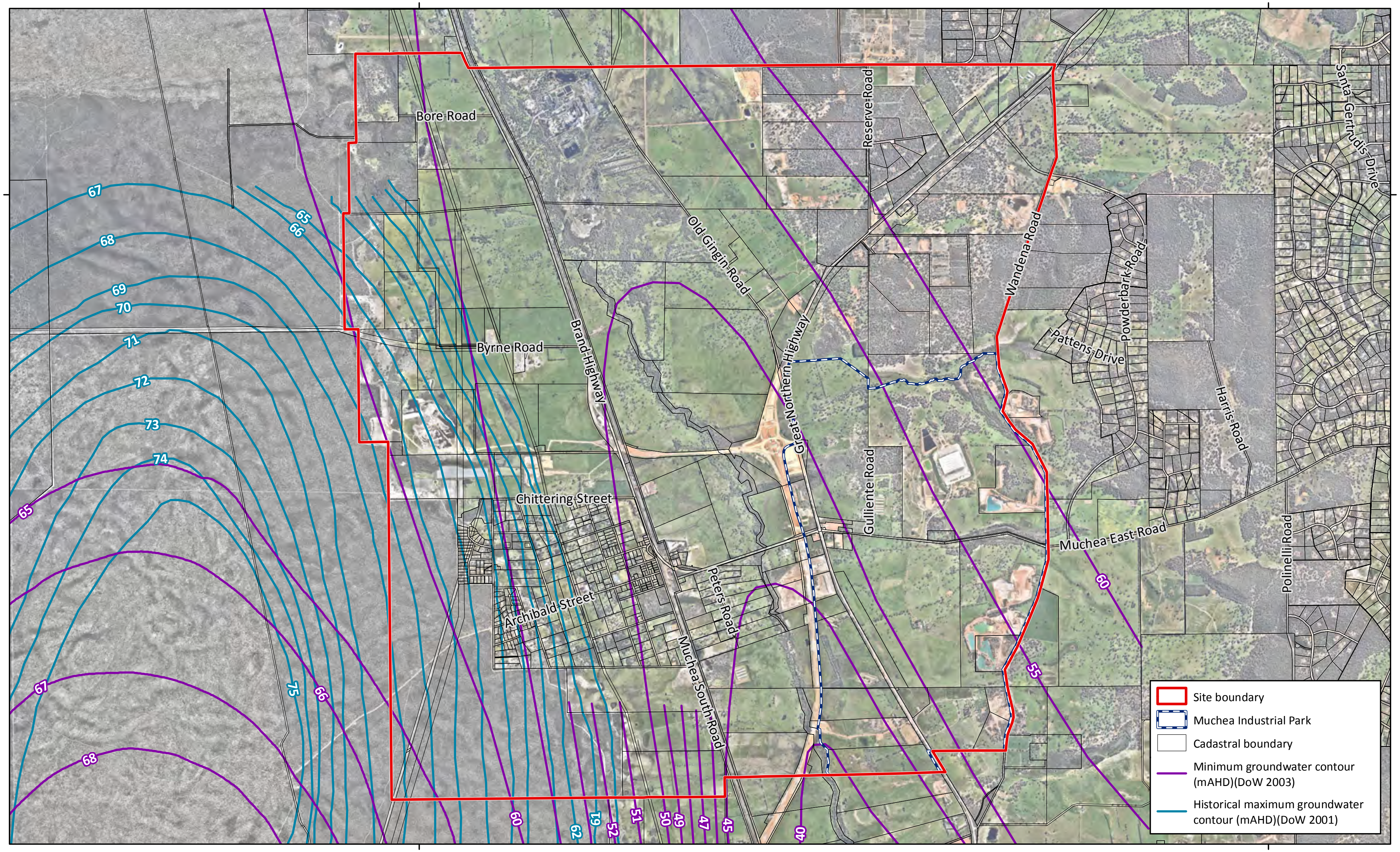

Figure 6:	**Historical Groundwater Contours**
Project:	Regional Water Management Strategy Muchea
Client:	Department of Planning, Lands and Heritage

Plan Number: EP18-104(02)--F16
Drawn: KNM
Date: 04/04/2019
Checked: ASC
Approved: RLE
Date: 06/06/2019

N

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Kilometres
Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

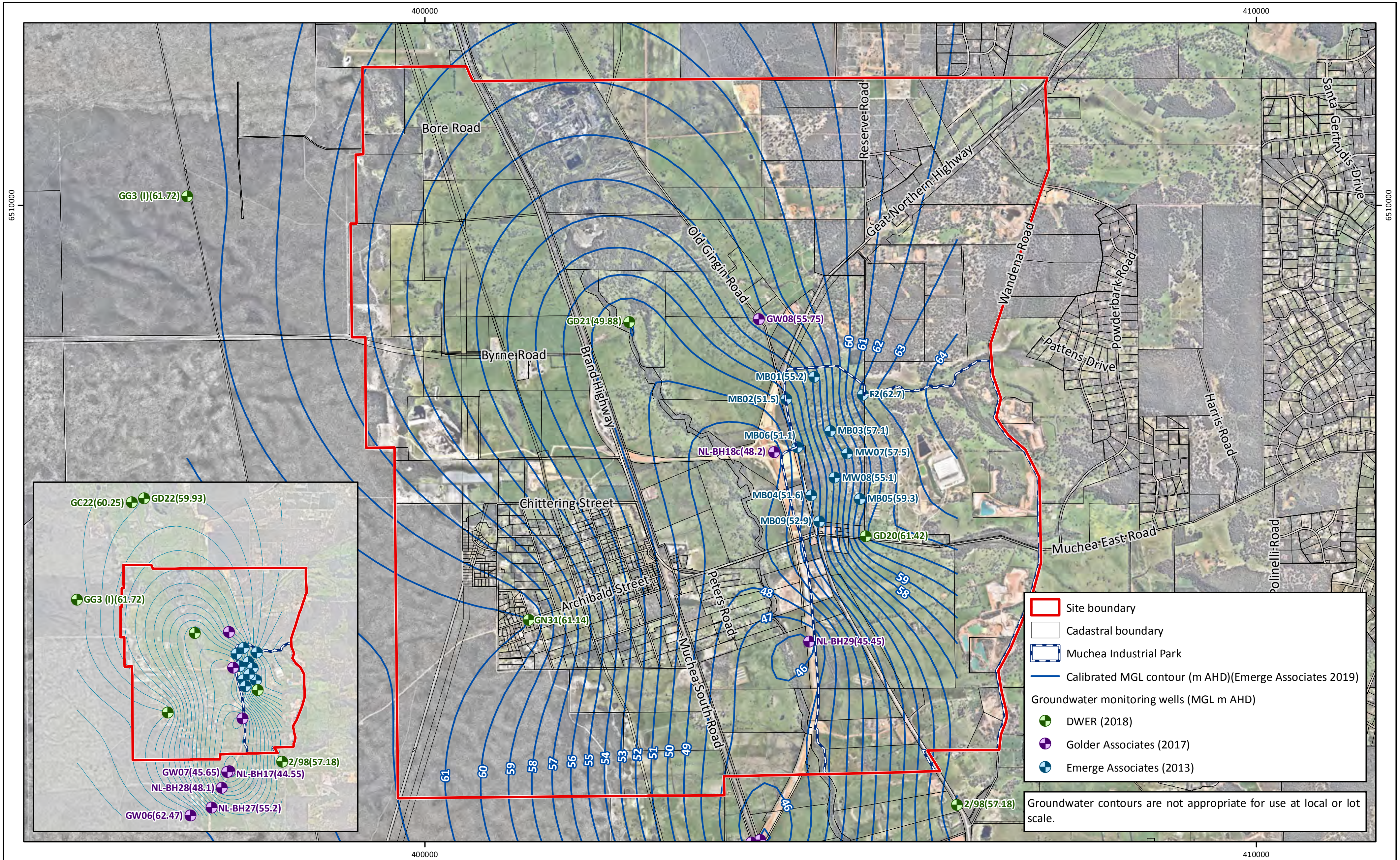

Figure 7: **Calibrated Groundwater Contours and Bore Locations**

Project: Regional Water Management Strategy
Muchea

Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F08
Drawn: KNM
Date: 07/12/2018
Checked: ASC
Approved: RLE
Date: 06/06/2019

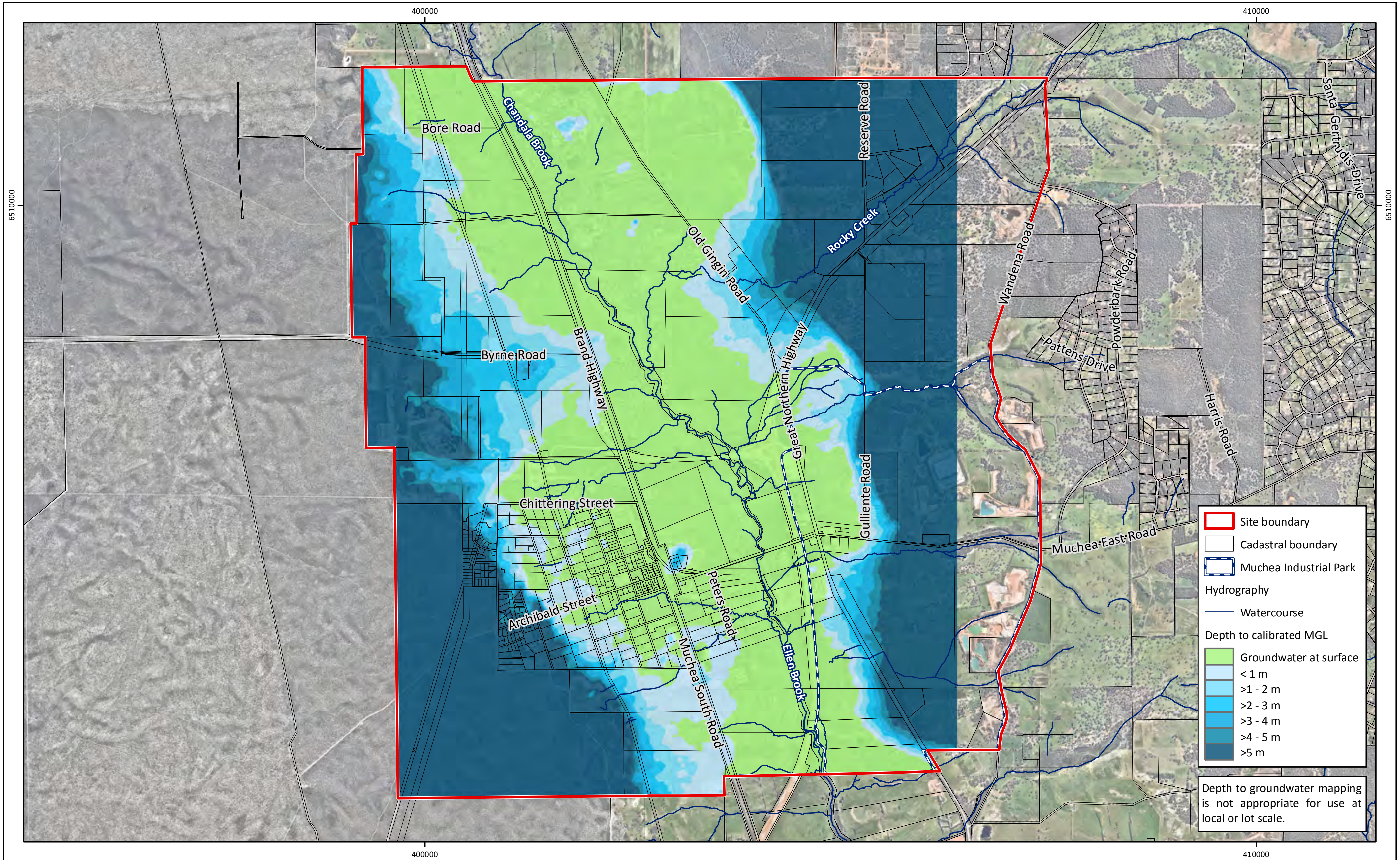

Figure 8: **Depth to Groundwater**

Project: Regional Water Management Strategy Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: **EP18-104(02)--F09**
Drawn: KNM
Date: 07/12/2018
Checked: ASC
Approved: RLE
Date: 06/06/2019

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Kilometres
Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

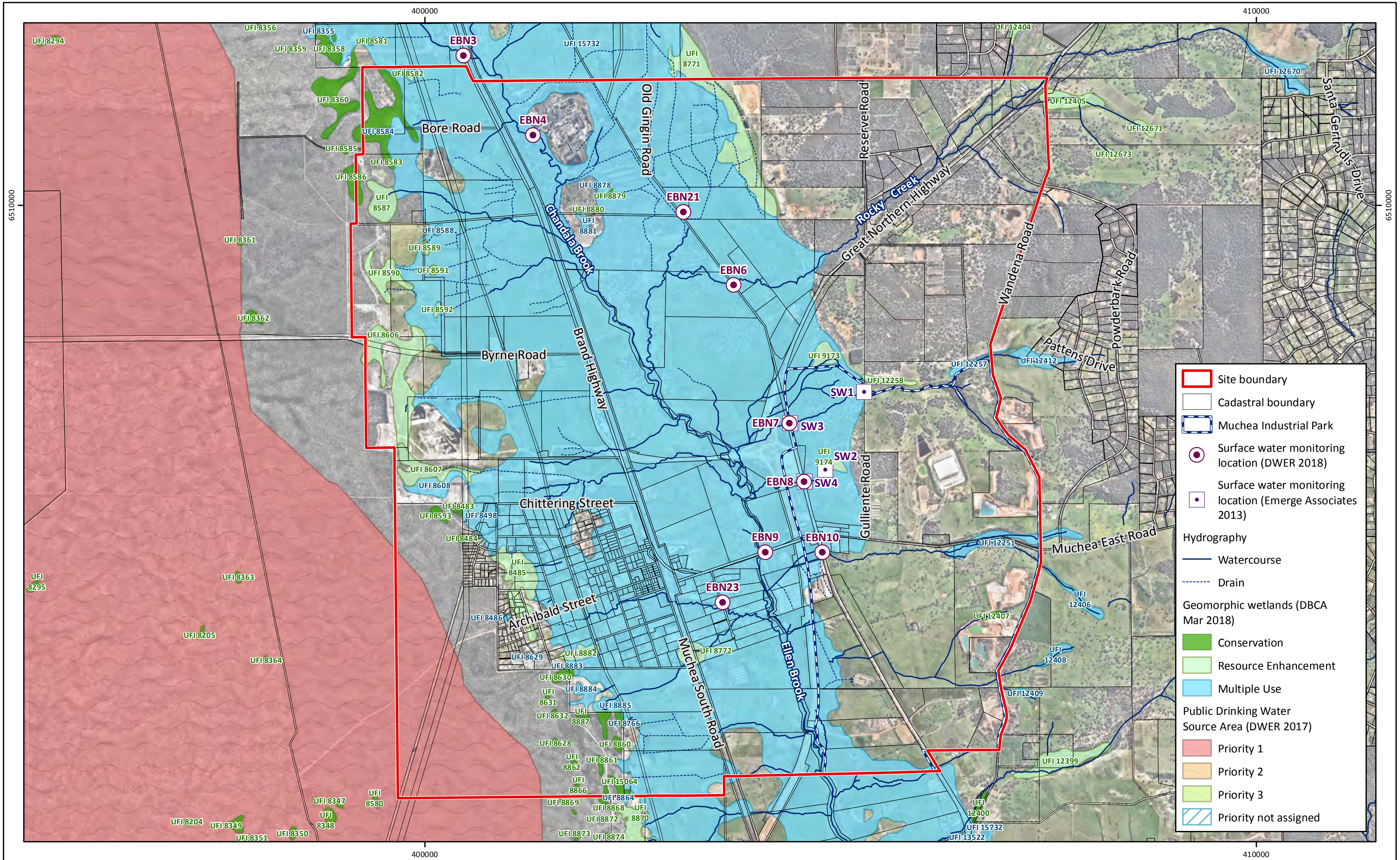

Figure 9: **Hydrological Features**

Project:	Regional Water Management Strategy Muchea
Client:	Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F10

Drawn:	KNM
Date:	07/12/2018
Checked:	ASC
Approved:	RLE
Date:	06/06/2019

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Plate 1: Muchea South Road 4 – culvert headwall on western side.


Plate 2: Muchea South Road 4 – looking west from culvert at upstream streamline.


Plate 3: Muchea South Road 3 – looking south towards culvert.


Plate 4: Muchea South Road 3 – culvert headwall on western side.


Plate 5: Muchea South Road 2 – culvert headwall on western side.


Plate 6: Muchea South Road 2 – looking north from culvert at roadside drain.


Plate 7: Muchea South Road 2a – looking east towards railway culverts and low-lying land.


Plate 8: Muchea South Road 1 – culvert headwalls on western side.


Plate 9: Muchea South Road 1 – looking north-west towards streamline.


Plate 10: Archibald Street 1 – roadside swales within Muchea townsite.


Plate 24: Wandena Road 1 – culvert on western side.

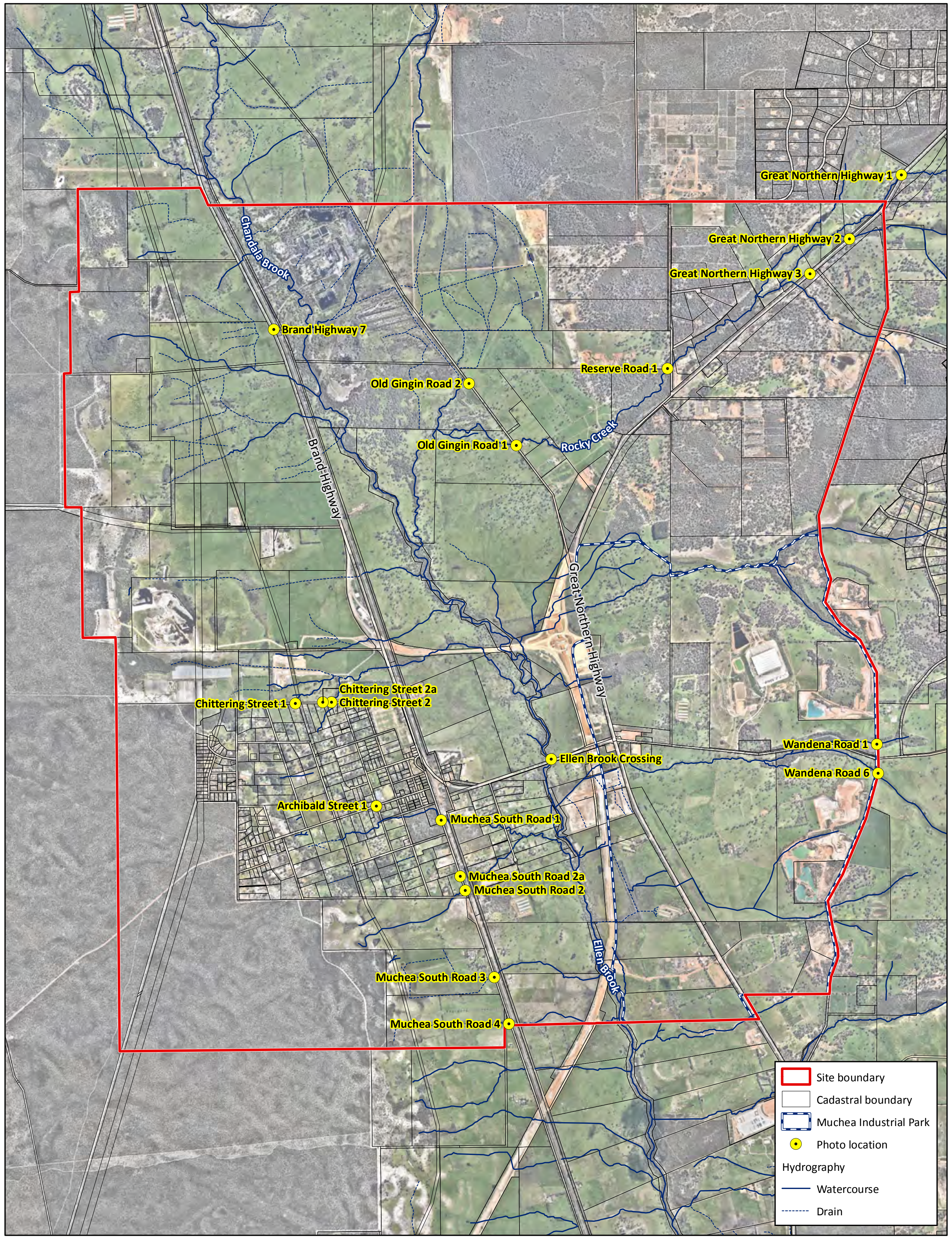


Plate 11: Chittering Street 1 – culvert and roadside swales on southern side.


Plate 18: Old Gingin Road 1 – looking west towards existing drain.


Plate 12: Chittering Street 2 – looking west towards culverts and roadside swale.


Plate 19: Old Gingin Road 2 – culverts on eastern side.


Plate 13: Chittering Street 2a – culverts on northern side.


Plate 20: Reserve Road 1 – looking towards Reserve Road along existing streamline.


Plate 14: Chittering Street 2a – looking south towards existing drain.


Plate 21: Great Northern Highway 2 – culverts headwall on northern side.


Plate 15: Brand Highway 7 – culvert headwall on eastern side.


Plate 22: Great Northern Highway 1 – culverts on northern side.


Plate 16: Ellen Brook Crossing.


Plate 23: Great Northern Highway 3 – culvert headwall on northern side.


Plate 17: Old Gingin Road 1 – culvert on western side.


Plate 25: Wandena Road 6 – looking south towards kerb breaks and culvert.

Figure 10: Site Visit Photo Points and Key Drainage Features

Project: Regional Water Management Strategy
Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: EP18-104(02)--F17
Drawn: KNM
Date: 04/04/2019
Checked: ASC
Approved: RLE
Date: 06/06/2019

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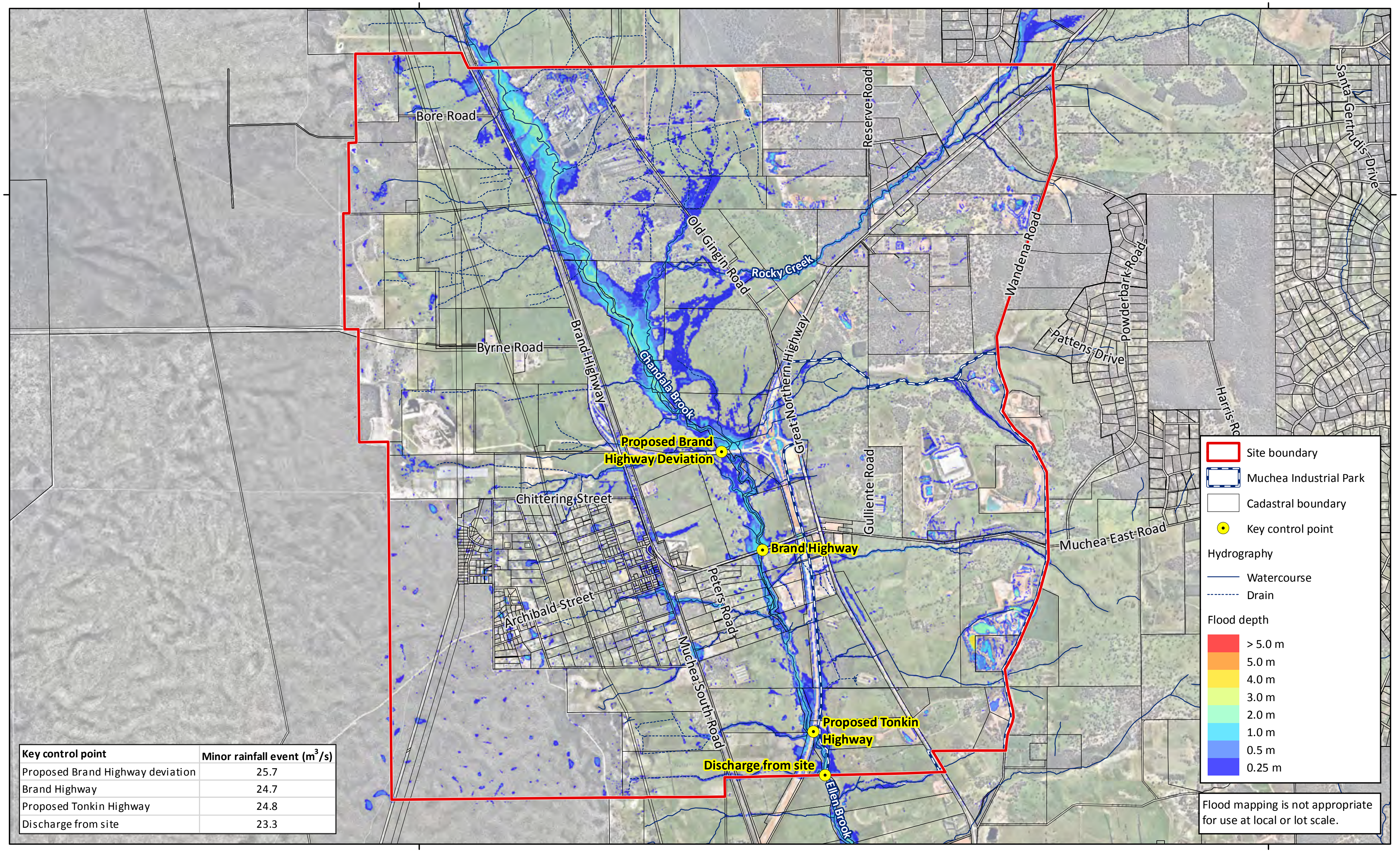
Scale: 1:50,000@A3
GDA 1994 MGA Zone 50

emerge ASSOCIATES



Key control point	Minor rainfall event (m^3/s)
Proposed Brand Highway deviation	25.7
Brand Highway	24.7
Proposed Tonkin Highway	24.8
Discharge from site	23.3

Figure 11: **Minor Event Flood Mapping (10% AEP 48 hour)**

Project: Regional Water Management Strategy Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: EP18-104(02)--F11a
Drawn: KNM
Date: 28/06/2019
Checked: ASC
Approved: RLE
Date: 19/07/2019

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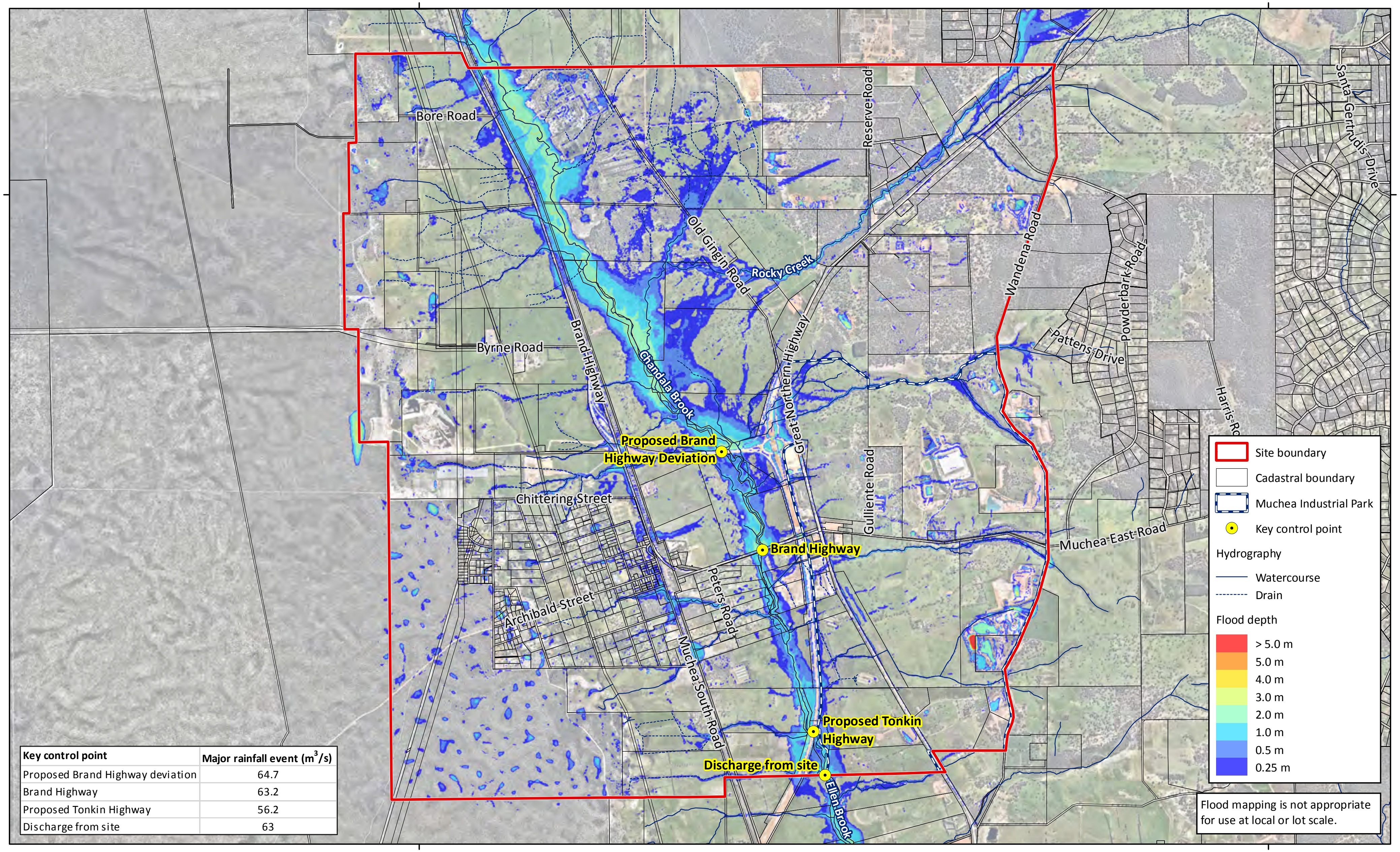
emerge ASSOCIATES



Key control point	Major rainfall event (m^3/s)
Proposed Brand Highway deviation	64.7
Brand Highway	63.2
Proposed Tonkin Highway	56.2
Discharge from site	63

Figure 12: **Major Event Flood Mapping (1% AEP 48 hour)**

Project: Regional Water Management Strategy Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: EP18-104(02)--F20a
Drawn: KNM
Date: 28/06/2019
Checked: ASC
Approved: RLE
Date: 19/07/2019

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Kilometres
Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

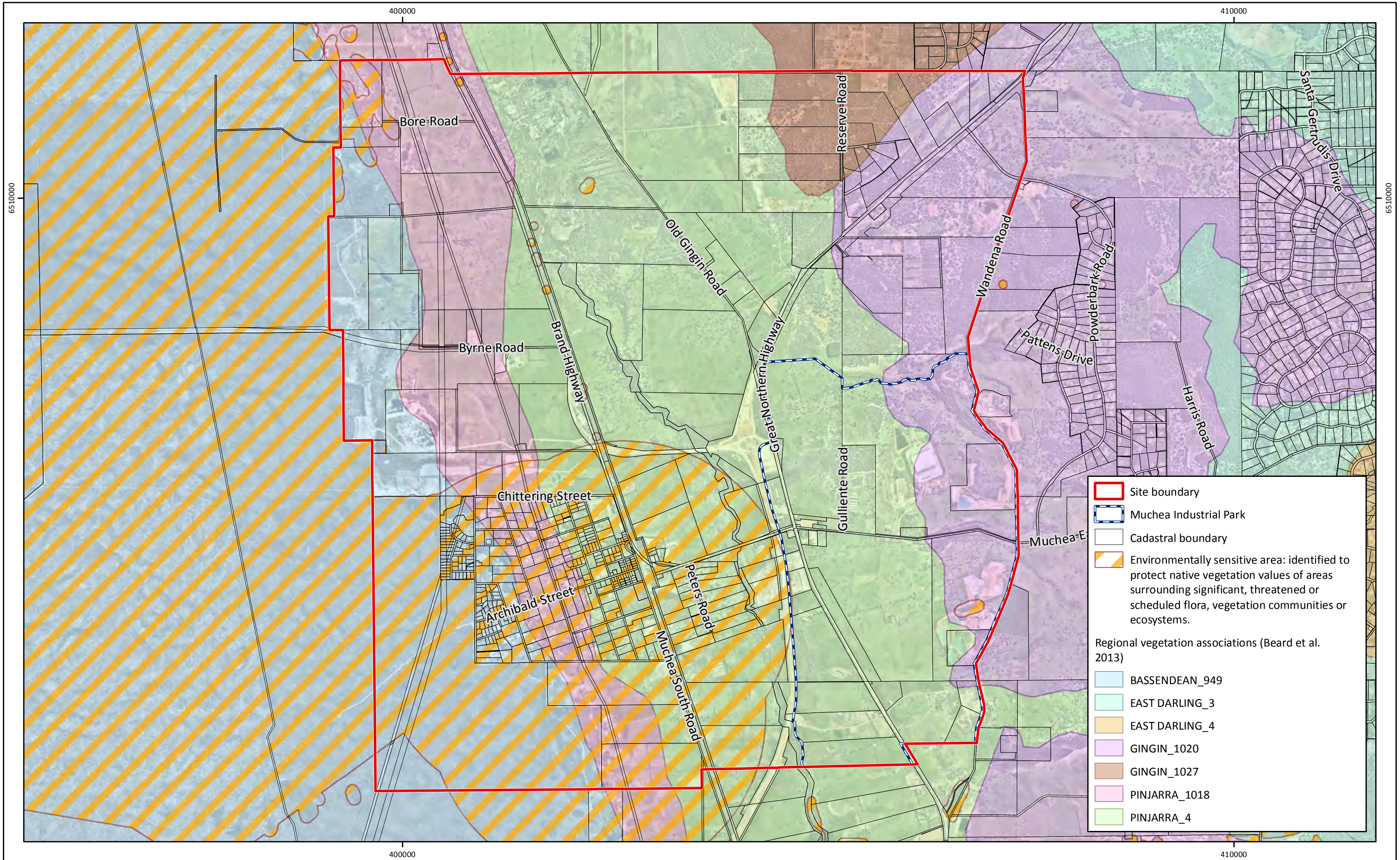

Figure 13: **Vegetation Mapping**

Project: Regional Water Management Strategy
Muchea

Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F12a
Drawn: KNM
Date: 07/12/2018
Checked: ASC
Approved: RLE
Date: 06/06/2019

N

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Kilometres
Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

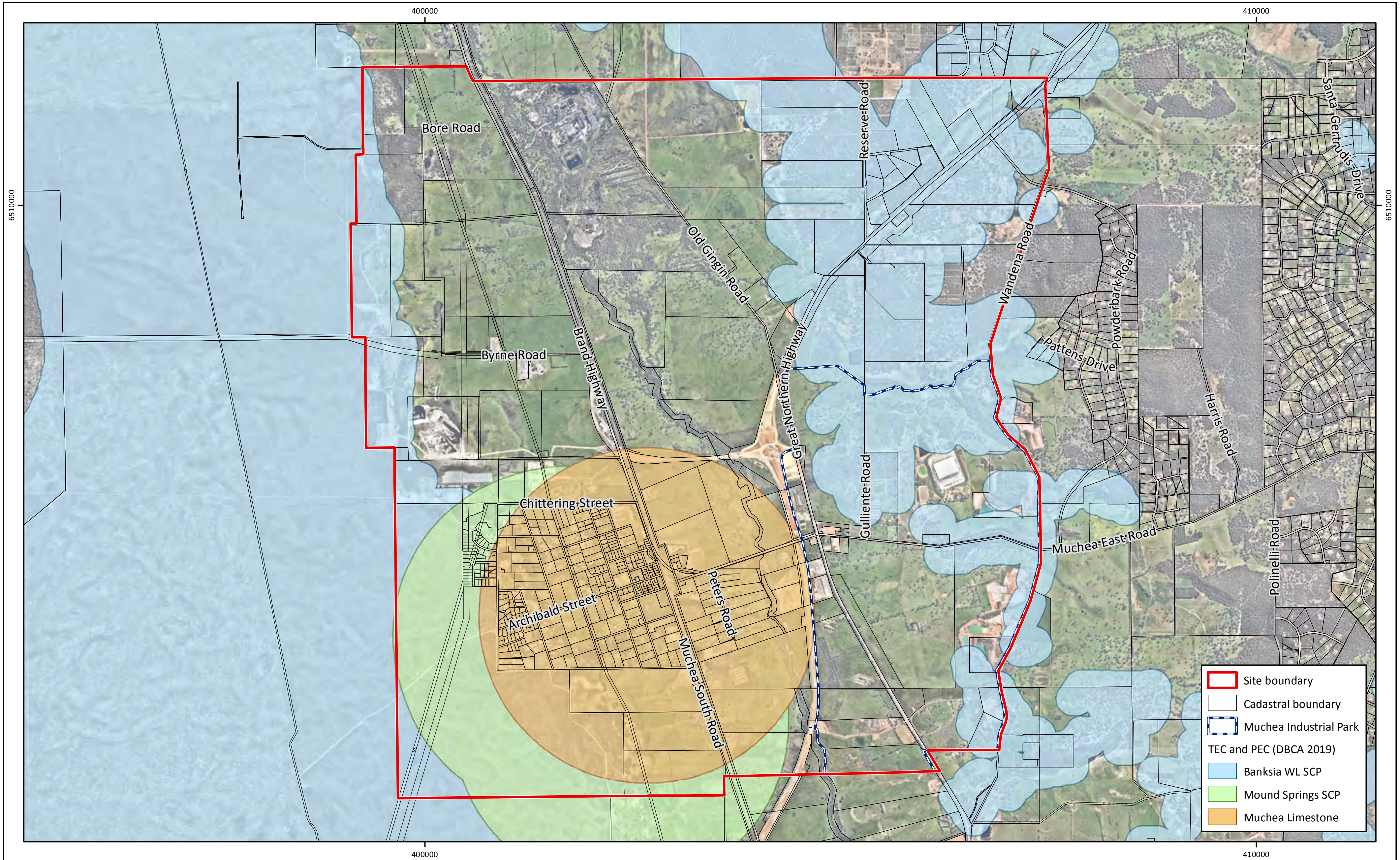

Figure 14: Threatened and Priority Ecological Communities

Project: Regional Water Management Strategy
Muchea

Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F18
Drawn: KNM
Date: 01/05/2019
Checked: ASC
Approved: RLE
Date: 06/06/2019

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Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

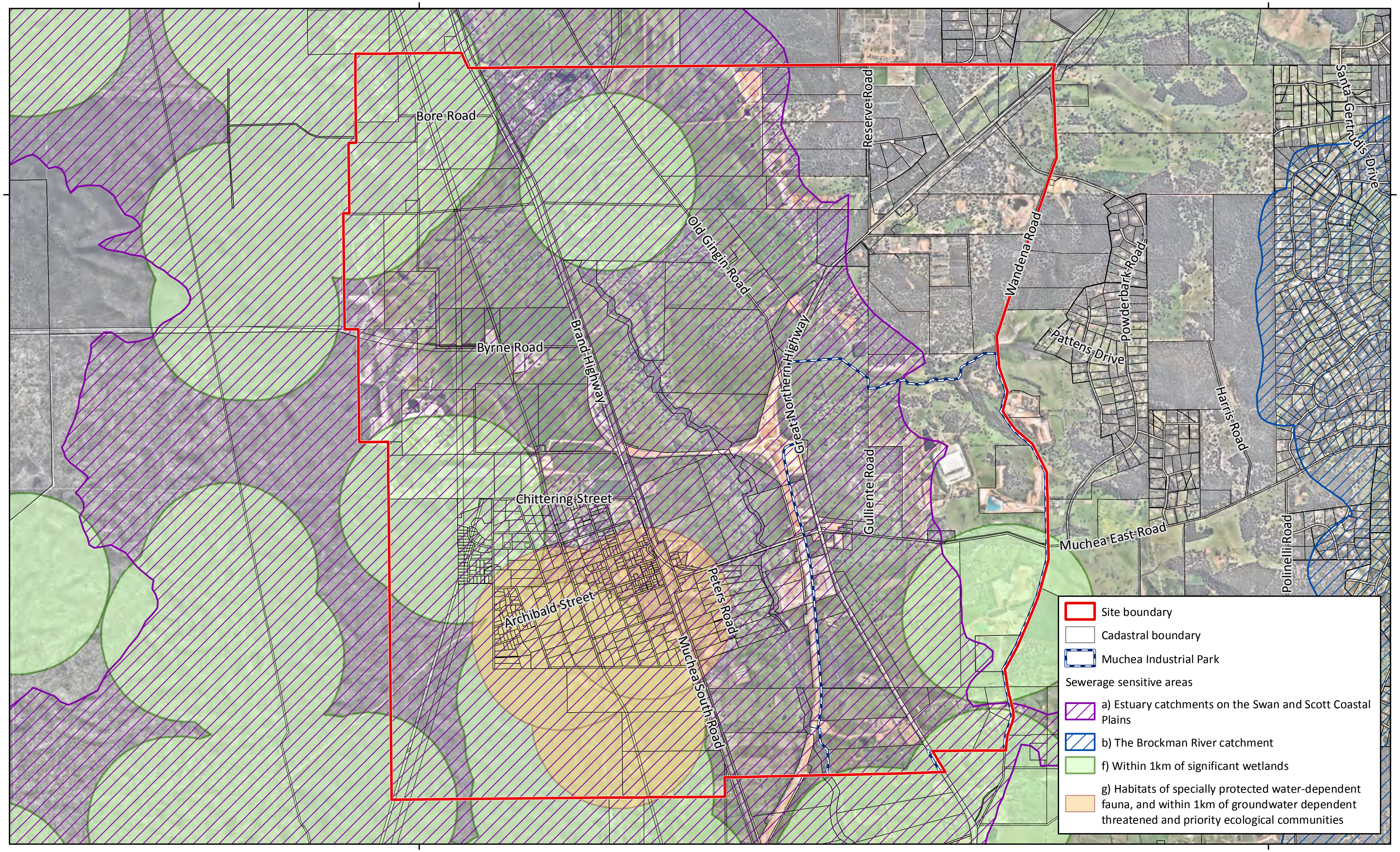

Figure 15: Sewerage Sensitive Areas

Project: Regional Water Management Strategy Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: EP18-104(02)--F06
Drawn: MGB
Date: 06/12/2018
Checked: ASC
Approved: RLE
Date: 06/06/2019

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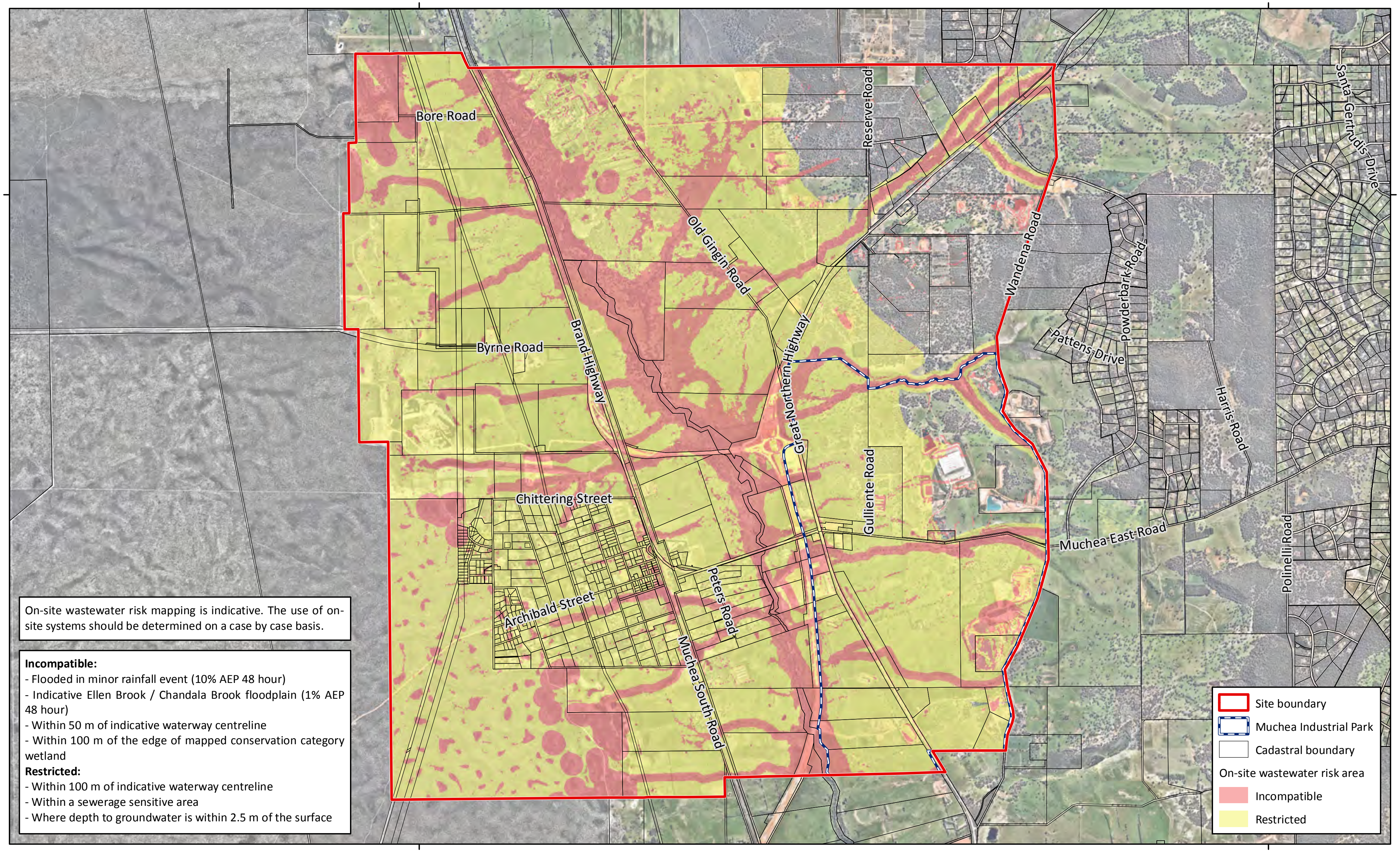

Figure 16: **On-Site Wastewater Risk Mapping**

Project: Regional Water Management Strategy Muchea

Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F15c

Drawn: KNM
Date: 22/08/2019
Checked: ASC
Approved: RLE
Date: 22/08/2019

N

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Kilometres

Scale: 1:60,000@A4

GDA 1994 MGA Zone 50

emerge ASSOCIATES

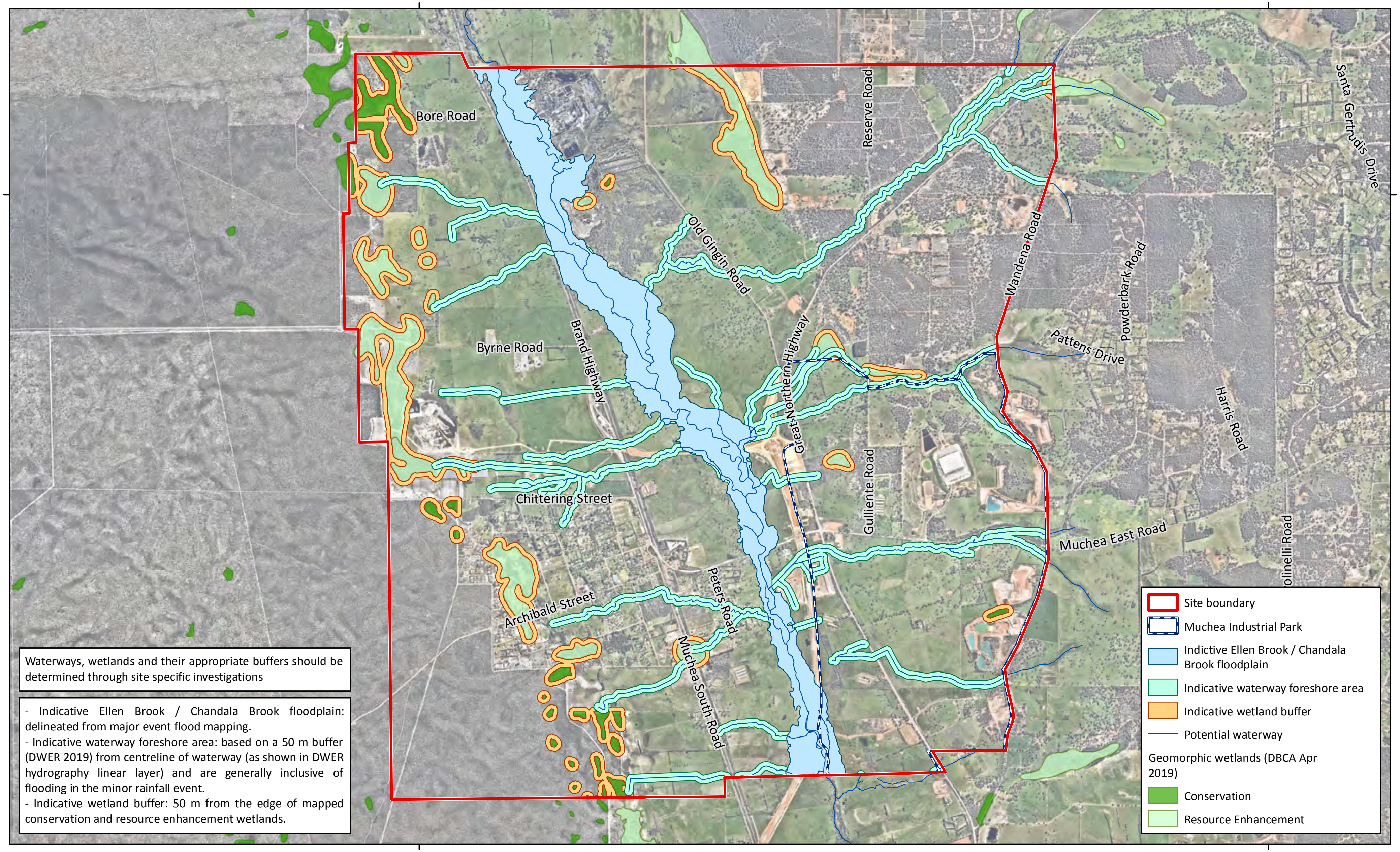

Figure 17: Indicative Wetland Buffers and Waterway Foreshore Areas

Project: Regional Water Management Strategy
Muchea

Client: Department of Planning, Lands and Heritage

Plan Number: EP18-104(02)--F14b
Drawn: KNM
Date: 22/08/2019
Checked: ASC
Approved: RLE
Date: 22/08/2019

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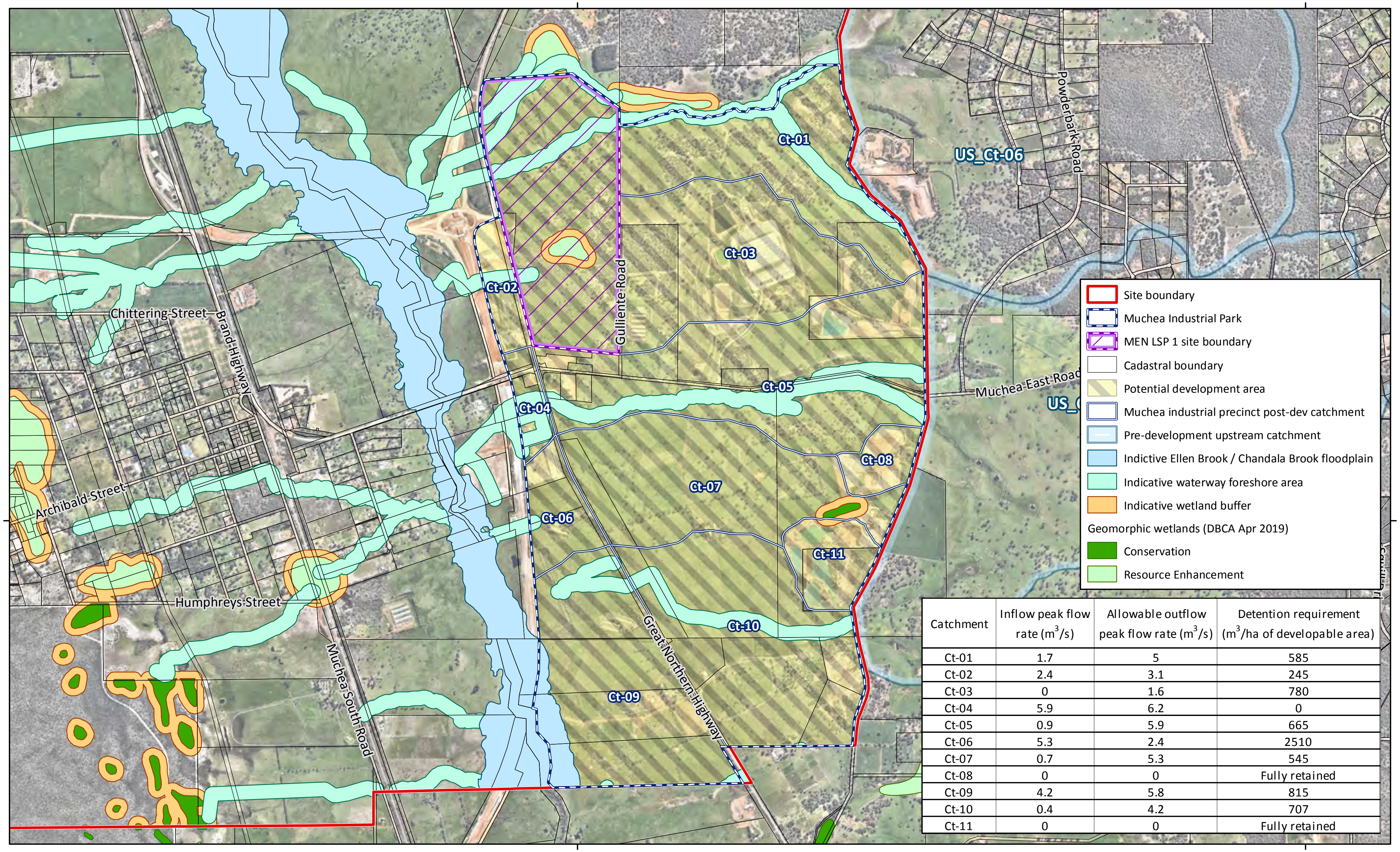
Kilometres
Scale: 1:60,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES



Catchment	Inflow peak flow rate (m^3/s)	Allowable outflow peak flow rate (m^3/s)	Detention requirement (m^3/ha of developable area)
Ct-01	1.7	5	585
Ct-02	2.4	3.1	245
Ct-03	0	1.6	780
Ct-04	5.9	6.2	0
Ct-05	0.9	5.9	665
Ct-06	5.3	2.4	2510
Ct-07	0.7	5.3	545
Ct-08	0	0	Fully retained
Ct-09	4.2	5.8	815
Ct-10	0.4	4.2	707
Ct-11	0	0	Fully retained

Figure 18: **Muchea Industrial Park Structure Plan Opportunities and Constraints Mapping**

Project: Regional Water Management Strategy
Muchea
Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F13a
Drawn: KNM
Date: 22/08/2019
Checked: ASC
Approved: RLE
Date: 22/08/2019

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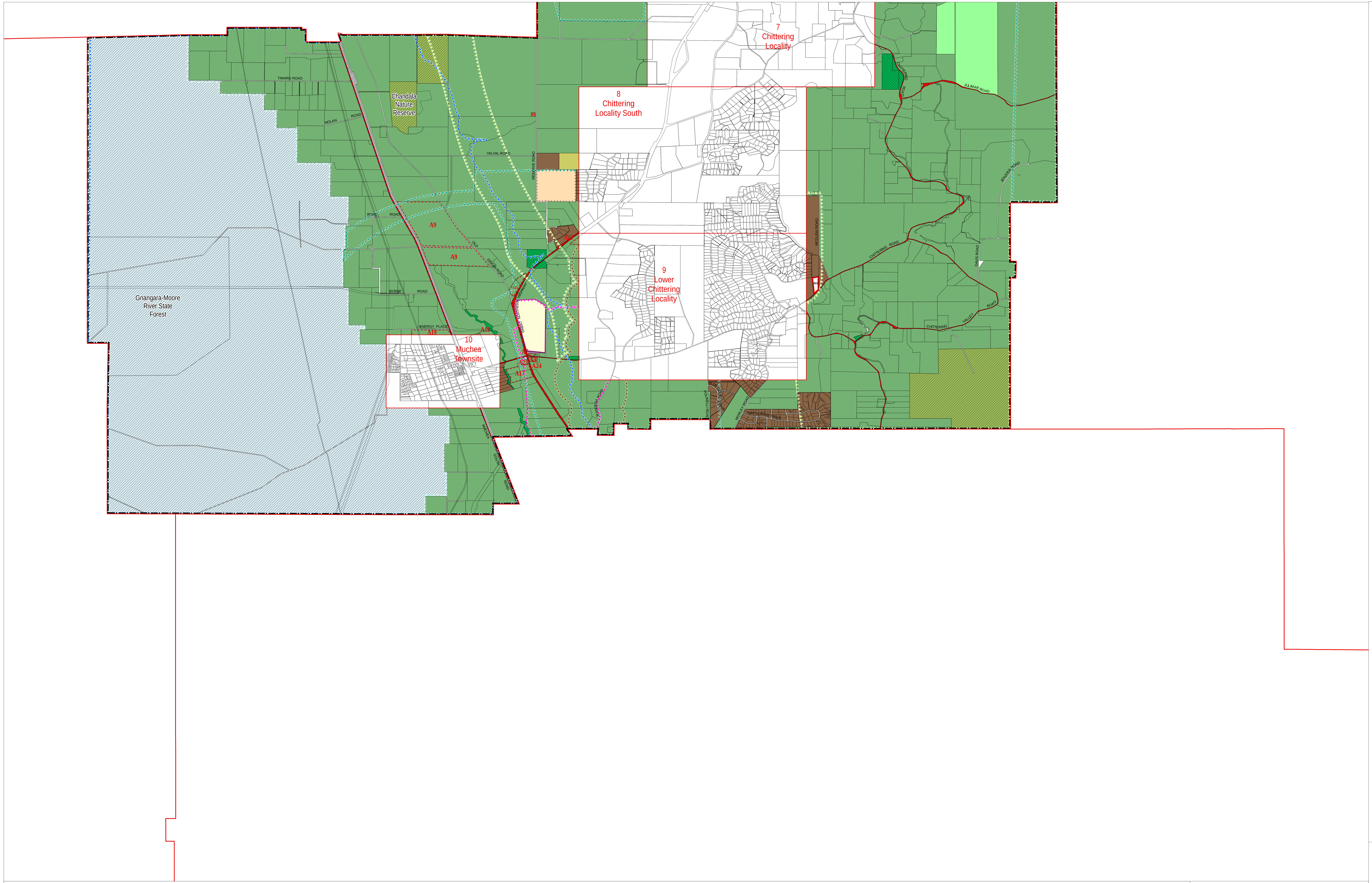
Kilometres
Scale: 1:35,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

Appendix A

Town Planning Scheme Maps



LEGEND

LOCAL SCHEME RESERVES

- Conservation
- Highway
- Major Road
- Parks and Recreation
- C Public Purposes : Cemetery
- CC Public Purposes : Civic and Cultural
- FFS Public Purposes : Fire Fighting Station
- G Public Purposes : Gravel
- LR Public Purposes : Land Refuse
- S Public Purposes : School
- SPA Public Purposes : School and Place of Assembly
- TEL Public Purposes : Telecommunications
- WS Public Purposes : Water Supply
- Railway
- Water Supply

LOCAL SCHEME ZONES

- Agricultural Resource
- Environmental Conservation
- General industry
- Industrial Development
- Light Industrial
- Residential
- Rural Conservation
- Rural Residential
- Rural Retreat
- Rural Smallholdings
- Special Use
- Townsite

OTHER CATEGORIES

(see scheme text for additional information)

- Waterbodies
- Scheme Area Boundary
- Local Government Boundary
- R20 R Codes
- A1 Additional Uses
- R1 Restricted Uses
- RR1 Rural Residential Area
- SU1 Special Use Area
- Landscape Protection
- Muchea Employment Node
- Basic Raw Materials
- Land Refuse
- Military Considerations
- Water and Waste Water Treatment Plant
- Water Prone
- Water Supply
- No Zone

VERSION No 1

Shire of Chittering

Town Planning Scheme No. 6

(District Scheme)

Department of Planning, Lands and Heritage

GOVERNMENT OF WESTERN AUSTRALIA

Whilst all care has been taken to accurately portray the current Scheme provisions, no responsibility shall be taken for any omission or errors in this documentation.

Consultation with the respective Local Government should be made to view a legal version of the Scheme. Please advise the Department of Planning, Lands and Heritage of any omissions or errors in the document at Spatialdata@dplh.wa.gov.au

Produced by GeoSpatial Planning Support, Department of Planning, Lands and Heritage.

Base Information Supplied by the Western Australian Land Information Authority, SLIP 1096-2018-1

Shire of Chittering

Town Planning Scheme No. 6

(District Scheme)

N

0 1 2 3 4

Kilometers

MAP OVERVIEW

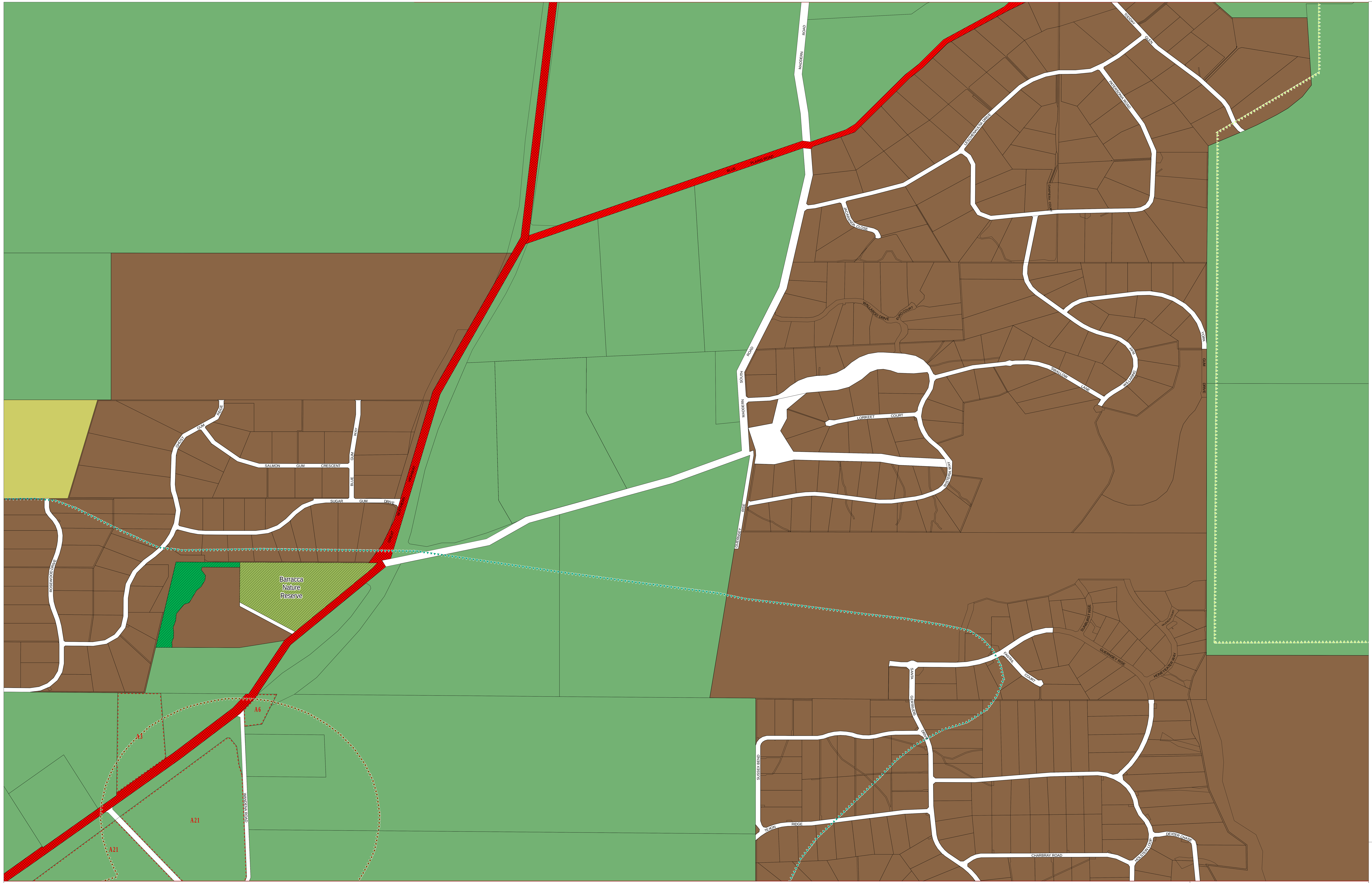
Authorised: T.Servaas

Plot Date: 26 June 2019

G.Gazette: Friday, 10 December 2004

Town Planning Scheme Map No. 3 of 10

MAP: Muchea Locality



LEGEND

LOCAL SCHEME RESERVES

- Conservation
- Highway
- Major Road
- Parks and Recreation
- C Public Purposes : Cemetery
- CC Public Purposes : Civic and Cultural
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- Agricultural Resource
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(see scheme text for additional information)

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VERSION No 1

Shire of Chittering

Town Planning Scheme No. 6

(District Scheme)

Department of Planning, Lands and Heritage

GOVERNMENT OF WESTERN AUSTRALIA

Produced by GeoSpatial Planning Support, Department of Planning, Lands and Heritage.

Base Information Supplied by the Western Australian Land Information Authority, SLIP 1096-2018-1

Shire of Chittering

Town Planning Scheme No. 6

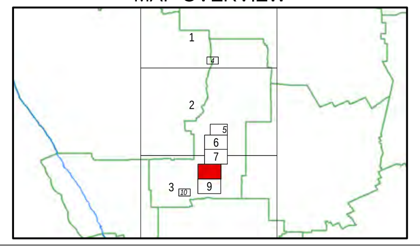
(District Scheme)

N

0 250 500 750 1,000

Meters

MAP OVERVIEW



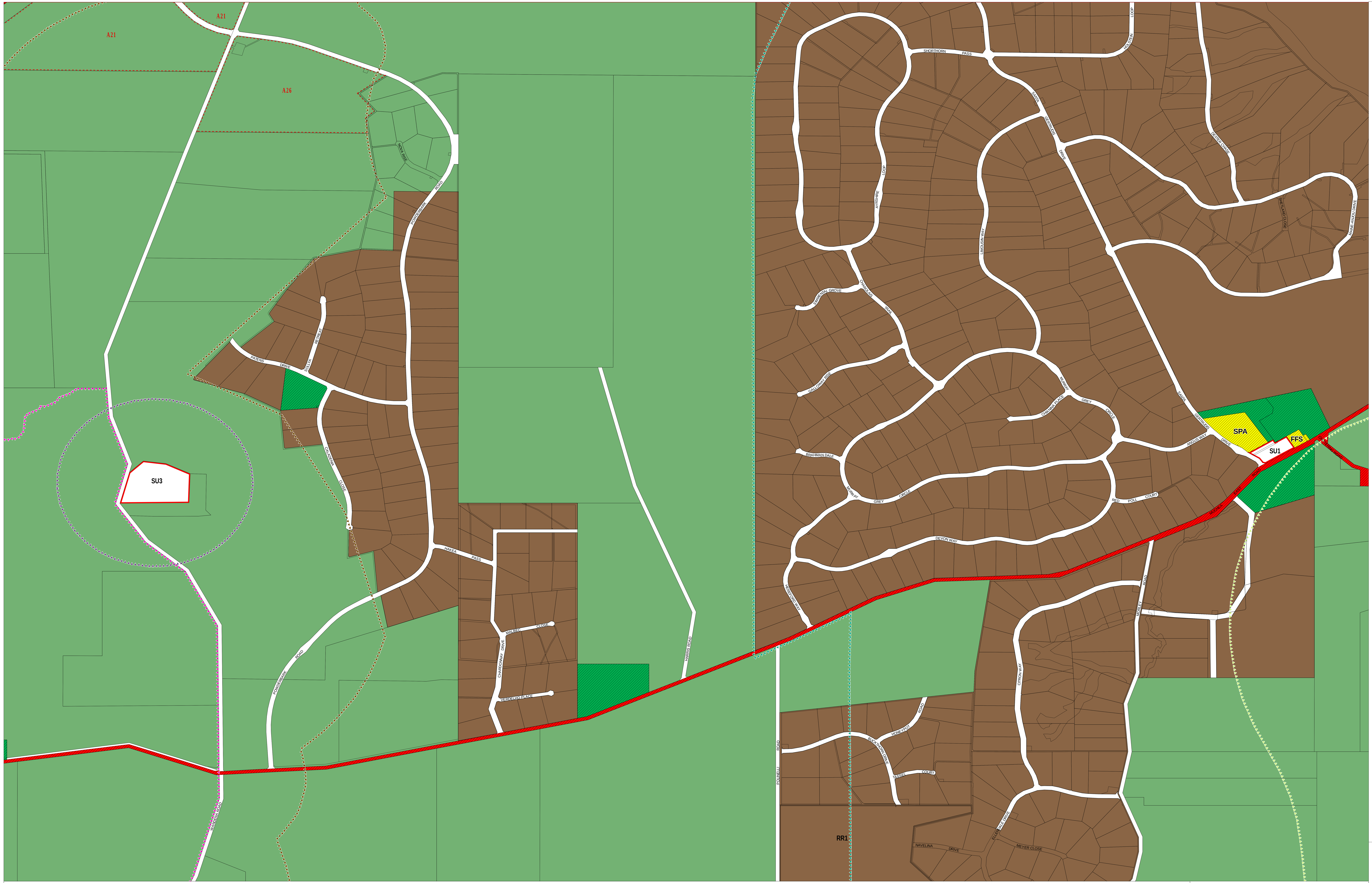
Authorised: T.Servaas

Plot Date: 26 June 2019

G.Gazette: Friday, 10 December 2004

Town Planning Scheme Map No. 8 of 10

MAP: Chittering Locality South



LEGEND

LOCAL SCHEME RESERVES

- Conservation
- Highway
- Major Road
- Parks and Recreation
- C Public Purposes : Cemetery
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- FFS Public Purposes : Fire Fighting Station
- G Public Purposes : Gravel
- LR Public Purposes : Land Refuse
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- SPA Public Purposes : School and Place of Assembly
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- WS Public Purposes : Water Supply
- Railway
- Water Supply

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- Rural Retreat
- Rural Smallholdings
- Special Use
- Townsite

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(see scheme text for additional information)

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- Landscape Protection
- Muchea Employment Node
- Basic Raw Materials
- Land Refuse
- Military Considerations
- Water and Waste Water Treatment Plant
- Water Prone
- Water Supply
- No Zone

VERSION No 1

Shire of Chittering

Town Planning Scheme No. 6

(District Scheme)

Department of Planning, Lands and Heritage

GOVERNMENT OF WESTERN AUSTRALIA

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Produced by GeoSpatial Planning Support, Department of Planning, Lands and Heritage.

Base Information Supplied by the Western Australian Land Information Authority, SLIP 1096-2018-1

Shire of Chittering

Town Planning Scheme No. 6

(District Scheme)

N

0 250 500 750 1,000

Meters

MAP OVERVIEW

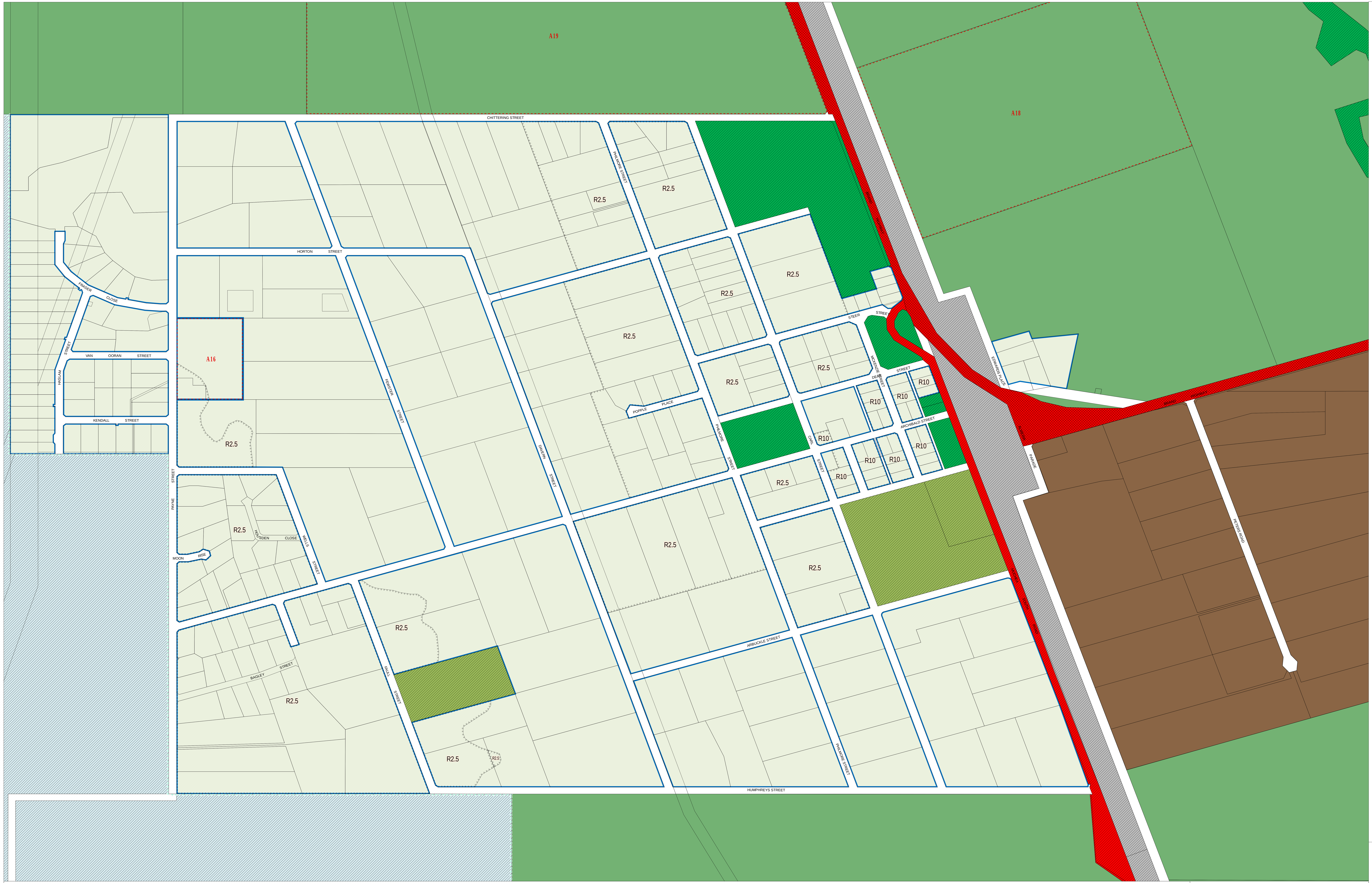
Authorised: T.Servaas

Plot Date: 26 June 2019

G.Gazette: Friday, 10 December 2004

Town Planning Scheme Map No. 9 of 10

MAP: Lower Chittering Locality



LEGEND

LOCAL SCHEME RESERVES

- Conservation
- Highway
- Major Road
- Parks and Recreation
- C Public Purposes : Cemetery
- CC Public Purposes : Civic and Cultural
- FFS Public Purposes : Fire Fighting Station
- G Public Purposes : Gravel
- LR Public Purposes : Land Refuse
- S Public Purposes : School
- SPA Public Purposes : School and Place of Assembly
- TEL Public Purposes : Telecommunications
- WS Public Purposes : Water Supply
- Railway
- Water Supply

LOCAL SCHEME ZONES

- Agricultural Resource
- Environmental Conservation
- General industry
- Industrial Development
- Light Industrial
- Residential
- Rural Conservation
- Rural Residential
- Rural Retreat
- Rural Smallholdings
- Special Use
- Townsite

OTHER CATEGORIES

(see scheme text for additional information)

- Scheme Area Boundary
- Local Government Boundary
- R20 R Codes
- A1 Additional Uses
- R1 Restricted Uses
- RR1 Rural Residential Area
- SU1 Special Use Area
- Landscape Protection
- Muchea Employment Node
- Basic Raw Materials
- Land Refuse
- Military Considerations
- Water and Waste Water Treatment Plant
- Water Prone
- Water Supply
- No Zone
- Waterbodies

VERSION No 1

Shire of Chittering

Town Planning Scheme No. 6

(District Scheme)

Department of Planning, Lands and Heritage

GOVERNMENT OF WESTERN AUSTRALIA

Produced by GeoSpatial Planning Support, Department of Planning, Lands and Heritage.

Base Information Supplied by the Western Australian Land Information Authority, SLIP 1096-2018-1

Shire of Chittering

Town Planning Scheme No. 6

(District Scheme)

N

0 125 250 375 500

Meters

MAP OVERVIEW

Authorised: T.Servaas

Plot Date: 26 June 2019

G.Gazette: Friday, 10 December 2004

Town Planning Scheme Map No. 10 of 10
MAP: Muchea Townsite

Appendix B

Northlink Geotechnical Investigation

LEGEND

CURRENT INVESTIGATIONS (2017)

- INFILTRATION TEST LOCATION
- TEST PIT LOCATION
- PAVEMENT DIPPING LOCATION
- SEISMIC CONE PENETROMETER LOCATION
- CONE PENETRATION TEST LOCATION
- DILATOMETER TEST LOCATION
- BOREHOLE LOCATION

PREVIOUS INVESTIGATIONS (2014)

- CONE PENETRATION TEST LOCATION
- PAVEMENT DIPPING LOCATION
- TEST PIT LOCATION
- FLORA BUFFERS - 10m

NOT FOR CONSTRUCTION
DRAFT

NOTES

1. COORDINATE SYSTEM: PERTH COASTAL GRID (PCG94)

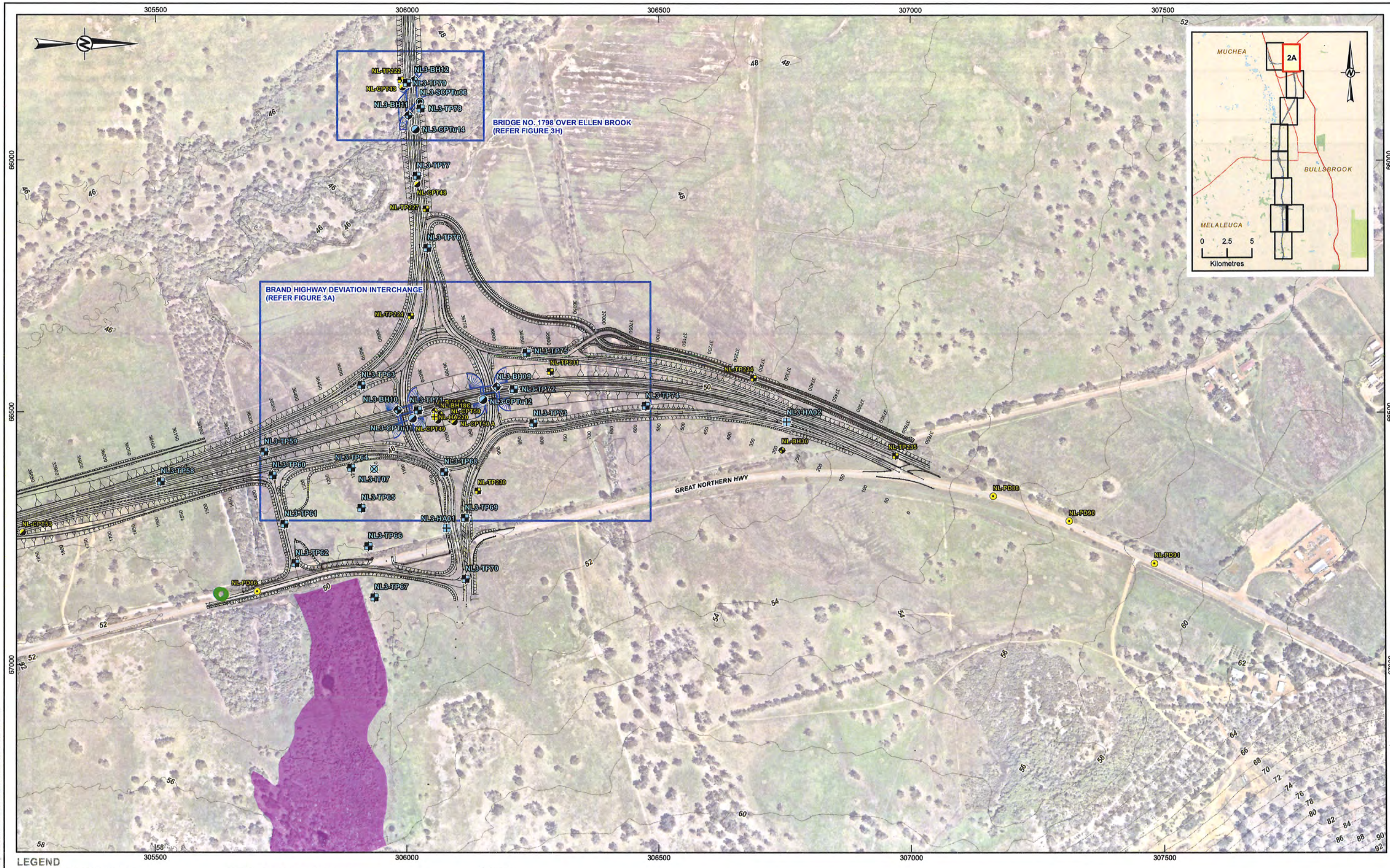
REFERENCE

AERIAL IMAGERY SOURCED FROM NEARMAP DATED MARCH 2017.
ROAD LAYOUT PROVIDED BY CLIENT.
DRAWING: NL3 - BGE - (601, 604) - RD-XR- (001,002) (B01).DWG
DRAWING: XR-140-1795-PLAN-85%.DWG
DRAWING: NL3-BGE- (120, 130, 150, 160, 210, 220, 230) -ST-XR-0001(A).DWG

0 200 400
1:7,000 METRES

CLIENT	BG&E PTY LTD
PROJECT	NORTHLINK STAGE 3
CONSULTANT	Golder Associates
YYYY-MM-DD	2017-11-28
DESIGNED	DN
PREPARED	JRP
REVIEWED	
APPROVED	
TITLE	SITE PLAN 10 OF 10
PROJECT NO.	1777556
CONTROL	006 R
REV.	C
FIGURE	2J

25mm
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3



LEGEND

CURRENT INVESTIGATIONS (2017)

- HAND AUGER LOCATION
- INFILTRATION TEST LOCATION
- TEST PIT LOCATION
- SEISMIC CONE PENETROMETER LOCATION
- CONE PENETRATION TEST LOCATION
- BOREHOLE LOCATION

PREVIOUS INVESTIGATIONS (2014)

- BOREHOLE LOCATION
- CONE PENETRATION TEST LOCATION
- HAND AUGER LOCATION
- PAVEMENT DIPPING LOCATION
- TEST PIT LOCATION
- FLORA BUFFERS - 10m
- CLAYPANS

NOT FOR CONSTRUCTION

DRAFT

NOTES

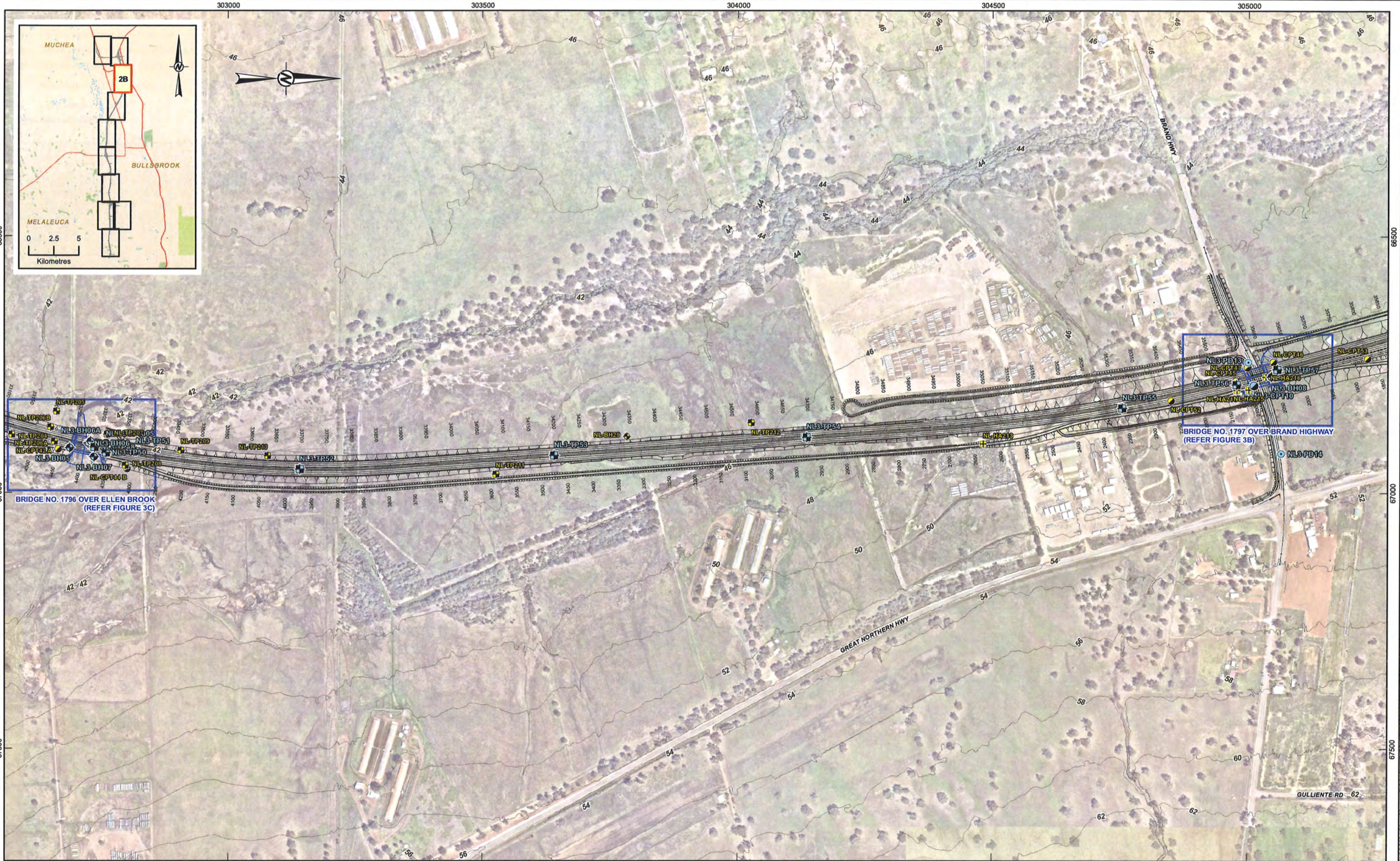
1. COORDINATE SYSTEM: PERTH COASTAL GRID (PCG94)

REFERENCE

AERIAL IMAGERY SOURCED FROM NEARMAP DATED MARCH 2017.
ROAD LAYOUT PROVIDED BY CLIENT.
DRAWING: NL3 - BGE - (601, 604) - RD-XR- (001,002) (B01).DWG
DRAWING: XR-140-1795-PLAN-85%.DWG
DRAWING: NL3-BGE- (120, 130, 150, 160, 210, 220, 230) -ST-XR-0001(A).DWG

0 200 400
1:7,000 METRES

CLIENT BG&E PTY LTD		PROJECT NORTHLINK STAGE 3	
CONSULTANT Golder Associates	YYYY-MM-DD: 2017-11-28 DESIGNED: DN PREPARED: JRP REVIEWED: APPROVED:	TITLE SITE PLAN 1 OF 10	
		PROJECT NO. 1777556	CONTROL 006 R · REV. C · FIGURE 2A



LEGEND

CURRENT INVESTIGATIONS (2017)

- TEST PIT LOCATION
- PAVEMENT DIPPING LOCATION
- SEISMIC CONE PENETROMETER LOCATION
- CONE PENETRATION TEST LOCATION
- BOREHOLE LOCATION

PREVIOUS INVESTIGATIONS (2014)

- BOREHOLE LOCATION
- CONE PENETRATION TEST LOCATION
- HAND AUGER LOCATION
- TEST PIT LOCATION

NOT FOR CONSTRUCTION

DRAFT

NOTES

1. COORDINATE SYSTEM: PERTH COASTAL GRID (PCG94)

REFERENCE

AERIAL IMAGERY SOURCED FROM NEARMAP DATED MARCH 2017.
ROAD LAYOUT PROVIDED BY CLIENT.
DRAWING: NL3 - BGE - (601, 604) - RD-XR- (001,002) (B01).DWG
DRAWING: XR-140-1795-PLAN-85%.DWG
DRAWING: NL3-BGE- (120, 130, 150, 160, 210, 220, 230) -ST-XR-0001(A).DWG

0 200 400
1:7,000 METRES

CLIENT	BG&E PTY LTD
CONSULTANT	Golder Associates
YYYY-MM-DD	2017-11-28
DESIGNED	DN
PREPARED	JRP
REVIEWED	
APPROVED	
PROJECT	NORTHLINK STAGE 3
TITLE	SITE PLAN 2 OF 10
PROJECT NO.	1777556
CONTROL	006 R
REV.	C
FIGURE	2B

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

25mm

Appendix C

MIP LSP 1 Geotechnical Investigation

5 FIELD WORK

5.1 Field work overview

Over the site, a range of both intrusive and non-intrusive testing was undertaken between the 28th and 30th October including:

- 20 x excavator dug test pits
- 20 x Dynamic Cone Penetrometers (DCP)
- 5 x Hand Auger holes with Infiltration tests
- 10 x Cone Penetrometer tests (CPT)
- 3 x Multi-Channel Analysis of Surface Waves test lines
- Samples taken for Laboratory testing.

The locations of the tests undertaken are shown in figure 4.

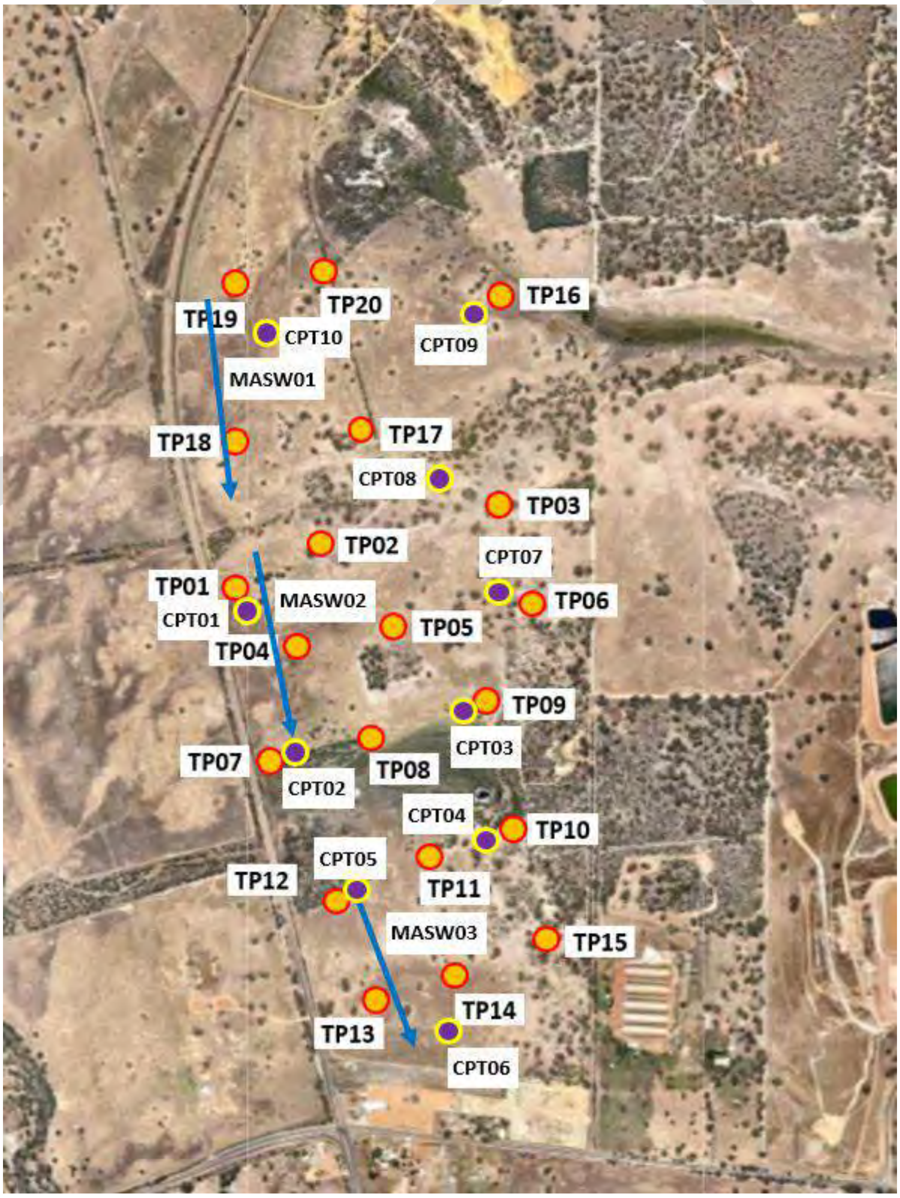


Figure 4: Locations of testing undertaken

infraTech

Excavation No.

TP01

Page 1 of 1

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404440,0 m E 6507297,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	50,00 m
Excavation Dimensions:	5,0 m Long 1,5 m Wide	Datum:	Operator:

Samples Tests Remarks	RL (m)	Depth (m)	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa)	Structure and Additional Observations
				Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
1 B 0,30-0,80 m			SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown	dry	L - MD		
2 B 0,80-2,50 m	49,0 / 48,0	1 / 2	CI-CH	Sandy CLAY. Firm to stiff. Moist. Mottled with brown and pale grey in colour.	moist	F - St		
	47,0	3		Bedrock. Weathered rock. very weak to weak rock strength. Brown, Green, pale grey in colour				
				Hole Terminated at 2,50 m Refusal				

Water: inflow at approx. 1,0 m.

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Moisture Condition
D - Dry
M - Moist
W - Wet

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

INFRA TECH 1.01 LIB.GLB Log IS AU TEST PIT 1 102_GT_NORTHERN_HIGHWAY.GPJ <<DrawingFile>> 26/11/2015 12:52 8.30.004 Datgel Lab and In Situ Tool - DGD | Lib: Infra Tech 1.01 2015-05-14 Prj: Infra Tech 1.01 2015-05-14

Excavation No.
TP02

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404613,0 m E 6507342,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	52,00 m
Excavation Dimensions:	5,0 m Long, 1,5 m Wide	Datum:	Operator:

Excavation Information								Soil Description						Observations
Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
									SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown	dry	L - MD		
						51,0	1		CI-CH	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Moist. Mottled with brown and pale grey in colour.	moist	F - St		
						50,0	2							
						49,0	3			Hole Terminated at 3,00 m Target depth				

Photo

Sketch

Method	Penetration	Water	Samples and Tests	Moisture Condition	Consistency/Relative Density
N - Natural Exposure X - Existing Excavation BH - Backhoe Bucket R - Ripper E - Excavator	No resistance ranging to refusal	Level (Date) Inflow	U - Undisturbed Sample D - Disturbed Sample CBR- CBR Mould Sample	D - Dry M - Moist W - Wet	VS - Very Soft S - Soft F - Firm VSt - Very Stiff H - Hard VL - Very Loose L - Loose MD - Medium Dense D - Dense VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

Engineering Log - Excavation

Excavation No. **TP03**

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	405060,0 m E 6507489,0 m N	Checked By:	NL
Equipment Type and Model:	12t Excavator	RL Surface:	59,00 m
Excavation Dimensions:	5,0 m Long 1,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa)	Structure and Additional Observations
				1 B 0,10-1,00 m					SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
										Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale grey in colour	dry	L - MD		
				2 B 1,00-2,50 m		58,0	1		CI-CH	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Moist. Mottled with brown and pale grey in colour.	moist	F - St		
						57,0	2							
				3 B 2,50-3,50 m		56,0	3							
										Hole Terminated at 3,50 m Target depth				

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Moisture Condition
D - Dry
M - Moist
W - Wet

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404563,0 m E 6507119,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	50,00 m
Excavation Dimensions:	5,0 m Long 1,5 m Wide	Datum:	Operator:

Excavation Information | **Soil Description** | **Observations**

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
									SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
										Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale grey in colour	dry	L - MD		
									CI-CH	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Moist. Mottled with brown and pale grey in colour.	moist	F - St		
						49,0	1			Bedrock. Weathered rock. very weak to weak rock strength. Brown, Green, pale grey in colour	dry			
										Hole Terminated at 1,50 m Refusal				
						48,0	2							
						47,0	3							

Photo

Sketch

Method	Penetration	Water	Samples and Tests	Moisture Condition	Consistency/Relative Density
N - Natural Exposure	No resistance ranging to refusal	Level (Date)	U - Undisturbed Sample	D - Dry	VS - Very Soft
X - Existing Excavation		Inflow	D - Disturbed Sample	M - Moist	S - Soft
BH - Backhoe Bucket			CBR- CBR Mould Sample	W - Wet	F - Firm
R - Ripper					VSt - Very Stiff
E - Excavator					H - Hard
				Plastic Limit	VL - Very Loose
Support			**Classification Symbols and Soil Descriptions**	< PL	L - Loose
T - Timbering			Based on Unified Soil Classification System	= PL	MD - Medium Dense
				< PL	D - Dense
					VD - Very Dense

infraTech

Excavation No.
TP05

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404892,0 m E 6507195,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	54,00 m
Excavation Dimensions:	5,0 m Long, 2,5 m Wide	Datum:	Operator:

Excavation Information | **Soil Description** | **Observations**

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
				1 B 0,10-1,00 m						Top Soil. Silty Sand, dark brown, grass and rootlets, dry	moist			
									SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale grey in colour	moist	L - MD		
				2 B 1,00-2,50 m		53,0	1		CI-CH	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Wet. Mottled with brown and pale grey in colour.	wet	F - St		
						52,0	2							
			Inflow (2,50 m)							Hole Terminated at 2,50 m Collapse				
						51,0	3							

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Moisture Condition
D - Dry
M - Moist
W - Wet

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Plastic Limit
< PL
= PL
< PL

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	405175,0 m E 6507250,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator		RL Surface:	61,00 m
Excavation Dimensions:	5,0 m Long	2,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
						60,0	1		SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown in colour. Dry	dry	L - MD		
						59,0	2							
						58,0	3			Hole Terminated at 3,00 m Target depth				

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Excavation No.
TP07
Page 1 of 1

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	405045,0 m E 6506979,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator		RL Surface:	57,00 m
Excavation Dimensions:	5,0 m Long	2,5 m Wide	Datum:	Operator:

Excavation Information								Soil Description						Observations
Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
			Inflow	1 B 0,20-1,00 m		56,0	1		SM	Silty SAND, fine to coarse grained, loose to medium dense, Pale grey in colour. Wet	wet	L - MD		
						55,0	2			Hole Terminated at 2,00 m Collapse				
						54,0	3							

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

infraTech

Excavation No.

TP08

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404555,0 m E 6506885,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator		RL Surface:	53,00 m	
Excavation Dimensions:	5,0 m Long	3,5 m Wide	Datum:		Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, rootlets, moist	dry			
			▷						SM	Silty SAND, fine to coarse grained, loose to medium dense, Pale grey in colour. Wet	wet	L - MD		
						52,0	1			Hole Terminated at 1,00 m Collapse				
						51,0	2							
						50,0	3							

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Excavation No.

TP09

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404781,0 m E 6506938,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	55,00 m
Excavation Dimensions:	3,5 m Long 3,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
				1 B 0,10-1,50 m						Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
			▷			54,0	1		SM	Silty SAND, fine to coarse grained, loose to medium dense, Pale grey in colour. Wet	wet	L - MD		
						53,0	2			Hole Terminated at 1,50 m Collapse				
						52,0	3							

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Excavation No.

TP10

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	28/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	28/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	405029,0 m E 6506736,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator		RL Surface:	59,00 m
Excavation Dimensions:	5,0 m Long	2,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
									SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
			▷							Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale grey in colour	moist	L - MD		
						58,0	1		CI-CH	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Wet. Mottled with brown, yellowish brown and pale grey in colour.	wet	F - St		
						57,0	2							
						56,0	3			Hole Terminated at 2,50 m Collapse				

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Moisture Condition
D - Dry
M - Moist
W - Wet

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

Engineering Log - Excavation

Excavation No. **TP11**

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404873,0 m E 6506665,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator		RL Surface:	56,00 m
Excavation Dimensions:	5,0 m Long	1,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
									SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown in colour	moist	L - MD		
									CI-CH	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Wet. Mottled with brown, yellowish brown and pale grey in colour.	wet	F - St		
						55,0	1			Bedrock. Weathered rock. very weak to weak rock strength. Brown, Green, pale grey in colour				
										Hole Terminated at 0,80 m Refusal				
						54,0	2							
						53,0	3							

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404670,0 m E 6506544,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator		RL Surface:	53,00 m
Excavation Dimensions:	5,0 m Long	2,0 m Wide	Datum:	Operator:

Excavation Information								Soil Description						Observations
Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
				1 B 0,10-0,80 m					SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
										Silty SAND, fine to coarse grained, with traces of angular to subangular gravel, loose to medium dense, brown, yellowish brown, Pale grey in colour	moist	L - MD		
			Inflow	2 B 0,80-3,00 m		52,0	1		GP-GM	Sandy GRAVEL. Angular to subangular gravel (Fe rich). With traces of clay. Loose. Wet. Reddish brown, yellowish brown in colour.	wet	F - St		
						51,0	2							
										Bedrock. Weathered rock. very weak to weak rock strength. Brown, Green, pale grey in colour	wet			
						50,0	3			Hole Terminated at 3,00 m Target depth				

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Excavation No.

TP13

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404813,0 m E 6506332,0 m N	Checked By:	NL
Equipment Type and Model:	12t Excavator	RL Surface:	53,50 m
Excavation Dimensions:	5,0 m Long 1,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
									SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
										Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale grey in colour	moist	L - MD		
			Inflow			52,5	1		CI-CH	Sandy CLAY. With some angular to subangular gravel (Fe rich). Firm to stiff. Wet. Mottled with brown, yellowish brown and reddish brown in colour.	wet	F - St		
						51,5	2							
						50,5	3			Hole Terminated at 3,00 m Target depth				

Photo

Sketch

Method	Penetration	Water	Samples and Tests	Moisture Condition	Consistency/Relative Density
N - Natural Exposure X - Existing Excavation BH - Backhoe Bucket R - Ripper E - Excavator	No resistance ranging to refusal	Level (Date) Inflow	U - Undisturbed Sample D - Disturbed Sample CBR- CBR Mould Sample	D - Dry M - Moist W - Wet	VS - Very Soft S - Soft F - Firm VSt - Very Stiff H - Hard VL - Very Loose L - Loose MD - Medium Dense D - Dense VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

Excavation No.

TP14

Page 1 of 1

Engineering Log - Excavation

Project No.: 1444

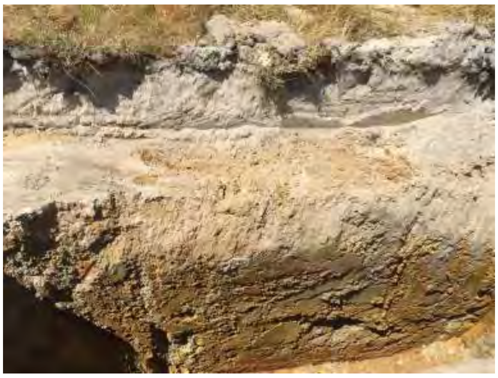
Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404939,0 m E 6506381,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	55,00 m
Excavation Dimensions:	5,0 m Long 1,5 m Wide	Datum:	Operator:

Samples Tests Remarks	RL (m)	Depth (m)	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Structure and Additional Observations
			SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry		
				Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale grey in colour	moist	L - MD	
	54,0	1	CI-CH	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Moist to Wet. Brown, yellowish brown and reddish brown in colour.			
2 B 1,45-3,50 m	53,0	2			wet	F - St	
	52,0	3					
				Hole Terminated at 3,50 m Target depth			

Excavation Information: Method; Penetration; Support; Water (inflow at approx. 0,8 m); Recovery. Hand Penetrometer UCS (kPa): 100, 200, 300, 400, 500.

Photo



Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Excavation No.

TP15

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	405215,0 m E 6506474,0 m N	Checked By:	NL
Equipment Type and Model:	12t Excavator	RL Surface:	60,00 m
Excavation Dimensions:	5,0 m Long 3,0 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
				1 B 0,10-2,00 m					SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
						59,0	1			Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown in colour, mosit to wet	wet	L - MD		
						58,0	2			Hole Terminated at 2,00 m Collapse				
						57,0	3							

Photo

Sketch

Method	Penetration	Water	Samples and Tests	Moisture Condition	Consistency/Relative Density
N - Natural Exposure X - Existing Excavation BH - Backhoe Bucket R - Ripper E - Excavator	No resistance ranging to refusal	Level (Date) Inflow	U - Undisturbed Sample D - Disturbed Sample CBR- CBR Mould Sample	D - Dry M - Moist W - Wet	VS - Very Soft S - Soft F - Firm VSt - Very Stiff H - Hard VL - Very Loose L - Loose MD - Medium Dense D - Dense VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

Excavation No.
TP16

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	405069,0 m E 6507754,0 m N	Checked By:	NL
Equipment Type and Model:	12t Excavator	RL Surface:	63,50 m
Excavation Dimensions:	5,0 m Long, 1,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
									SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale brown in colour	dry	L - MD		
						62,5	1		CL-CI	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Moist. Brown, yellowish brown and Pale grey in colour.	moist	F - St		
				1 B 2,00-2,50 m		61,5	2							
										Bedrock. Weathered rock. very weak to weak rock strength. Brown, Green, pale grey in colour				
						60,5	3			Hole Terminated at 2,50 m Refusal				

Photo

Sketch

Method	Penetration	Water	Samples and Tests	Moisture Condition	Consistency/Relative Density
N - Natural Exposure	No resistance ranging to refusal	Level (Date)	U - Undisturbed Sample	D - Dry	VS - Very Soft
X - Existing Excavation		Inflow	D - Disturbed Sample	M - Moist	S - Soft
BH - Backhoe Bucket			CBR- CBR Mould Sample	W - Wet	F - Firm
R - Ripper					VSt - Very Stiff
E - Excavator					H - Hard
					VL - Very Loose
					L - Loose
					MD - Medium Dense
					D - Dense
					VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

Excavation No.
TP17
Page 1 of 1

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404776,0 m E 6507615,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	58,50 m
Excavation Dimensions:	5,0 m Long 1,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
									SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown, Pale brown in colour	dry	L - MD		
						57,5	1		CL-CI	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Moist. Brown, yellowish brown and Pale grey in colour.	moist	F - St		
				1 B 1,50-2,50 m		56,5	2							
										Bedrock. Weathered rock. very weak to weak rock strength. Brown, pale grey in colour				
						55,5	3			Hole Terminated at 2,50 m Refusal				

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Excavation No.
TP18
Page 1 of 1

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404506,0 m E 6507528,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator		RL Surface:	54,00 m
Excavation Dimensions:	5,0 m Long	1,5 m Wide	Datum:	Operator:

Excavation Information								Soil Description						Observations
Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
									SM	Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
										Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown in colour. dry	dry	L - MD		
						53,0	1		CL-CI	Sandy CLAY. With traces of angular to subangular gravel (Fe rich). Firm to stiff. Moist. Mottled with brown, yellowish brown and Pale grey in colour.	moist	F - St		
						52,0	2			Bedrock. Weathered rock. very weak to weak rock strength. Brown, pale grey in colour				
										Hole Terminated at 2,00 m Refusal				
						51,0	3							

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Moisture Condition
D - Dry
M - Moist
W - Wet

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Support
T - Timbering

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Plastic Limit
< PL
= PL
< PL

Excavation No.
TP19
Page 1 of 1

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404488,0 m E 6507924,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	53,00 m
Excavation Dimensions:	5,0 m Long 1,5 m Wide	Datum:	Operator:

Excavation Information | **Soil Description** | **Observations**

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description soil type: plasticity or particle characteristics, secondary and minor components, colour	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
									SM	Silty SAND, fine to coarse grained, loose to medium dense, brown, yellowish brown in colour	dry	L - MD		
			Inflow	2 B 1,20-2,20 m		52,0	1		CI-CH	Sandy CLAY. With some angular to subangular gravel (Fe rich). Firm to stiff. Moist to wet. Mottled with brown, reddish brown and Pale grey in colour.	moist	F - St		
						51,0	2			Bedrock. Weathered rock. very weak to weak rock strength. Brown, pale grey in colour				
						50,0	3			Hole Terminated at 2,20 m Refusal				

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Excavation No.
TP20
Page 1 of 1

Engineering Log - Excavation

Project No.: 1444

Client:	Cossil and Webley	Commenced:	29/10/2015
Project Name:	102 Great Northern Highway Geotechnical Investigation	Completed:	29/10/2015
Hole Location:	Muchea	Logged By:	KA
Hole Position:	404638,0 m E 6507950,0 m N	Checked By:	NL

Equipment Type and Model:	12t Excavator	RL Surface:	54,00 m
Excavation Dimensions:	5,0 m Long, 1,5 m Wide	Datum:	Operator:

Method	Penetration	Support	Water	Samples Tests Remarks	Recovery	RL (m)	Depth (m)	Graphic Log	Classification Symbol	Material Description (soil type: plasticity or particle characteristics, secondary and minor components, colour)	Moisture Condition	Consistency Relative Density	Hand Penetrometer UCS (kPa) 100 200 300 400 500	Structure and Additional Observations
										Top Soil. Silty Sand, dark brown, grass and rootlets, dry	dry			
						53,0 / 52,0	1 / 2		GC-GM	Clayey GRAVEL. Angular to subangular gravel (Fe rich). Loose. dry. Yellowish brown, reddish brown in colour.	dry	L - MD		
										Bedrock. Weathered rock. very weak to weak rock strength. Brown, pale grey in colour				
						51,0	3			Hole Terminated at 2,30 m Refusal				

Photo

Sketch

Method
N - Natural Exposure
X - Existing Excavation
BH - Backhoe Bucket
R - Ripper
E - Excavator

Support
T - Timbering

Penetration
No resistance ranging to refusal

Water
Level (Date)
Inflow

Samples and Tests
U - Undisturbed Sample
D - Disturbed Sample
CBR- CBR Mould Sample

Classification Symbols and Soil Descriptions
Based on Unified Soil Classification System

Moisture Condition
D - Dry
M - Moist
W - Wet

Plastic Limit
< PL
= PL
< PL

Consistency/Relative Density
VS - Very Soft
S - Soft
F - Firm
VSt - Very Stiff
H - Hard
VL - Very Loose
L - Loose
MD - Medium Dense
D - Dense
VD - Very Dense

Appendix D

Groundwater Areas and Subareas Mapping

emerge ASSOCIATES

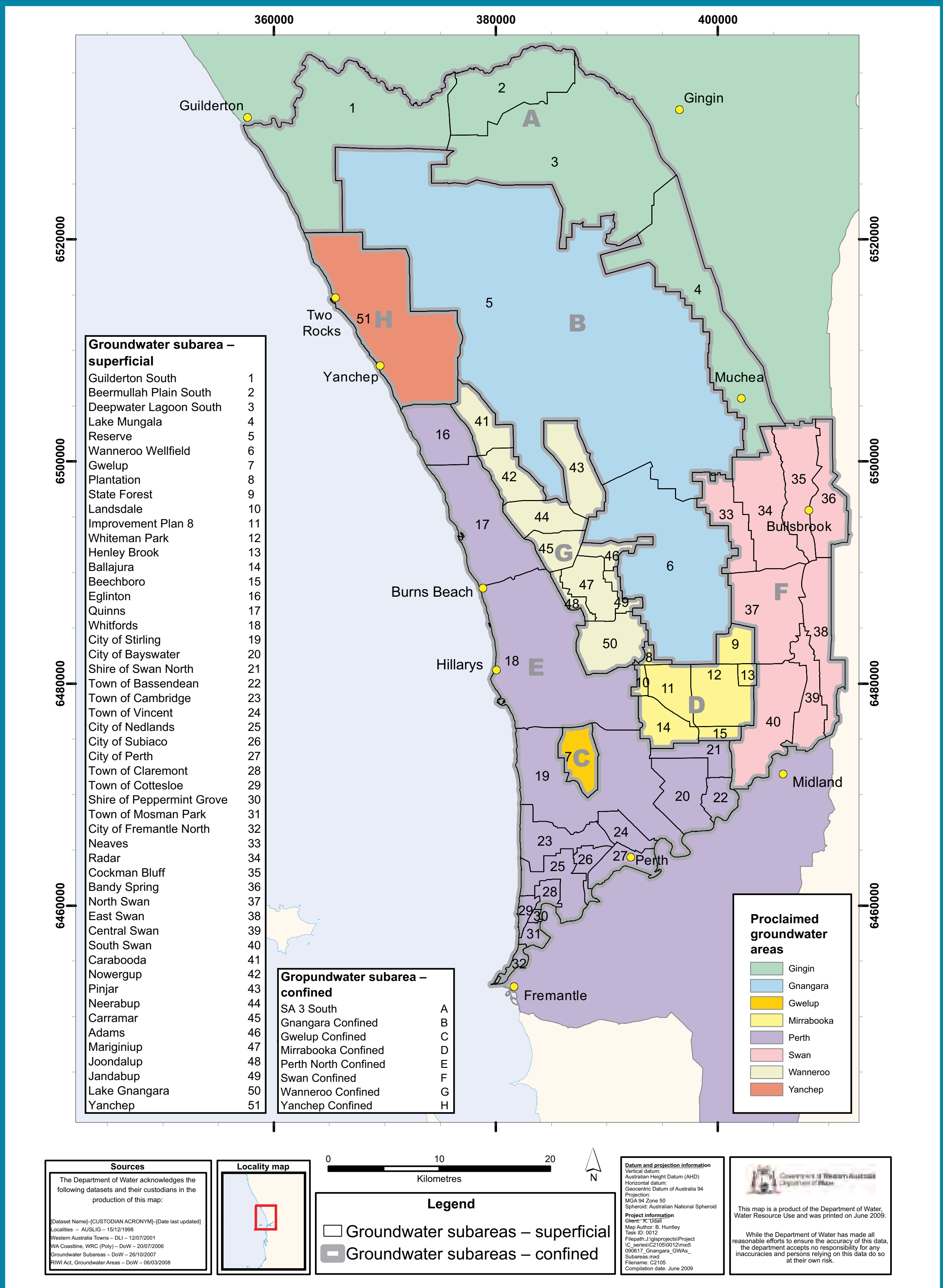


Figure 8

Groundwater areas and subarea in the- plan area

Figure 2

Subareas covering the superficial and surficial aquifers

Gingin groundwater allocation plan

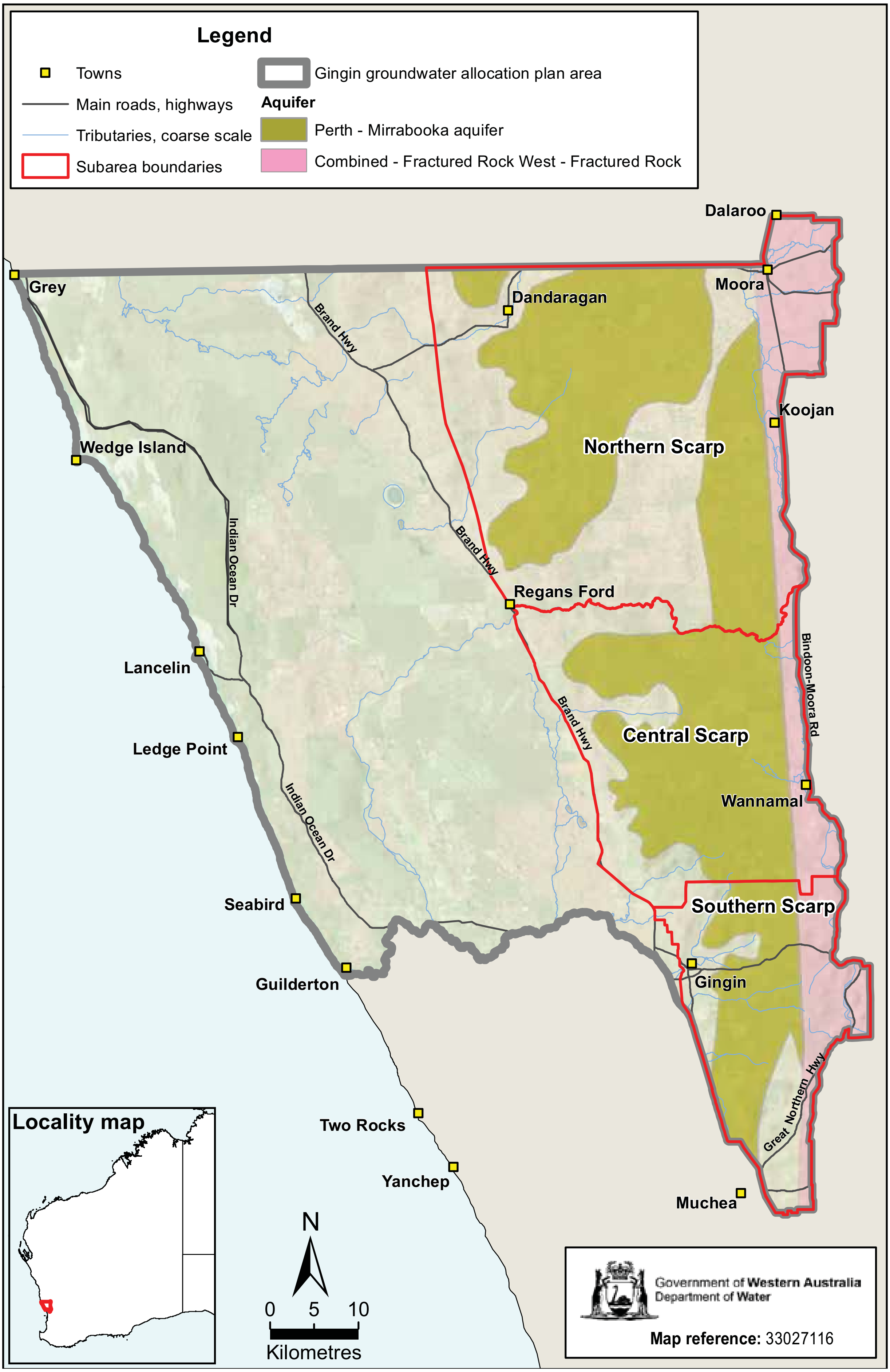


Figure 3

Subareas covering the Mirrabooka and fractured rock aquifers

Gingin groundwater allocation plan

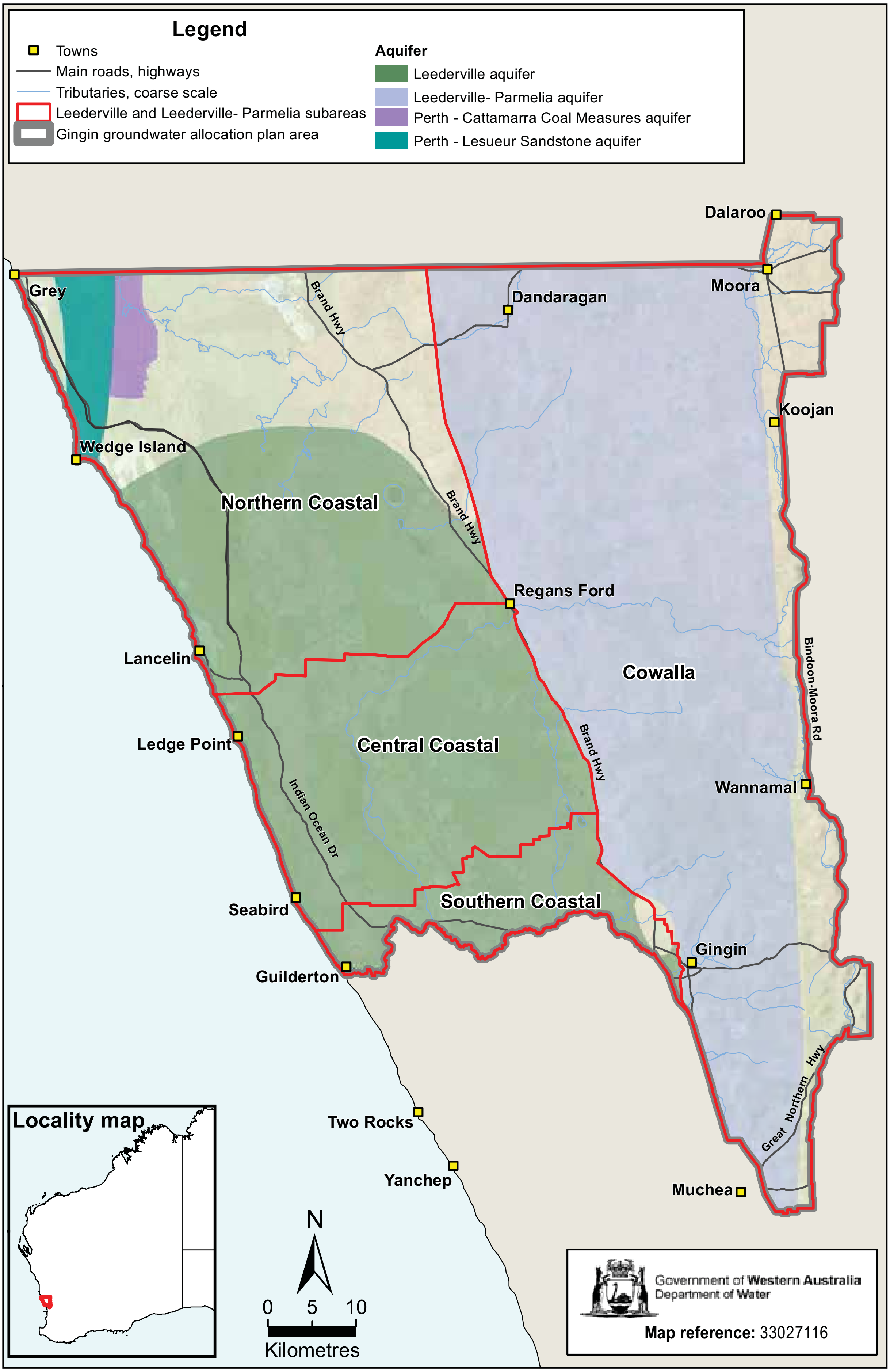


Figure 4

Leederville, Leederville–Parmelia, Lesueur and Cattamarra aquifer subarea boundaries

Gingin groundwater allocation plan

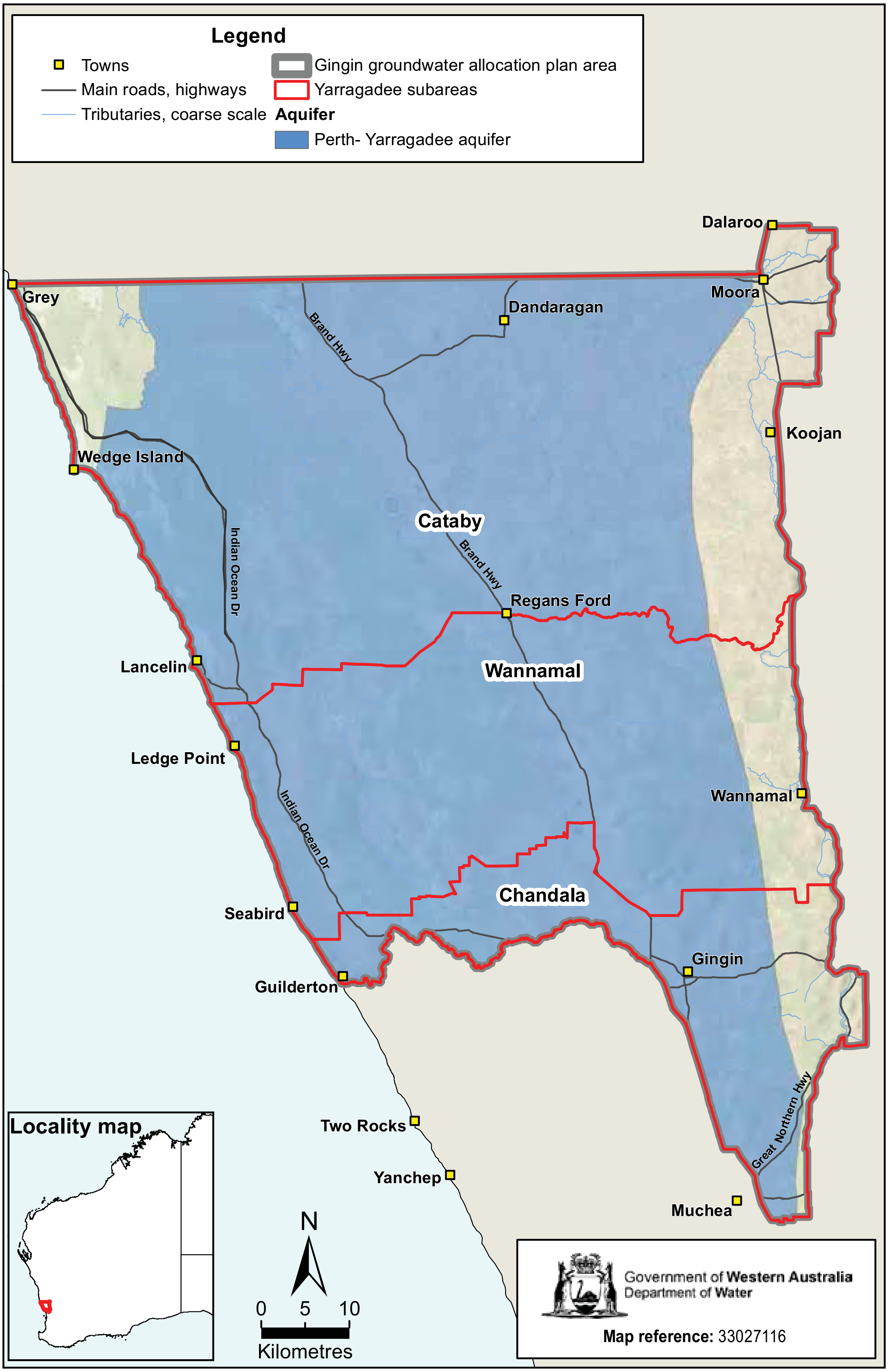


Figure 5

Yarragadee aquifer subarea boundaries

Gingin groundwater allocation plan

Appendix E

Modelling Report

Modelling Report

Muchea Regional Water Management Strategy

Project No: EP18-104(02)

Prepared for Department of Planning, Lands and Heritage
July 2019

Document Control

Doc name:	Modelling Report Muchea Regional Water Management Strategy				
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	Appendix to Muchea RWMS				

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Abbreviation Tables

Table A1: Abbreviations – Organisations

Organisations	
DPLH	Department of Planning, Lands and Heritage
WAPC	Western Australian Planning Commission

Table A2: Abbreviations – General terms

General terms	
AEP	Annual Exceedance Probability
AHD	Australian height datum
IFD	Intensity-frequency-duration
LSP	Local structure plan
LWMS	Local water management strategy
MIP-SP	Muchea Industrial Precinct Structure Plan
RWMS	Regional water management strategy
WSUD	Water sensitive urban design

Table A4: Abbreviations – units of measurement

Units of measurement	
cm	Centimetre
ha	Hectare
km	Kilometres
m	Metre
m/day	Metre per day
m^2	square metre
m^3/ha	Cubic metre per hectare
m^3/s	Cubic metre per second
m AHD	m in relation to the Australian height datum
mm	Millimetre
mm/hr	Millimetre per hour
n	Manning's n
%	Percentage

1 Introduction

1.1 Background

The Department of Planning, Lands and Heritage (DPLH) engaged Emerge Associates to prepare a regional water management strategy (RWMS) for the Muchea area including the townsite, industrial park and surrounding agricultural land (herein referred to as 'the site') to form a key input into the Western Australia Planning Commission (WAPC) update of the Muchea Industrial Park Structure Plan (MIP-SP). This modelling report is an appendix to the *Muchea RWMS* (Emerge Associates 2019) and is intended to broadly describe the surface water modelling methodology and results for the site and MIP-SP area.

1.2 Previous studies

1.2.1 Ellen Brook Flood Study

The *Ellen Brook Flood Study* (WAWA 1987) was prepared to provide peak flow and flood level estimates at specific locations within the Ellen Brook, from Rutland Road (located approximately 6 km south of the site) to the confluence with the Swan River (approximately 28 km downstream of the site). Two runoff and routing models were utilised (FLOUT and RORB) with results of each being within 8% of each other.

The peak flow and flood elevation identified at Rutland Road was 81 m^3/s and 35.05 m Australian height datum (AHD) respectively for the critical duration event (i.e. 48 hour) (WAWA 1987). Peak flow rates for the 1%, 2% and 4% annual exceedance probability (AEP) event discharging from Railway Parade gauging station (station number 616189 - located approximately 8 km upstream of the Ellen Brook and Swan River confluence) were identified as 97 m^3/s, 86 m^3/s and 75 m^3/s, respectively.

1.2.2 NorthLink WA Stage 2 Waterways Report

The *NorthLink WA Stage 3 Waterways Report* (BG&E 2017) was prepared to document designs of the proposed bridges crossing Ellen Brook at Tonkin Highway (Bridge 1796) and Brand Highway Deviation (Bridge 1798) for NorthLink WA Stage 3. A RORB model of the Ellen Brook catchment was created to replicate the *Ellen Brook Flood Study* (WAWA 1987). The temporal patterns and rainfall depth from the BG&E (2017) critical duration event (i.e. 48 hour) were utilised. Pre-development peak flow rates at Tonkin Highway, Brand Highway Deviation and Rutland Road were 64.5 m^3/s, 69.7 m^3/s and 79.3 m^3/s, respectively.

1.2.3 MEN Local Structure Plan 1 Local Water Management Strategy

The *Muchea Employment Node Local Structure Plan 1 Local Water Management* (LWMS) was prepared by Emerge Associates (2017) to support water management planning for the Local Structure Plan (LSP) 1 area on behalf of Sirona Capital Management Pty Ltd.

LSP 1 covers an area of 149 ha and allows for the creation of 23 transport related industrial lots. The development is targeted towards service-based and complementary uses such as transport, livestock, fabrication, warehousing, wholesaling and general commercial. Development of the LSP has allowed for integration of stormwater drainage and retention of existing environmental assets including waterways, wetlands and native vegetation within dedicated reserves.

Water management objectives for LSP 1 are to mimic the existing hydrological regime of the site whilst protecting properties and the downstream environment from flooding and pollution. The LSP 1 design objectives seek to deliver best practice outcomes using a water sensitive urban design (WSUD) approach, including detailed management approaches for:

- Potable water consumption
- Flood mitigation
- Stormwater quality management
- Groundwater management
- Waterway management.

1.3 Modelling methodology

Innovyze XPSWMM v2018.1 hydrologic and hydraulic modelling software was used to model the Muchea RWMS area.

A 1D-2D coupled hydrological model encompassing the site and upstream contributing catchments was developed to provide a regional scale understanding of the existing surface water hydrological regime, herein referred to as the 'existing model'. Specifically, the existing model was prepared to characterise the pre-development peak flows entering and exiting the site and illustrate the extent and depth of flooding in minor and major rainfall events across the site. **Section 2** details the existing model assumptions.

A 1D model was developed for the MIP-SP area to estimate flood detention required to meet existing peak flow rates leaving the MIP, herein referred to as the 'post-development model'. The modelling assumptions used for the post-development environment are detailed in **Section 3**.

The hydrologic component of the existing and post-development models used the runoff and Laurenson runoff-routing methods respectively, to simulate runoff from design storm events. Key assumptions regarding the hydrologic component include:

- Intensity Frequency and Duration (IFD) data was derived from the Bureau of Meteorology (BoM 2018). Temporal patterns given in *Australian Rainfall and Runoff* (Ball J *et al.* 2016) were used with the IFD values.
- Runoff was proportional to slope, area, infiltration and percentage of imperviousness of a catchment, as well as catchment width for the existing model.
- Rainfall on grid was applied over the 2D area for the existing model, utilising constant time intervals to generate absolute depth rainfall from IFD data (BOM 2018).
- Infiltration rates and percentage imperviousness were selected based on experience with model preparation for similar soil conditions.

- Catchment areas and slopes for both models were determined from topographical contours, the digital terrain model, aerial imagery and/or assessment of existing hydraulic structures.

Runoff from each catchment was routed through the catchment using the hydraulic component of XPSWMM. Generally, assumptions associated with the hydraulic component of the model include:

- Virtual links (i.e. purely for model construction, not equivalent to on-ground flows) between nodes within a catchment were given the length of 10 m and slope of 0.05 to minimise the lag time of conveying the water from a catchment node to a 'storage' node, a 'dummy intermediate' node or a conduit/link.
- Links between catchment storages act as conveyance channels (e.g. they represented sheet flow within roads in a major, i.e. 1% average exceedance probability (AEP), rainfall event). These links were given lengths and slopes that are representative of the site conditions and actual pathway lengths between catchments.
- Both links were designed with a width of 5 m, roughness (Manning's n) of 0.014 and are trapezoidal in shape. This allows for easy conveyance and represents concrete pipes and road surfaces within the model.

2 Muchea RWMS Area Existing Model

2.1 Modelling upstream catchments

The existing model accounts for runoff from catchments upstream of the site by modelling these in 1D. How these 1D hydrologic and hydraulic components were linked to the 2D components is described in **Section 2.2** below.

2.1.1 Hydrology

The extent of upstream catchments are shown in **Figure 1**. These areas were derived from the broadscale H*ydrographic Catchments – Subcatchments* dataset (DWER 2018) and further sub-divided to create the following sub-catchments:

- Contributing to tributaries of Chandala Brook to the north-west of the site.
- Contributing to the waterways that discharge into the MIP-SP.
- Contributing to tributaries of Ellen Brook to the east of the site.
- That align with the southern boundary of the site.

Land use type across the site were identified based upon the Gozzard (2011) *Permeability* dataset, which was based on a qualitative estimate of the permeability of surficial geology across the Swan Coastal Plain. The exception to this were existing roads. Land use areas for each upstream catchment are summarised in **Table 1**.

Table 1: Upstream catchments – existing land use areas

Catchment	Total area (ha)	Road reserve (ha)	Low permeability (ha)	Medium permeability (ha)	Medium to high permeability (ha)	High permeability (ha)	Catchment slope
US_Ct-01	4507	11	958	113	2721	704	0.009
US_Ct-02	3077	5	590	75	1750	657	0.011
US_Ct-03	4330	9	1198	0	1937	1185	0.015
US_Ct-04	9672	14	1009	0	0	8648	0.002
US_Ct-05	5305	27	1257	0	3522	499	0.013
US_Ct-06	858	5	345	0	373	135	0.027
US_Ct-07	1942	0	5	0	0	1937	0.014
US_Ct-08	722	0	24	0	0	698	0.007
US_Ct-09	617	5	127	0	380	105	0.025
Totals	31030	76	5513	188	10683	14568	NA

An “initial loss – continuing loss” infiltration model was adopted to characterise the existing land use types across the upstream catchments, with loss values chosen based on project team experience with similar environments. Manning’s ‘n’ values were determined based upon the surficial geology and vegetation cover identified from aerial imagery for each land use type. These characteristics are summarised in **Table 2**.

Table 2: Land use characteristics

Land use type	Initial loss (mm)	Continuing loss (mm/hr)	Manning's n
Road reserve	1	0.1	0.01
Low permeability	10	1.5	0.15
Medium permeability	20	2.5	0.35
Medium to high permeability	30	3	0.3
High permeability	40	4	0.35

2.1.2 Hydraulics

Chandala Brook, which discharges into the site along the north-west boundary, was represented as a wide 1D trapezoidal link. Specifically, the trapezoidal link has a 30 m wide base, 1:20 side slopes, is nominally 2 m deep and has a manning's 'n' of 0.03. Upstream catchments US_Ct-01, US_Ct-02, US_Ct-03 and US_Ct-04 discharge into this 1D link prior to entering the site at the boundary of the 2D modelled area (see **Figure 1**).

2.2 Modelling the RWMS

The 1D hydrologic and hydraulic components of the existing model (as described above) were linked to the 2D hydrologic and hydraulic components through nodes via 1D-2D interfaces and trapezoidal channel sections at the site boundary (see **Figure 1**). It was assumed that all the 1D catchment flows are distributed evenly across the 1D – 2D boundary. Interconnection allows the 1D runoff to enter the 2D modelled area and to exit from 1D components dynamically, depending on the hydraulic head of the connected 2D cells and 1D elements.

2.2.1 Digital terrain model

Spatial data for the site was provided by the Department of Planning Lands and Heritage. Similarly, spatial data for the NorthLink WA highway design was provided by Main Roads WA. This data included aerial imagery, raw LiDAR data, geo-tiff surfaces, and triangulated irregular network data. The 2 m grid geo-tiff surface files were converted using Blue Marble Global Mapper 18 into a grid file to produce a Digital Terrain Model within the XPSWMM model software.

2.2.2 Hydrology

In addition to the land use types described in **Section 2.1.1**, the 2D modelled area includes land use types for the townsite and other rural residential lots, and a portion of the Ellen Brook itself. The land use areas within the site are summarised in **Table 3**. This includes the area set aside for the proposed NorthLink road reserve.

Table 3: 2D modelled area – land use areas

Land use type	Area (ha)
Road reserve	65
Low permeability	2464
Medium permeability	0
Medium to high permeability	844
High permeability	2582
Muchea townsite and rural residential	515
Ellen Brook	112
Total	6582

Initial loss, continuing loss, and Manning's 'n' values for the townsite and other rural residential lots and Ellen Brook are summarised in **Table 4**. Otherwise, loss rates and Manning's 'n' values are consistent with those summarised in **Table 2**.

Table 4: 2D modelled area - land use characteristics

Land use type	Initial loss (mm)	Continuing loss (mm/hr)	Mannings' n
Townsite and rural residential	20	2	0.02
Ellen Brook	5	1	0.03

2.2.3 Hydraulics

The 2D modelled area incorporates three bridges and 165 culvert sets. The bridges cross Chandala and Ellen Brooks at the proposed Brand Highway Deviation, existing Brand Highway and proposed Tonkin Highway. The culvert sets are generally located along existing major road reserves across the site, proposed road reserves associated with NorthLink, within the Muchea townsite, and along the railway.

Historical culvert data was provided by DPLH via relevant parties (i.e. Public Transport Authority and Main Roads WA). In addition, a culvert survey was completed in March 2019 (engaged by DPLH) following a site visit in October 2018 and review of the available data indicating existing data was insufficient to inform the modelling process. Proposed culvert designs (inclusive of reports and design drawings) for NorthLink WA highway design were provided by Main Roads WA (NorthLink WA 2015; BG&E 2017, 2018a, b).

2.2.4 Tailwater

Ellen Brook from the southern site boundary towards the south was represented as a 1D trapezoidal link. The trapezoidal link has a 30 m wide base, 1:20 side slopes, is nominally 3 m deep and has a manning's 'n' of 0.03. The 1D channel discharges from the site as a free outfall at a sufficient distance downstream of the 2D modelled area (550 m) to avoid impacting the results at the site boundary.

2.3 Results

2.3.1 Critical duration analysis

Previous studies (as described in **Section 1.2**) and critical event analysis of the 1D upstream catchments, informed the selection of the design storm durations. A comparison of the 2 hour, 6 hour and 48 hour major (1% AEP) rainfall event was made in order to determine the major contributor to inundation within Ellen Brook and peak flow rates at the ultimate discharge location along the southern boundary of the site. Based on this analysis, the 48 hour duration was determined to be the critical duration event for both the minor (10% AEP) and major rainfall events.

2.3.2 Peak flow rates

Existing peak flow rates at key controls points (i.e. the three road bridges and discharge point from site) within Chandala and Ellen Brook are provided in **Table 5** in the minor and major rainfall events. Peak flow rates at other locations can be extracted from the model on request.

Table 5: Peak flow rates within Chandala and Ellen Brook at key control points

Key control point	Minor rainfall event (m^3/s)	Major rainfall event (m^3/s)
Proposed Brand Highway Deviation	25.7	64.7
Brand Highway	24.7	63.2
Proposed Tonkin Highway	24.8	56.2
Discharge from site	23.3	63.0

2.3.3 Flood mapping

Flood mapping over the site has been prepared for the major and minor events, and are shown in Figure 11 and Figure 12 of the RWMS, respectively. The flood mapping has been resolved to a suitable resolution for regional scale investigations (e.g. rezoning of local planning schemes).

3 MIP-SP Post-development Model

3.1 Modelling of upstream catchments

The upstream catchments to the east of the MIP-SP area (i.e. US_Ct-06 and US_Ct-09) were consistent with the description provided in **Section 2.1**.

3.2 Modelling of the MIP-SP

3.2.1 Hydrology

The post-development catchments are shown in Figure 18 of the overarching RWMS. These areas were derived by considering the following:

- The MIP and existing LSP 1 boundaries.
- Existing road reserves and culverts, which act as control points for runoff.
- Location of indicative waterways and existing topographical contours.
- Location of existing sand quarries (i.e. Ct-08 and Ct-11).

Land use types across the site were based upon the assumption that existing road reserves will be maintained and that indicative waterway foreshore areas, wetlands and associated buffers, and the identified Ellen Brook floodplain (1% AEP extent) will not be developed. The RWMS describes how these areas were determined (see Section 9).

The remaining area (referred to as 'potential development area' in Figure 18) are divided into lots and road reserve. It is assumed that road reserves will make up approximately 12% of the potential development area within each catchment. This assumption is based upon the LSP 1 layout.

Land use areas for each catchment are summarised in **Table 6**.

Table 6: Post-development land use areas

Catchment	Total area (ha)	Indicative waterway foreshore area or Ellen Brook / Chandala floodplain (ha)	Indicative wetland and buffer (ha)	Lots (ha)	Road reserve (ha)
Ct-01	125	11	0.1	110	3
Ct-02	18	1	0	15	2
Ct-03	147	0	0	145	2
Ct-04	15	4	0	8	3
Ct-05	197	23	0	164	10
Ct-06	31	0	0	27	3
Ct-07	143	0	5	136	2
Ct-08	20	0	0	19	1

Table 6: Post-development land use areas (continued)

Catchment	Total area (ha)	Indicative waterway foreshore area or Ellen Brook / Chandala floodplain (ha)	Indicative wetland and buffer (ha)	Lots (ha)	Road reserve (ha)
Ct-09	152	9	0	139	5
Ct-10	169	10	0	153	5
Ct-11	33	0	0	31	1
Totals	1049	59	5.1	948	36

An "initial loss – continuing loss" infiltration model was adopted for the post-development model. Loss rates for the indicative waterway foreshore areas, Ellen Brook / Chandala Floodplain, and wetlands and their indicative buffers are consistent with those described in **Table 2** and **Table 4**. Loss values chosen to characterise post-development land use types are based on project team experience with similar industrial developments. These characteristics are summarised in **Table 7**.

Table 7: Post-development land use characteristics

Land use type	Initial loss (mm)	Continuing loss (mm/hr)	Manning's roughness (n)
Lots - roof	15	0.1	0.014
Lots - impervious	15	0.1	0.02
Lots - pervious	25	3.5	0.05
Road reserve - bitumen	15	0.1	0.014
Road reserve - verge	15	2	0.04

The infiltration rates used in the post-development model were predominantly based upon the following assumptions:

- Steeper areas (i.e. development areas in the eastern portion of the MIP) are assumed to have lots that are 85% impervious, while lots within flatter areas are assumed to be 95% impervious. It is assumed that treatment of the small rainfall event on lots (i.e. the first 15 mm of rainfall) will be treated at-source within lots.
- Indicative waterway foreshore areas, Ellen Brook / Chandala Floodplain, wetlands and their indicative buffers will likely contain vegetation (existing or planted) and mulch over a sand-based landscape mix, which has a relatively high permeability.
- Pervious areas within lots are assumed to have similar loss rates to medium to high permeabilty soils
- Road reserves are assumed to be 60% bitumen and 40% verge. Road verges have reduced infiltration rates compared to pervious areas to account for driveways, footpaths and parking. It is assumed that treatment of the small rainfall event on road reserves (i.e. the first 15 mm of rainfall) will be treated as close to source as possible.
- There will be no infiltration on roads, pavements and driveways. There will however be some minor absorption storage loss, this is accounted for in the initial and continuing loss values.

3.2.2 Hydraulics

Existing and proposed culverts, as described in **Section 2.2.3**, are maintained in the MIP-SP post-development model.

Runoff from each catchment (above the small rainfall event) and any upstream catchments (see **Figure 1**) is conveyed towards a storage node via virtual links. The exception to this are Ct-08 and Ct-11; these catchments are currently sand quarries that fully retain runoff.

Storage nodes were modelled as 1 m deep basins with vertical side slopes. The infiltration rates assumed within these storage nodes are conservative. An infiltration rate of 0.5 m/day was used for catchments located to the west of Great Northern Highway given the flatter topography, proximity to the floodplain and shallow groundwater (see Section 3 of the RWMS). To the east of Great Northern Highway, a higher infiltration rate of 1 m/day was used. These infiltration rates should be refined for future structure planning through on site geotechnical investigations and permeability testing.

Volumes leaving the system through evapotranspiration were assumed to be negligible when compared to the total runoff volume. XPSWMM default evapotranspiration assumptions are therefore used.

3.3 Results

As discussed in **Section 3.2.1**, it is assumed that the small rainfall event will be appropriately treated as close to source as possible. Runoff beyond the small rainfall event will be conveyed towards detention structures within lots and across the development area.

It is assumed that runoff within Ct-08 and Ct-11 will be fully retained to be consistent with the existing environment.

Storage nodes for the remaining catchments were sized to ensure the allowable peak outflow for each catchment in the major rainfall event (i.e. 1% AEP 48 hour) are achieved. The allowable peak flow for each catchment (summarised in **Table 8**) were determined by combining peak flow hydrographs across the catchment boundary from the existing model (see **Section 2**). The combined peak flow hydrographs accounted for:

- Flow within culverts (both existing and proposed)
- Flow over Great Northern Highway
- Overland flow at the interface of the existing LSP 1
- Overland flow at the interface of the potential development area and indicative floodplain within Ct-09.

Detention requirements required to achieve allowable peak flow rates are summarised in **Table 8**. Ct-04 is not required to provide additional storage (beyond treating the small rainfall event) to achieve the allowable peak flow rate. Ct-06 has a relatively high detention requirement (2,510 m^3/ha) due to the fact that the allowable outflow of 2.4 m^3/s is significantly lower than the inflow from Ct-07 of 5.4 m^3/s. For the remaining catchments, the required detention ranges from approximately 245 m^3/ha to 815 m^3/ha.

Table 8: Peak flow rates and post-development detention requirements

Catchment	Inflow peak flow rate (m^3/s)	Allowable outflow peak flow rate (m^3/s)	Total development area (ha)	Detention requirement (m^3)	Detention requirement (m^3/ha of developable area)	Peak discharge achieved (m^3/s)
Ct-01	1.7	5	114	66440	585	5
Ct-02	2.4	3.1	17	4230	245	3.1
Ct-03	0	1.6	146	114490	780	1.6
Ct-04	5.9	6.2	11	0	0	5.6
Ct-05	0.9	5.9	174	115210	665	5.9
Ct-06	5.3	2.4	30	75540	2510	2.4
Ct-07	0.7	5.3	138	75540	545	5.3
Ct-08	0	0	20	Fully retained		0
Ct-09	4.2	5.8	144	116850	815	5.8
Ct-10	0.4	4.2	158	111990	705	4.2
Ct-11	0	0	32	Fully retained		0

4 References

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Figures

Figure 1: Existing upstream catchments and 2D modelled area.

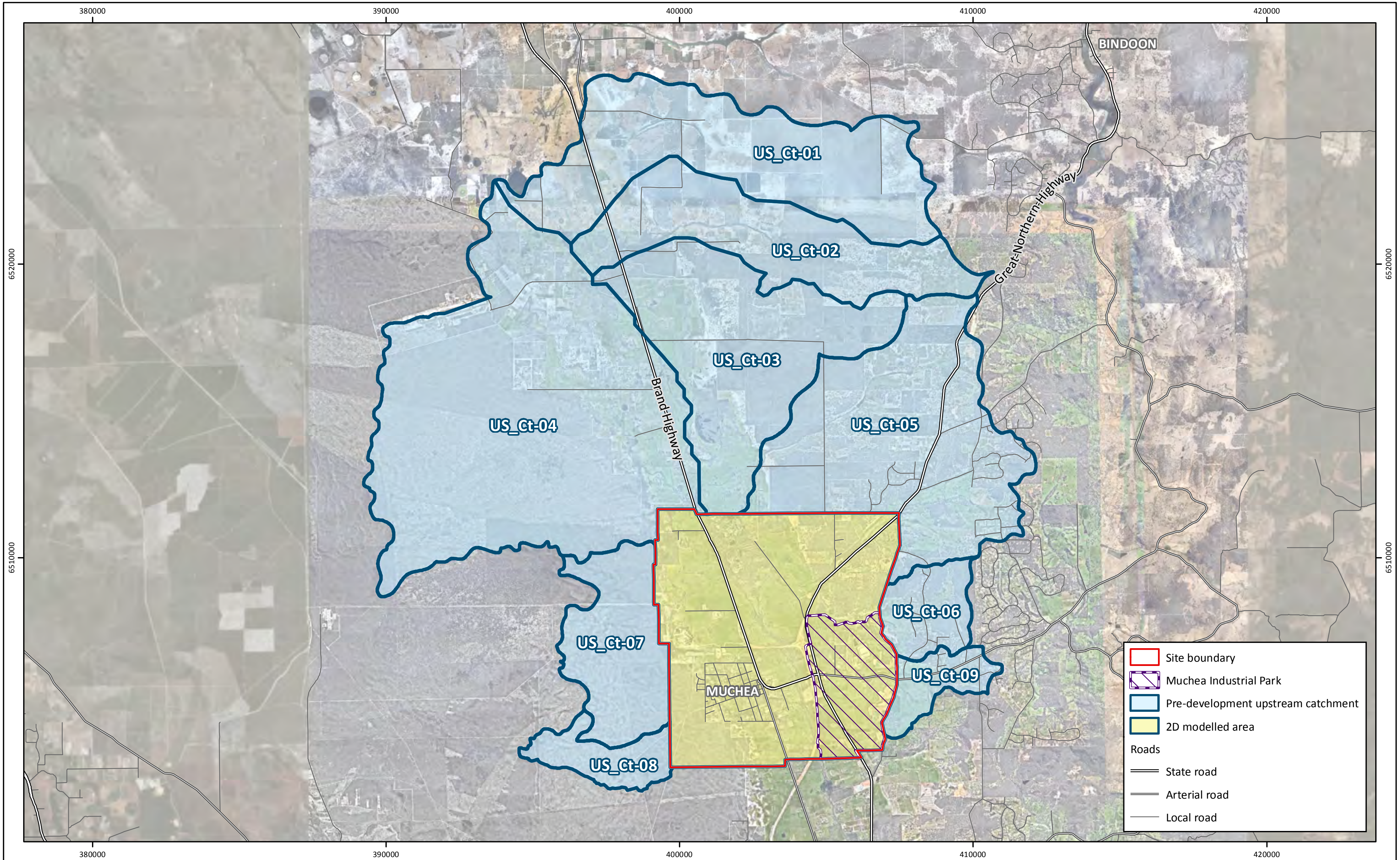

Figure 1: Existing Upstream Catchments and 2D Modelled Area

Project: Modelling Report
DPLH Muchea Regional Water Management Strategy
Client: Department of Planning, Lands and Heritage

Plan Number:
EP18-104(02)--F19
Drawn: KNM
Date: 13/05/2019
Checked: ASC
Approved: RLE
Date: 06/06/2019

N

0 2 4 6
Kilometres
Scale: 1:170,000@A4
GDA 1994 MGA Zone 50

emerge ASSOCIATES

Appendix F

EBICG Surface Water Quality Monitoring Summary Tables

Table F1. Average measured value and (standard deviation) for key physiochemical parameters (DWER 2018c)

Analyte	Units	SCWQIP target	NWQMS trigger value*	Monitoring location								
				EBN3	EBN4	EBN6	EBN7	EBN8	EBN9	EBN10	EBN21	EBN23
pH	pH units	-	6.5 - 8.0	7.34 (0.19)	6.95 (0.22)	7.33 (0.26)	4.58 (0.53)	6.24 (0.28)	7.10 (0.19)	4.72 (0.62)	7.47 (0.23)	7.51 (0.28)
Electrical conductivity (EC)	mg/L	-	66- 165**	711 (170)	634 (102)	1643 (182)	2662 (232)	2481 (240)	797 (101)	2808 (550)	1016 (110)	495 (48)
Total nitrogen (TN)	mg/L	1 - 2	1.2	4.10 (0.60)	2.93 (0.30)	1.26 (0.21)	0.66 (0.13)	2.34 (0.87)	2.02 (0.35)	0.57 (0.09)	3.67 (0.46)	4.10 (0.28)
Total phosphorous (TP)	mg/L	0.1 - 0.2	0.065	1.175 (0.322)	0.606 (0.138)	0.035 (0.013)	0.028 (0.018)	0.108 (0.060)	0.351 (0.114)	0.012 (0.004)	0.311 (0.149)	0.703 (0.105)

** NWQMS default trigger values for slightly disturbed ecosystems for lowland rivers in south-west Australia (ANZECC and ARMCANZ 2000).*

*** NWQMS trigger value based on approximate conversion from mS/cm to mg/L. Conversion factor of 550.*

Some outliers have been removed.

Table F2. Average measured value and (standard deviation) of key metal concentrations (DWER 2018c)

Analyte	Units	LOR	NWQMS trigger value*	Monitoring location								
				EBN3	EBN4	EBN6	EBN7	EBN8	EBN9	EBN10	EBN21	EBN23
Aluminum	mg/L	<0.01	0.055	0.613 (0.870)	0.238 (0.043)	-	6.355 (2.857)	0.275 (0.364)	0.173 (0.102)	1.792 (0.943)	-	0.250 (0.169)
Arsenic	mg/L	<0.001	0.013	0.004 (0.0013)	0.001 (0.0003)	-	0.001 (0.0002)	0.002 (0.0018)	0.001 (0.0004)	0.001 (0.0002)	-	0.005 (0.0043)
Cadmium	mg/L	<0.0001	0.0002	0.0001 (0)	0.0001 (0)	-	0.0001 (0.00013)	0.0001 (0.00003)	0.0003 (0.00036)	0.0001 (0.00002)	-	0.0001 (0)
Chromium	mg/L	<0.001	0.001	0.002 (0.0019)	0.003 (0.0102)	-	0.001 (0.0007)	0.002 (0.0013)	0.001 (0)	0.001 (0.0003)	-	0.002 (0.0004)
Copper	mg/L	<0.001	0.0014	0.003 (0.0015)	0.002 (0.0007)	-	0.001 (0.0009)	0.002 (0.0033)	0.002 (0.0019)	0.001 (0.0007)	-	0.001 (0.0006)
Iron	mg/L	<0.01	0.3	5.48 (6.45)	2.04 (0.58)	-	5.04 (2.24)	14.19 (26.51)	1.54 (0.40)	5.03 (3.52)	-	0.96 (0.49)
Mercury	mg/L	<0.0001	0.00006	0.0001 (0)	0.0001 (0.00006)	-	0.0001 (0.00001)	0.0001 (0.00002)	0.0001 (0)	0.0001 (0)	-	0.0001 (0)
Manganese	mg/L	<0.001	1.9	-	-	-	0.098 (0.042)	-	0.003 (0.002)	0.028 (0)	-	-
Nickle	mg/L	<0.001	0.011	0.001 (0.0008)	0.002 (0.0010)	-	0.034 (0.0128)	0.004 (0.0035)	0.003 (0.0015)	0.012 (0.0057)	-	0.002 (0.0014)
Lead	mg/L	<0.001	0.0034	0.001 (0.0004)	0.007 (0.0295)	-	0.002 (0.0013)	0.002 (0.0023)	0.001 (0)	0.002 (0.0015)	-	0.001 (0.0003)
Zinc	mg/L	<0.005	0.008	0.010 (0.0050)	0.006 (0.0027)	-	0.046 (0.0160)	0.009 (0.0109)	0.005 (0.0017)	0.016 (0.0075)	-	0.011 (0.0066)

**Default trigger values for slightly-moderately disturbed freshwater systems for a 95% level of protection (ANZECC and ARMCANZ 2000).*
Some outliers have been removed.
Results below the LOR are reported as the LOR.