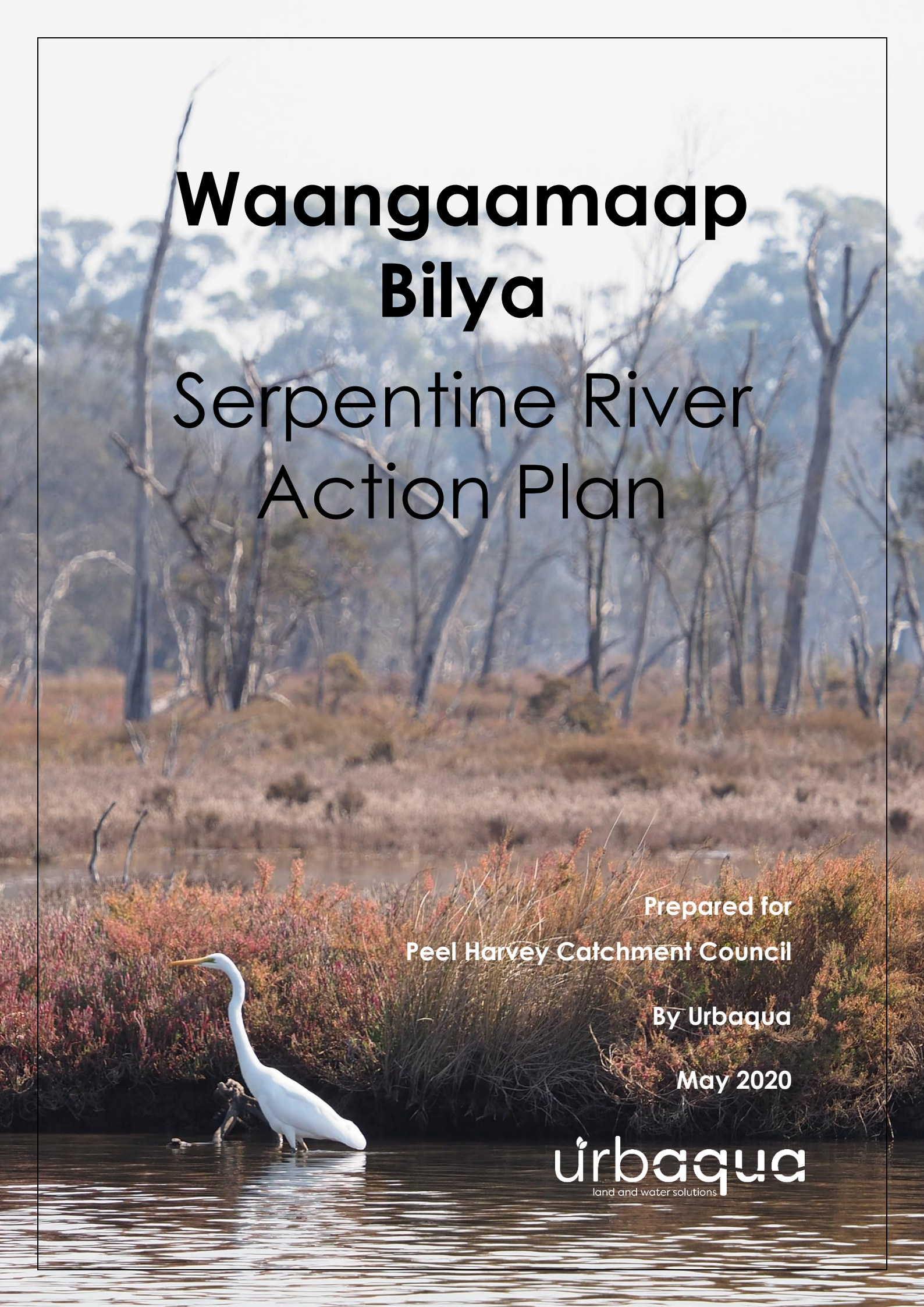
Waangaamaap Bilya

Serpentine River Action Plan



Prepared for

Peel Harvey Catchment Council

By Urbaqua

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1. Peel Harvey Catchment Council;
2. Alcoa Foundation;
3. Department of Water and Environmental Regulation;
4. Department of Communities; and,
5. Local Bindjareb Noongar Community.

EXECUTIVE SUMMARY

The Serpentine River is one of the three main rivers that discharge into the Peel-Harvey Estuary, along with the Murray River and Harvey River. As with most rivers in the south west of Western Australia, the Serpentine River catchment has been subject to significant disturbances since European settlement in the 1830s from agriculture, urban expansion, training and dam construction. Along with these past and current pressures, the Serpentine River also faces threats from the impacts of projected decline in rainfall and sea-level rise.

The River Action Plan (RAP) has been prepared to provide a basis for rehabilitation works and a summary of baseline conditions to reference future works against. The document was prepared in partnership between the Peel-Harvey Catchment Council and Urbaqua, with funding provided by the Aloca Foundation under the *Connecting Corridors and Communities: Restoring the Serpentine River* project. The RAP addresses approximately 38 km of river from the Lowlands Nature Reserve to the Peel-Harvey Estuary, divided into eight (8) reaches that vary from meandering natural channels, to artificial drains to estuarine systems.

The RAP was prepared based on field inspections of the reaches and desktop analysis of aerial imagery and previous investigations. Each reach was assessed in accordance with the Department of Water and Environmental Regulation's *River Restoration Manual* (WRC, 1999), specifically the Pen-Scott method that grades foreshore between grades A (pristine) and D (ditch). Scoring of the foreshore condition allowed for determination of priority areas for rehabilitation.

The majority of the river demonstrated the impacts of land use pressures and the construction of levee systems. There is considerable erosion and instability at the downstream end of Reach 1 that can be attributed to bed lowering at the confluence with the Birrega Main Drain. Riparian vegetation on the levees in Reaches 2, 3 and the majority of 4 is either non-existent or dominated by weeds. The use of these reaches by 4WDs has also caused damage to the banks. Poor water quality in these reaches is also emphasised by the observation of algae and the presence of invasive aquatic vegetation such as typha and red water fern, and weeds such as water hyacinth.

Reach 5 between Lake Amarillo and Guanaup Pool resumes a meandering profile with a series of deep pools. The channel has been modified in the past through the construction of bypass channels to reduce flooding in adjacent rural areas. Grazing has degraded riparian vegetation along the majority of the reach. A common theme in the estuarine reaches (6, 7 and 8) is the presence of dying trees, particularly around tidal flats. Reach 8 has the most urban setting, and water recreation has caused erosion of many foreshore areas.

The assessment also identified areas along the river with good quality remnant vegetation, a diversity of stream habitats and minimal bank erosion that are potentially references for future rehabilitation work. Areas within the Lowlands Nature Reserve (Reach 1), downstream of Lake Amarillo (Reach 5) and upstream of the Kwinana Freeway (Reach 7) are examples for further documentation.

Common themes for management of the river emerged from the field and desktop assessment, consistent with the objective of the *Connecting Corridors and Communities: Restoring the Serpentine River* project. A summary of these recommendations is provided in Table 1, with opportunities to restore the ecological condition of the river and engagement with the community to increase knowledge and appreciation of the value of the Serpentine River.

Table 1: Serpentine River Actions and Recommendations Summary

Priority	Location	Action
1. Improve ecological health of the Serpentine River and surrounds		
Short term	Reaches 1 to 7	Provide controls to prevent stock and vehicle access
Short term	Reach 2	At high value areas, undertake trials for weed removal, bank stabilisation and riparian vegetation rehabilitation
Short term	Reaches 3 & 4	Remove car bodies, bulk litter and informal recreational facilities
Short term	Reaches 2 to 5	Continue to control aquatic weeds such as water hyacinth and consider thinning of other invasive aquatic species such as typha and red water fern.
Short term	Reaches 1,2,4,5 & 8	Stabilise banks to protect healthy trees from bank collapse
Short term	Reach 4	Trial the importation of woody debris to improve habitat
Short term	Reach 5	Continue to monitor the pool depths in Reach 5 in conjunction with the Punrak Drain phosphorus-binding clay trials
Long term	Reaches 1 & 2	Investigate the instability from bed lowering at the Birrega confluence
Long term	Reach 2	Consider relocation of the fence on the western bank to prevent direct access but allow community use of levee
Long term	Reaches 2 & 3	Trap and remove sediment here to buffer downstream reaches
Long term	Reach 3	Consider implementing diversions to improve water quality treatment
Long term	Reach 4	Investigate sources of nutrients within the tributaries and catchment
Long term	Reach 8	Retrofit WSUD in any local catchment with low water quality discharge
Long term	Reach 8	Replace ineffective erosion protection structures
2. Increase community environmental and cultural knowledge, awareness and capacity		
Short term	Reach 2	Contact landholders to discourage equestrian access to the river
Long term	Reaches 2 & 7	Establish education sites with signage of the project profile, river values and restoration efforts (including actions for the community)
3. Increase vegetation connectivity to improve aquatic, riparian and terrestrial habitats		
Short term	Reach 5	Protect high quality riparian vegetation downstream from Lake Amarillo
Short term	Reach 3 & 4	Protect existing trees and plant additional trees to improve cockatoo habitat
Long term	Reaches 1 to 3	With landholders, establish a vegetation corridor between Hymus Swamp and Lowlands Nature Reserve
Long term	Reach 1	Work to replace invasive grasses with native ground cover and shrubs.
Long term	Reaches 4 to 6	Improve riparian vegetation in areas of bare ground and ground cover
4. Enhance relationships with the Bindjareb Noongar community including the provision of skills and training for future employment opportunities		
Short term	All reaches	Identify and build opportunities for training and employment linked to working on country.
Short term	All reaches	Ensure due diligence is followed in implementing consultation, engagement and on-ground works under the Native Title Act.
Short term	All reaches	Work with contractors to identify opportunities for Bindjareb Noongar procurement and training when implementing on-ground works.
Long term	All reaches	Identify and implement related skills based training opportunities for the local Bindjareb Noongar community linked to working on country.
5. Increase stakeholder networks and connections		
Short term	Reach 8	Work with the DoT to enforce 5 knot speed limit to prevent boat wake

Long term	Reaches 4 to 7	Advocate for the establishment of the Peel Regional Park to protect the river downstream of the Peel Main Drain confluence
6. Increase knowledge and capacity of private landholders, groups and organisations to deliver projects		
Short term	Reaches 1 & 8	Provide resources to landholders to identify and eradicate weeds
Short term	Reaches 3 & 4	Encourage landholders to control feral animals
Short term	Reach 1	Provide resources to landholders to identify erosion risks
Short term	Reach 8	Monitor new development in Coodanup to ensure suitable water quality and no sediment mobilisation
Long term	All Reaches	Encourage land holders to reduce nutrient inputs within the catchment
Long term	Reaches 1, 6 & 8	Encourage land holders to plant local natives within the riparian zone
7. Mitigate impacts of climate change		
Short term	Reaches 4 to 8	Investigate die-off of trees and implement recommendations
Long term	Reaches 2, 3 & 5	Consider increasing connection with fringing wetlands

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1 INTRODUCTION

The Serpentine River Action Plan (RAP) has been prepared to assess the current state of the river and guide future restoration actions. Conservation and restoration of the river is paramount to protecting the environmental, economic, social, and heritage values of the river and the Peel-Harvey Estuary. The river has been assessed from downstream of the Lowlands Nature Reserve and has identified areas of high priority for on-ground works. The document outlines the findings of field inspections and desktop data review and presents recommendations for roles, responsibilities and timeframes to implement the RAP.

1.1 Project Aims

The Serpentine RAP has been prepared consistent with the Peel-Harvey Catchment Council's (PHCC) vision for the catchment:

The Peel-Harvey catchment is once again a flourishing network of interconnected, productive landscapes, with diverse, healthy and resilient ecosystems, globally and locally recognised, acknowledged and embraced for its environmental significance. It is wisely managed by a community that values it – people working together for a healthy environment.

PHCC Strategic Directions 2019-2026 (PHCC, 2019) provides the goals that guide the preparation of the RAP, namely;

- Influence key decision-makers for better governance;
- Facilitate collaborative adaptive management;
- Deliver quality environmental outcomes; and,
- Engage and enable individuals and communities.

Specifically the Serpentine RAP is a key component of the PHCC and Alcoa Foundation's *Connecting Corridors and Communities: Restoring the Serpentine River* project. The project will be achieved through a collaborative approach to improve the health, biodiversity, ecosystem health through engagement with private landholders and the Bindjareb Noongar community, focusing on the riparian zones. The aims for the project are:

- Improve ecological health of the Serpentine River and surrounds;
- Increase community environmental and cultural knowledge, awareness and capacity;
- Increase vegetation connectivity to improve aquatic, riparian and terrestrial habitats;
- Enhance relationships with the Bindjareb Noongar community including the provision of skills and training for future employment opportunities;
- Increase stakeholder networks and connections;
- Increase knowledge and capacity of private landholders, groups and organisations to deliver projects; and,
- Mitigate impacts of climate change.

The RAP has been prepared to addressing these aims through a combination of field inspections and desktop review of existing datasets. Specifically, the RAP provides a summary of the river condition to determine priority sites for future restoration actions. The RAP also acts as a reference document outlining baseline conditions. The methodology used to assess the river condition is replicable and the condition should be reassessed at regular intervals to review the performance of restoration works and identify any new threats that require intervention.

1.2 Preparation

Preparation of the Serpentine River Action Plan included a review of existing studies and available data sets supported by field assessments to ground truth desktop findings and consultation with relevant stakeholders. The key data sets and methodology are outlined below.

1.2.1 Existing studies

The Serpentine River Action Plan has been prepared having consideration of a number of existing studies as outlined below. Key considerations included existing land use, landform and vegetation.

- Water quality improvement plan for the rivers and estuary of the Peel-Harvey system – phosphorus management (EPA, 2008);
- Managing releases for the Serpentine River: allocation statement (DWER, 2017a);
- Peel-Harvey Catchment Nutrient Reports 2015 and 2017 update (DWER, 2017b, c, d, e);
- Lower Serpentine hydrological studies: land development, drainage and climate scenario report (DoW, 2015); and,
- Draft Lower Serpentine river action plan (unpublished) (City of Mandurah, 2007).

The RAP has also been prepared in parallel with the River Health Assessment of the Serpentine River undertaken by the Centre for Sustainable Aquatic Ecosystems (2020) at Murdoch University. The River Health project includes assessment of the ecological condition at five sites (Reaches 1 and 2) to provide a baseline to quantify the effects of future management actions. Sampling focused on sampling fish, crayfish and macroinvertebrates, and water quality assessments. Preliminary results are discussed further in Section 2.1.

1.2.2 Consultation

The RAP was prepared by PHCC and Urbaqua staff in consultation with:

- The Department of Water and Environmental Regulation who provided staff for field assessments, bathymetry data and information on other DWER projects that relate to the RAP, including the regional estuaries initiative and phosphorus-binding clay trials (discussed further in the condition assessment of Reach 5);
- Local Bindjareb Noongar elders and representatives, through site visits and participation in fieldwork as well as workshops, forums and knowledge sharing events.

1.2.3 Assessment

The field assessment was completed for approximately 38 km of river reaches from Lowlands Nature Reserve to the Peel-Harvey Estuary. The river was divided into eight (8) reaches aligned to significant features on the river including confluences with regional drains, lakes, pools and wetlands. The reaches are shown in Figure 1 and outlined in Table 2.

The field assessment was undertaken consistent with the Department of Water and Environmental Regulation's *River Restoration Manual* (WRC, 1999). PHCC and Urbaqua along with DWER staff, Alcoa staff, volunteers and land owners completed the field assessment in April and May 2019 prior to winter rainfall. The methodology is based on the standardised Pen-Scott method (Pen & Scott, 1995, WRC, 1999) that results in sub-categories for foreshore condition of grades A (pristine) to D (ditch), as shown in Figure 2. Further detail on the assessment methodology, adaptation of

the Pen-Scott methodology and rating system is provided in Attachment 1. The methodology was developed to be repeatable and allow for future assessment by non-technical volunteers.

Field investigations were supported by desktop assessment of data sets including aerial imagery, bathymetry, regional soil and wetland mapping, and helicopter-based photography of the river banks and floodplain commissioned by PHCC in December 2018. Portions of the river were difficult to access due to dense vegetation or waterlogging of surrounding floodplains, and in some cases access was restricted by land ownership, assessment in these areas was solely desktop based.

Plate 1: Community Consultation Photos

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 1 - Serpentine River Action Plan Reaches

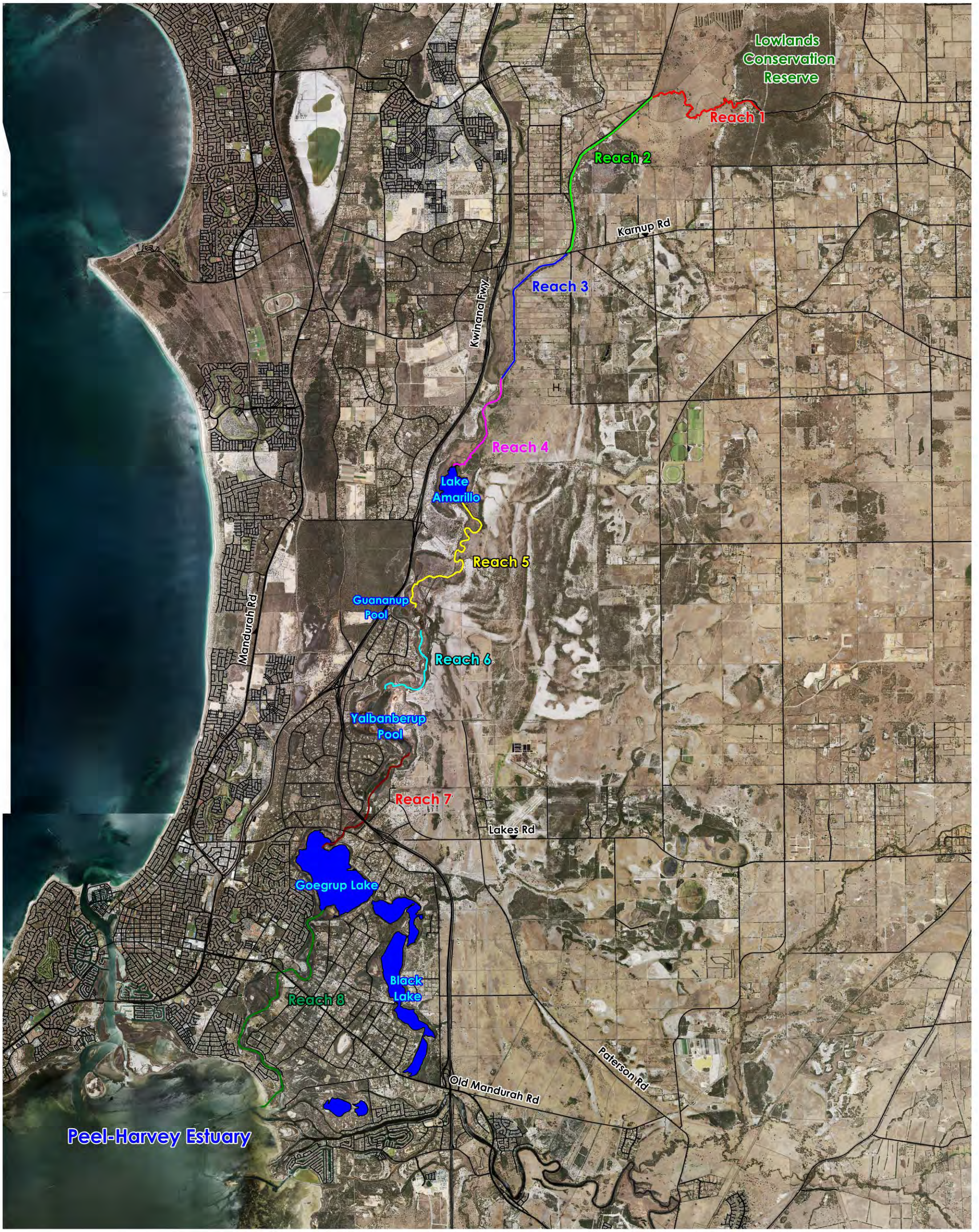

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Table 2: Reach definitions

Reach	Start	Coordinates	Finish	Coordinates	Length	Characteristics	Page Ref
1	Lowlands Nature Reserve	E397047 N6421680	Birrega Main Drain confluence	E394105 N6422151	5 km	Natural meandering channel with continuous canopy on each bank, surrounded by grazing land.	16
2	Birrega Main Drain	E394105 N6422151	Karnup Road	E391850 N6417991	5.2 km	Artificial drain with high levee banks, limited connection with surrounding floodplain and scattered bank vegetation.	22
3	Karnup Road	E391850 N6417991	Peel Main Drain confluence	E390067 N6414606	4.3 km	Extension of the artificial drain (Reach 2) with minimal riparian vegetation and damage from vehicle access.	28
4	Peel Main Drain confluence	E390067 N6414606	Lake Amarillo	E388803 N6412308	3.1 km	Transitional reach from a meandering artificial drain to a natural channel at downstream end. Scattered bank vegetation, aquatic weeds and tidal influence.	34
5	Lake Amarillo	E389030 N6411314	Guananup Pool	E387700 N6408632	5.3 km	Meandering channel with artificial high-flow bypass channels. Downstream from Punrak Drain confluence and features numerous deep pools.	41
6	Guananup Pool	E387925 N6407884	Yalbanberup Pool	E386978 N6406344	3.1 km	Estuarine reach with a wide channel that flows between rural residential (west) and stock grazing (east). Continuous vegetation cover.	47
7	Yalbanberup Pool	E387604 N6404614	Goegrup Lake	E385286 N6402086	3.7 km	Estuarine reach with wide pool areas and low, shallow banks. Vegetation damaged by vehicle and stock access.	52
8	Goegrup Lake	E385311 N6400409	Peel-Harvey Estuary outlet	E383644 N6395159	8.2 km	Estuarine reach through urban and rural residential areas that is used extensively for boating and recreation.	58

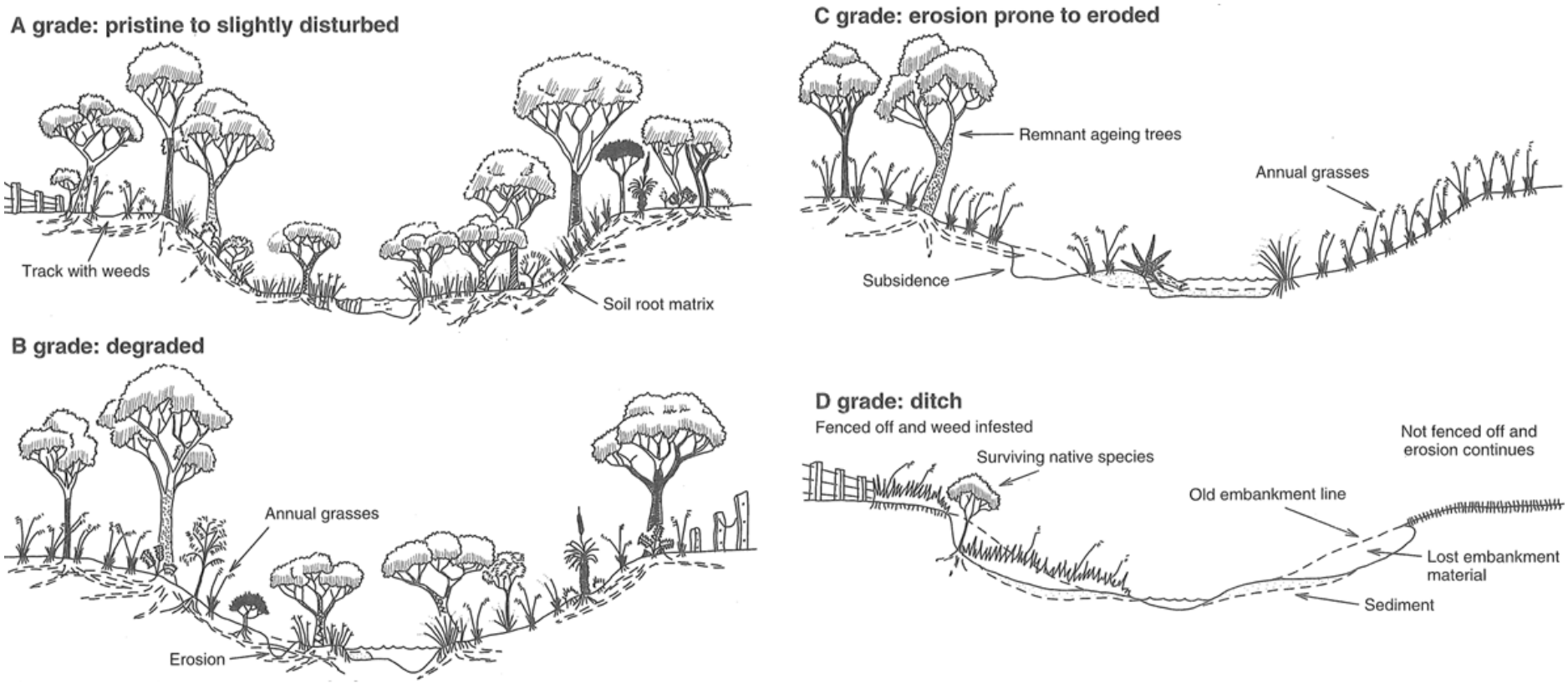


Figure 2: Pen-Scott Foreshore Condition Assessment (Pen & Scott, 1995)

A Grade Foreshore

A1: Pristine
The river embankments and floodway are entirely vegetated with native species, and there is no evidence of human presence or livestock damage.

A2: Near pristine
Native vegetation dominates. Some introduced weeds may be present in the understorey, but not to the extent that they displace native species. Otherwise there is no evidence of human impact. A river valley in this condition is as good as will be found today.

A3: Slightly disturbed
Native vegetation dominates, but there are some areas of human disturbance where soil may be exposed and weeds are relatively dense (such as along tracks). The native vegetation would quickly recolonise the disturbed areas if human activity declined.

B Grade Foreshore

B1: Degraded - weed infested
Weeds have become a significant component of the understorey vegetation. Although native species are dominant, a few have been replaced by weeds.

B2: Degraded - heavily weed infested
In the understorey, weeds are about as abundant as native species. The regeneration of some tree and large shrub species may have declined.

B3: Degraded - weed dominated
Weeds dominate the understorey, but many native species remain. Some trees and large shrub species may have declined or disappeared altogether.

C Grade Foreshore

C1: Erosion prone
Trees remain, and possibly some large shrubs or tree grasses, but the understorey consists entirely of weeds, mainly annual grasses. The trees are generally resilient or long lived species but there is little or no evidence of regeneration. The shallow-rooted weedy understorey provides no support to the soil, and only a small increase in physical disturbance will expose the soil and make the river embankments and floodway vulnerable to erosion.

C2: Soil exposed
Older trees remain, but the ground is virtually bare. Annual grasses and other weeds have been removed by livestock trampling or grazing, or through over use by humans. Low-level soil erosion has begun, by the action of either wind or water.

C3: Eroded
Soil is washed away from between tree roots, trees are being undermined and unsupported embankments are subsiding into the river valley.

D Grade Foreshore

D1: Ditch - eroding
There is not enough fringing vegetation to control erosion. Some trees and shrubs remain and act to retard erosion in certain spots, but are doomed to be undermined eventually.

D2: Ditch - freely eroding
No significant fringing vegetation remains and erosion is completely out of control. Undermined and subsided embankments are common, and large sediment plumes are visible along the river channel.

D3: Drain - weed dominated
The highly eroded river valley has been fenced off, preventing control of weeds by stock. Perennial (long-lived) weeds have become established. The river has become a simple drain, similar or identical to a typical major urban drain.

2 THE SERPENTINE RIVER

The Serpentine River is one of the three main rivers discharging to the Peel-Harvey Estuary and has undergone significant changes since European settlement in the 1830s. A summary of the environmental and historical factors that influence the current condition of the river is provided below.

2.1 River System

The Serpentine River is one of the three main rivers feeding the Peel-Harvey Estuary along with the Murray River and Harvey River. The Serpentine River catchment (1,682 km^2) extends from the Darling Scarp, where the river is dammed, to the estuary (Figure 3). The catchment upstream of the Serpentine Dam is largely state forest and reserves, including the Serpentine National Park and a special mining lease for Alcoa to extract bauxite from Crown land with requirements to protect environmental values (DoW, 2007). Downstream of the Serpentine Dam towards the Lowlands Conservation Reserve, the river has been assessed as in a good condition, with higher values than other river systems on the Scarp, particularly where riparian vegetation is protected by fencing (DWER, 2017a).

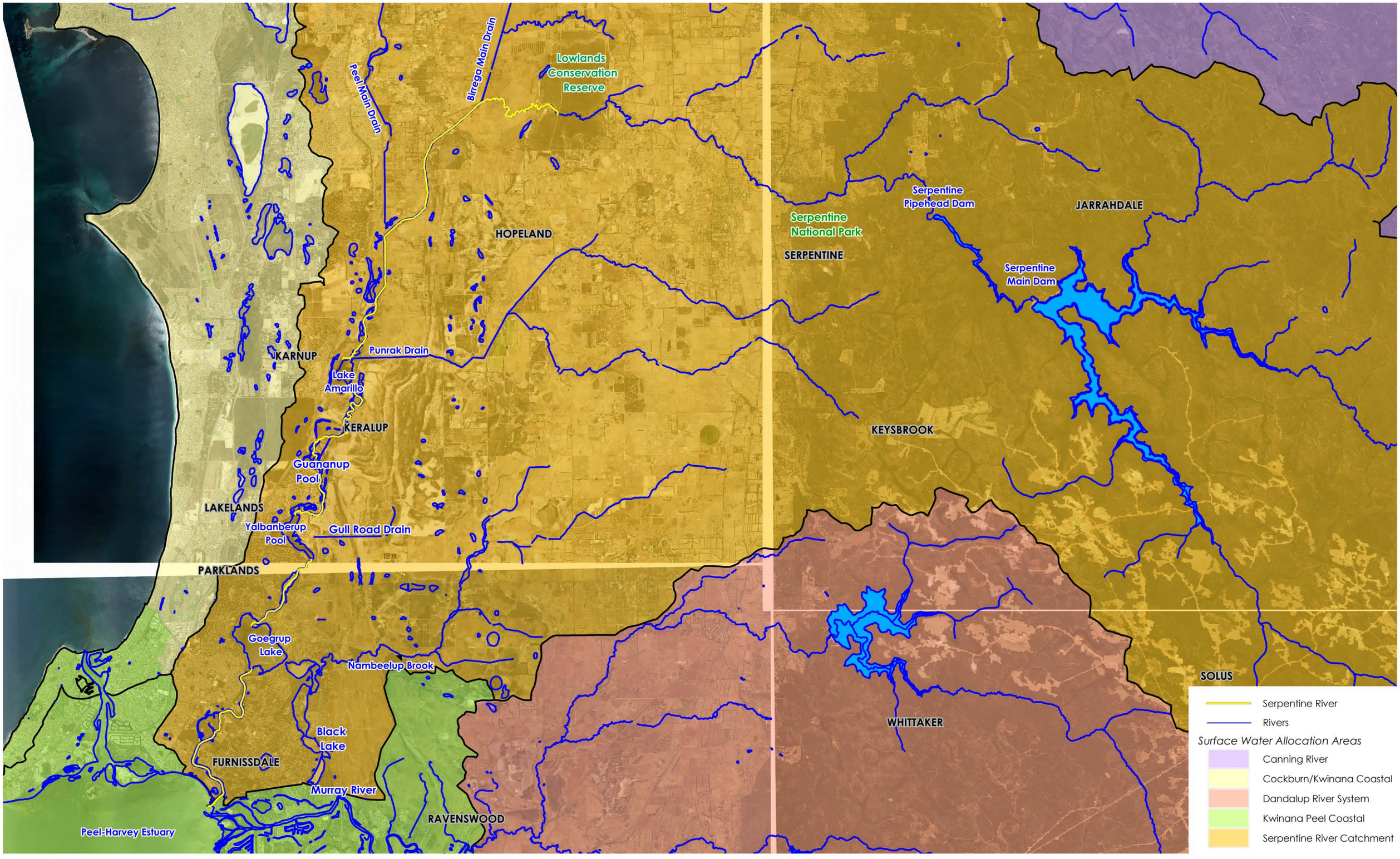
Within the assessment area, downstream of the Lowlands Conservation Reserve, the river meanders through the Swan Coastal Plain in a variety of forms; natural channel (Reach 1), artificial drains (Reaches 2 to 4), modified channels (Reach 5) and an estuarine system (Reaches 6 to 8). These rivers connect a series of pools and lakes along the river, including Lake Amarillo, Guananup Pool, Yalbanberup Pool and Goegrup Lake (Figure 3). The river, lakes and pools are generally mapped as Conservation Category Wetlands.

The wider catchment on the Swan Coastal Plain connects to the Serpentine River via constructed drains including the Birrega Main Drain, Peel Main Drain and Punrak Drain (Figure 3). This drainage system was constructed to open land for agricultural in the early 1900s and includes construction of artificial levee banks (3-4 m high) effectively disconnecting the upper reaches of the river (Reach 2 to 4) from adjacent historic floodplains.

The Serpentine River and surrounding floodplains are low-lying, with elevations ranging from 5.0 mAHD at the Birrega Main Drain Confluence (Reach 2) to 0.0 mAHD at the estuary (Reach 8). The adjacent floodplain broadly consists of clayey silt (C_2 soil unit) and peaty clay (C_p soil unit) near the river, transitioning to sand overlying impermeable clay (S_{10} soil unit). The floodplains are prone to water-logging, particularly around the Birrega Main Drain, Peel Main Drain and east of the river in Keralup (DoW, 2015a). Shallow groundwater levels generate base-flow in the river during the summer.

Agricultural practices and urban development within the catchment have led to poor water quality both within the Serpentine River and the Peel Harvey Estuary (EPA, 2008). DWER have undertaken water quality monitoring at four sites in the assessment area, shown in Figure 3. This monitoring identified high and very high nutrient concentrations since monitoring commenced in 2003 (DWER, 2017b, DWER, 2017c, DWER, 2017d, and DWER, 2017e). Notably, the highest concentrations of nitrogen and phosphorus in the Peel-Harvey Catchment were recorded from the Gull Road Drain (historically associated with the Wandalup Farms' piggery). Very high concentrations have also been measured in Punrak Drain (nitrogen and phosphorus) and the Peel Main Drain (phosphorus) since 2013 and 2008 respectively. Between 2001 and 2014, ten fish kills were reported in the lower Serpentine River, generally in February or March and attributed to deoxygenation caused by the collapse and decomposition of algal blooms (DWER, 2017b).

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 3 - Serpentine River Catchment



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The river continues to support native fish populations based on the preliminary findings of the River Health Assessment (Centre for Sustainable Aquatic Ecosystems, 2020). The variety of habitats within the Serpentine River, including areas with artificial levees, (see Section 2.3) still supports an abundance of native fish species.

2.2 Climate

The climate for the Serpentine River assessment area is typical of the south western region of Western Australia and is characterised by the Koppen Climate Classification as Dry Subtropical featuring mild winters and hot to very hot summers. The dominant rainfall mechanisms are frontal systems caused by cold fronts associated with low pressure systems that extend across southern Australian between May and October. During the summer months, thunderstorms and ex-tropical cyclones can bring intense rainfall and flooding of low lying areas, however the majority of flows enter the estuary during a 4-6 month period over winter (EPA, 2008).

In the south-west of Western Australia, there has been a significant decline in winter rainfall, a result of weakened and less frequent frontal systems. At the Serpentine (9039) meteorological station, the three lowest rainfall years since records commenced have been recorded in the past 20 years (DoW, 2015b). Rainfall has decline by more than 10% since 1975 at Karnet (9111), with a corresponding reduction in inflows to dams of 58% (DWER, 2017a). Record low inflows occurred in 2015, and future decline in rainfall is anticipated to reduce inflows to zero in some years. Declining rainfall also impacts groundwater discharge zones that provide base-flow in summer. Monitoring and investigations by DWER indicate that the discharge zone is migrating to the west, and base-flow will also decline (DWER, 2017a). Sea-level rise will add to increasing water levels in the lower tidal reaches of the Serpentine River (DWER, 2015a). The impacts of climate change on the river system require mitigation in coming years.

2.3 Cultural Heritage

The Serpentine River is significant to the Aboriginal people from a 'domestic' and 'spiritual' viewpoint. They lived in groups near the Serpentine River and along the coastal plain. The Serpentine River provided sources of food, water and shelter/camping grounds as well as forming an important part of the spiritual heritage.

Aboriginal people have inhabited the landscape of the southwest of Western Australia for more than 50,000 years. During this time, traditional folklore and spiritual beliefs have developed around the natural features of the landscape giving importance to the connection with country. Waterways and wetlands form an integral part of the aboriginal heritage and culture, with the Waugal, a powerful serpent-like being forming and inhabiting all freshwater bodies (Dortch and Cuthbert, 2005). Disturbance of water sources amounts to disturbance of the Wuagal, particularly at certain times of the year, hence the importance of good consultation when doing restoration projects within these areas.

"Looking after our waterways makes our spirit strong. The river's name is Bilya and bilya also means umbilical cord. The Bilya sustains life for humans, marine life, land animals, water birds and plant ecosystems; the healthier the river [and umbilical cord] is, the healthier all life is. If the umbilical cord is sick then we will be sick." - Harry Nannup - Bindjareb Noongar Local Elder

The Serpentine River is a site of aboriginal significance and is specifically identified as a mythological site by the Department of Planning, Lands and Heritage Inquiry System. The Aboriginal Heritage Act 1972, protects all Aboriginal Heritage sites in Western Australia whether they are registered with the Department or not. Before undertaking any work on country, officers,

contractors and community members should engage with the delegated local Bindjareb Noongar Elders, Traditional Owners and/or Representatives. Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site. The draft PHCC Bindjareb Noongar Consultation and Engagement Guidelines should also be followed. If the on-ground actions are deemed likely to have an impact on the significant site, the consent of the Minister must be sought under Section 18 of the Aboriginal Heritage Act.

2.4 European Heritage

European settlement commenced in the Peel region in late 1829. Shortly after the establishment of the Swan River Colony, Thomas Peel was granted 250,000 acres extending from Cockburn Sound to the Murray River and inland to the Darling Scarp. Under the Peel Settlement Scheme farming of the land commenced in 1835, displacing Bindjareb Noongar camping and foraging areas, clearing land and introducing stock (Bradby, 1997).

Prior to European settlement, the middle reaches of the Serpentine River (Reaches 2 to 4) featured a series of interconnected wetlands with paperbarks, flooded gums and sedges. The river from Lowlands Reserve (Reach 1) was described as a small, shallow channel, connected to wider flats (Bradby, 1997). This form, along with shallow groundwater, resulted in large portions of land being inundated over winter months and unsuitable for agriculture. Drainage works commenced in the 1900s in the region, including de-snagging (logs and debris removal within the channel) and clearing (systematic tree removal) works in the 1930s on the Serpentine River (Bradby, 1997). Middle reaches were straightened with the creation of artificial levee banks to prevent flooding of surrounding farming properties.

Further changes to the Serpentine River occurred with the construction of the Serpentine Dam and Serpentine Pipehead Dam on the Darling Scarp in the 1961. These dams capture water from the river and store output from Water Corporation desalination plant in Binningup to supply scheme water to Mandurah and Perth (DWER, 2017a). Water is released from the dams to the Serpentine River for aquatic ecology, amenity and licenced uses downstream. The releases occur between October and May, with volumes managed by factors including annual inflows, forecasted hot weather and flow gauging downstream.

Since the 1980s, residential development has expanded in the lower reaches (Reach 7 and 8), increasing recreational use of the Serpentine River. The extension of the Kwinana Freeway in the late 2000s increased opportunities for further residential development, including the Department of Communities West Keralup residential development project. Other land use opportunities are under consideration for East Keralup including establishment of Peel Regional Park.

2.5 Key issues

Previous investigations have identified the following key issues for the Serpentine River that required consideration during field assessments and formulation of management recommendations:

- Since 1975 there has been a **decline in rainfall** of more than 10%, with record low inflows to the Serpentine Dam in 2015;
- **Dam releases** are required to offset declining rainfall and reduced baseflow during summer months to maintain a functioning riverine system;
- Limited remnant vegetation within the catchment and severely reduced riparian vegetation, caused by **clearing for agricultural and urban land uses**;

- The form of the river upstream of Lake Amarillo has been significantly modified from a series of low-lying, connected wetlands to a straight channel with **artificial levees,** disconnected from the floodplain;
- **Urban development** has expanded within the catchment in the previous 30 years; and,
- Associated with agricultural and urban land uses, **poor water quality** within the Serpentine River and tributaries is common, generally featuring high and very high nitrogen and phosphorus concentrations.

3 REACH ASSESSMENTS

Results of the site inspections are provided in this section, along with management recommendations to improve identified issues. The data and information is provided for each reach (1 to 8) in the format outlined in Table 3.

Table 3: Reach Assessment Data Format

Item	Format	Title	Notes
1	Figure	Reach Location Map	Reach, tributaries and surrounding features
2	Figure	Reach Elevation Map	River and floodplain digital elevation model based on DWER LIDAR data
3	Table	Description and Conditions	Summary of the characteristics of each reach and description of assessment scores
4	Table	Management Actions and Recommendations	Recommendations to improve the reach based on condition assessment and notable features
5	Figure	Condition Assessment	Assessment scores for each sub-reach with points of interest including infrastructure, weeds and significant erosion

An additional bathymetry figure for Reach 5 is provided based on survey data provided by DWER. The bathymetry data has been collected as part of the Regional Estuaries Initiative and trials of phosphorus-binding clay trials in Punrak Drain. The bathymetry figure demonstrates pool depths within the reach.

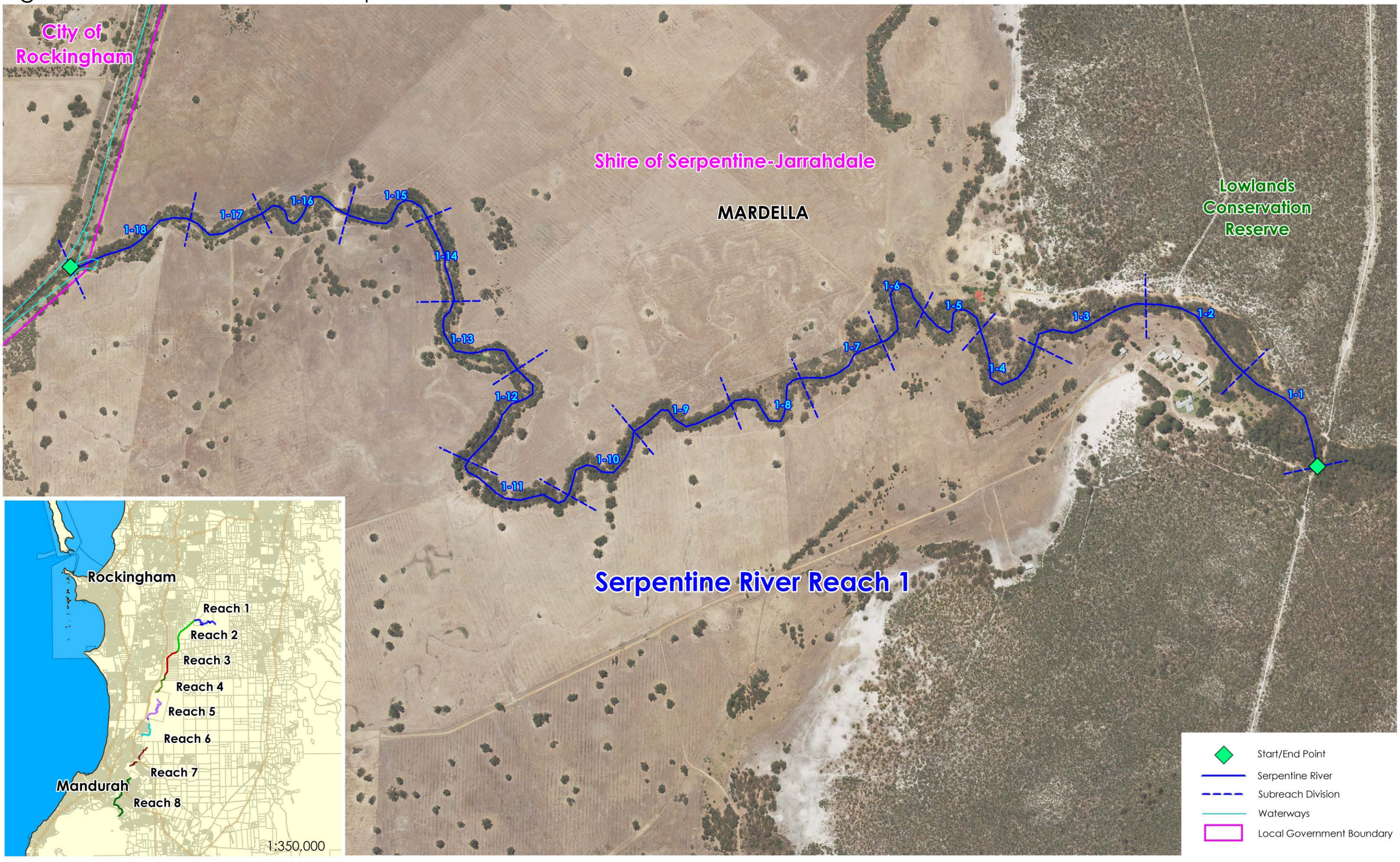
The detailed scoring for each sub-reach and bank is provided in Appendix 2 based on the methodology outlined in Appendix 1 (example in Figure 4). Further mapping of land uses and wetlands is provided in Appendix 3 and 4 respectively and reference to these maps is made selectively through the reach assessments. Finally electrical conductivity and dissolved oxygen measurement maps for reaches 1 to 3 are provided in Appendix 5.

		Left Bank						
Reach	Subreach	Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Total Score	Rating
2	1	2.5	2.5	2.50	2	1	10.50	C2
2	2	1.5	2	1.86	7	2	14.36	C1
2	3	2.5	1	2.29	7	1.5	14.29	C1
2	4	3.5	3	3.00	6	2	17.50	B2-B3
2	5	3	6	2.00	4	2	17.00	B3
2	6	2.5	3	4.00	7	2.5	19.00	B2-B3
2	7	2	3	3.00	7	2	17.00	B3
2	8	1.5	4.5	2.00	6	1.5	15.50	B3-C1
2	9	2.5	2	2.57	3.5	2	12.57	C1-C2
2	10	2.5	3	3.00	6	1.5	16.00	B3-C1
2	11	2	3	2.43	6	2.5	15.93	B3-C1
2	12	2.5	4	2.71	5	2	16.21	B3
2	13	3	4	2.00	7	1.5	17.50	B2-B3

Figure 4: Reach Scoring Example

Peel Harvey Catchment Council - Serpentine River Action Plan

Figure 5 - Reach 1 Location Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

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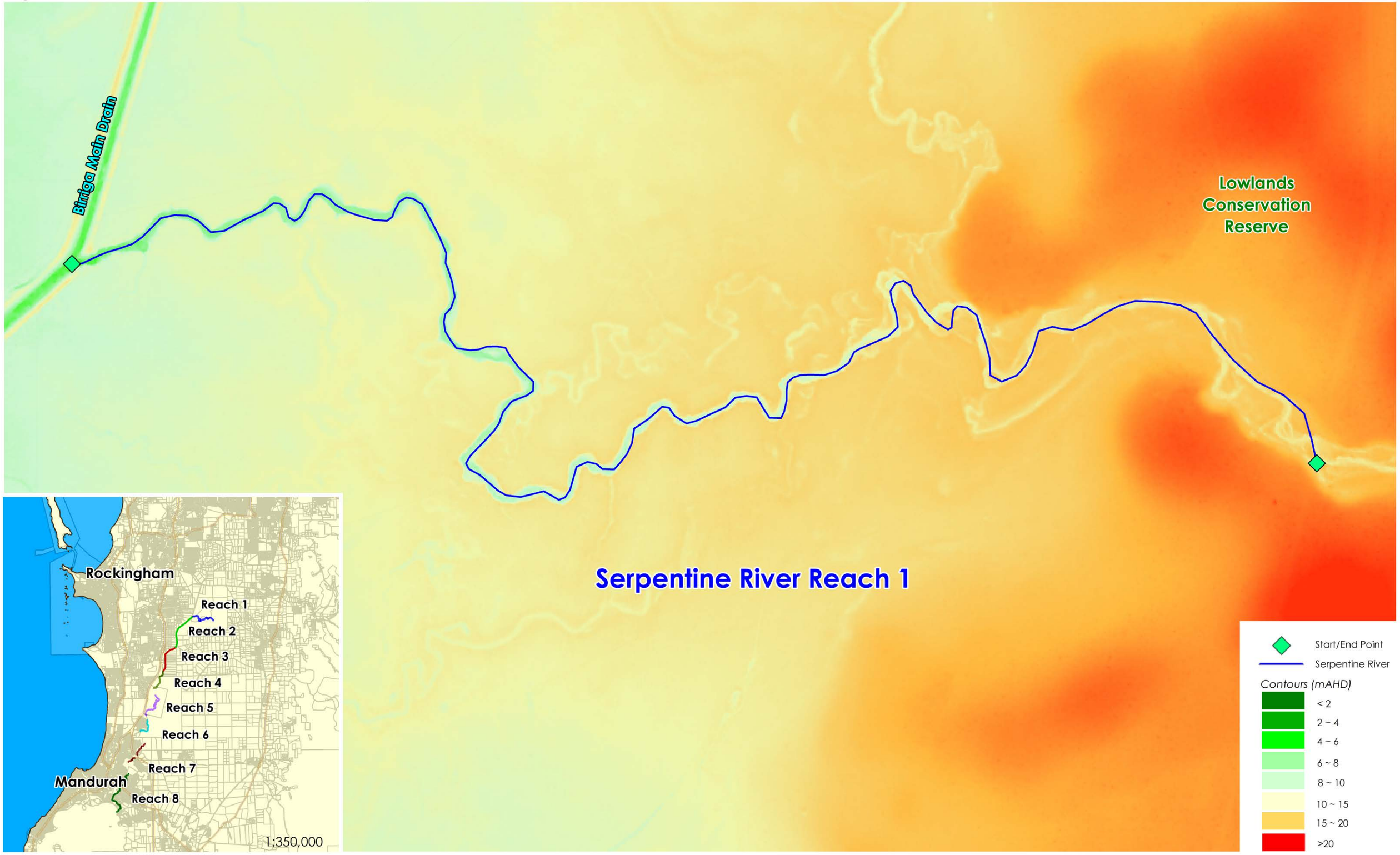
Figure 6 - Reach 1 Elevation Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

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3.1 Reach 1

Reach 1 (5.0 km) extends from Lowland Nature Reserve to the confluence with the Birrega Main Drain in the Shire of Serpentine-Jarrahdale. Assessment of this reach included the definition of 18 sub-reaches, each being approximately 300 m in length (Figure 5). The upper parts of the reach sit within the fringe of the Lowlands Nature Reserve (managed by DBCA), surrounded by mature banksia woodland, while the remainder of the reach is bounded by rural land uses. The majority of the reach is fenced, with stock access limited to one crossing and several fenced watering points. There is also a continuous canopy of trees on both sides of the river for the majority of the reach.

This reach of the Serpentine River transitions from a confined form within the valley floor at Lowlands to an unconfined, meandering form in the relatively low gradients area downstream. Figure 6 demonstrates the paleo channels within the floodplain, evidence of previous channel avulsions (abandonment and cut-offs) and the activity of the channel. In downstream areas, bed lowering and channel instability were observed. The general condition of the reach decreased towards the downstream end.


Dense riparian vegetation near Lowlands


Collapsed trees


Invasive grasses within channel


Limited large trees


Artificial bar near confluence

Plate 2: Reach 1 Photos

Table 4: Reach 1 Description and Conditions

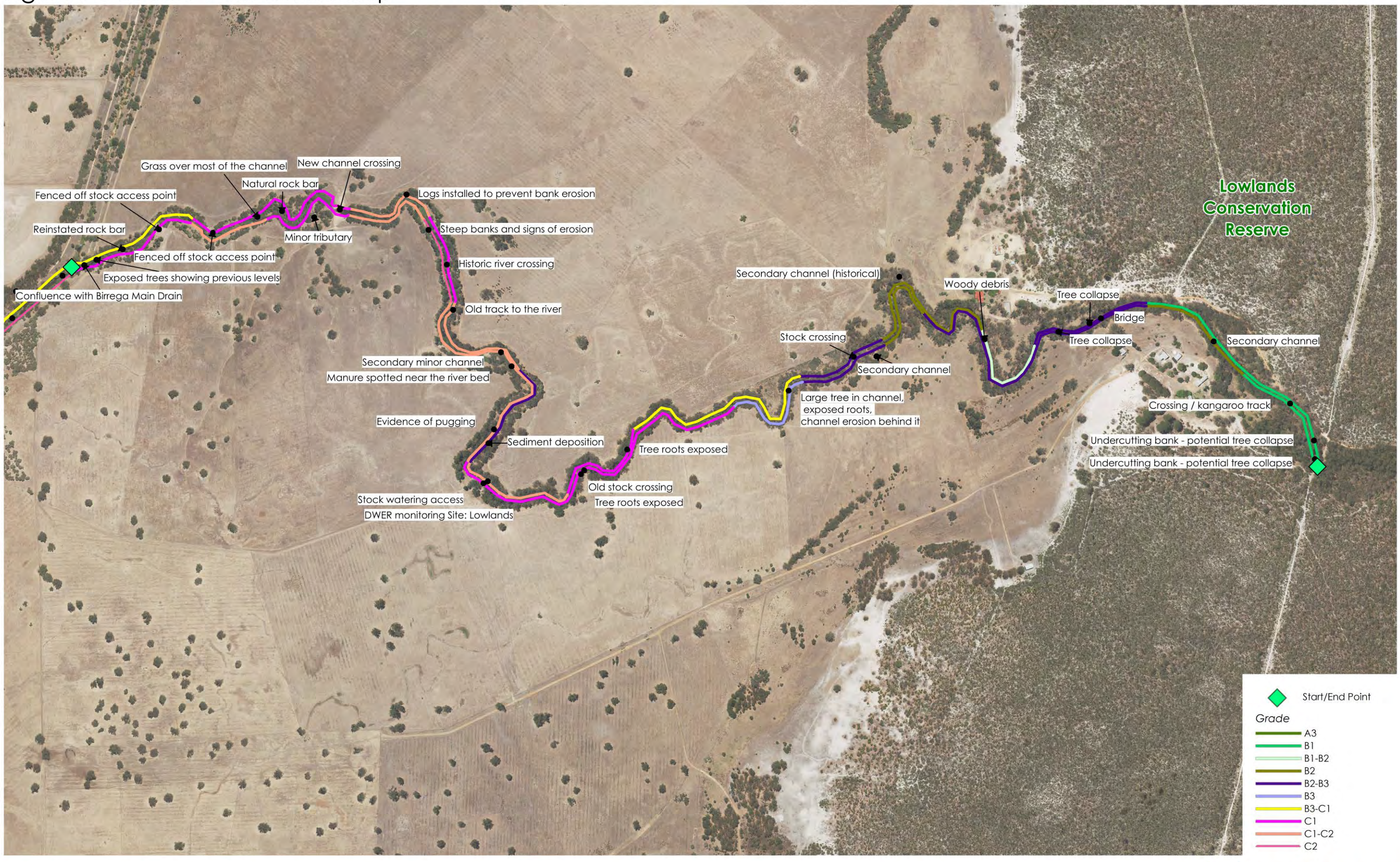
Feature	Comments
Landuse	The majority of the reach is surrounded by rural land use with stock (cattle). The upper portion of the reach is on the fringe of the Lowlands Nature Reserve. West of the reserve is a homestead, with the most buildings south of the river, and one on the northern side.
Fencing and Infrastructure	Apart from the initial sub-reach within the Lowlands Nature Reserve, the river is fenced on both sides. The condition of the fencing varies between poor and good, with some evidence of stock access within the channel (pugging). A recently constructed stock crossing (Figure 7) provides a better control of this access with design discouraging stock from remaining in the channel. Other infrastructure includes a timber bridge at the homestead, a DWER monitoring station (weir) and several rock bars (both natural and artificial).
Channel Form	The channel has a sinuous form, with regular meanders and a depth >3 m for the entire reach. Erosion associated with the meanders has cause many trees to collapse within the channel, creating small backwater areas.
General Foreshore Condition	Assessment of the foreshore conditions (as per the methodology outlined in Appendix 1), ranges from relatively good (B1 - degraded) to erosion prone (C2 - soil exposed). The general trend is decreasing condition downstream away from Lowlands associated with reduced riparian and verge vegetation condition and increased bed and bank instability. The initial reaches near Lowlands Reserve represent reference vegetation and stream cover conditions for the upper reaches of the Serpentine River, though minor erosion and bank collapse was noting in these areas.
Vegetation Cover and Stream Health	Riparian vegetation is dominated by mature trees, providing a near continuous canopy along the reach with good shading and woody debris within the channel. The quality of the understorey however decreases considerably downstream from Lowlands Reserve. The mid-storey and understorey in middle and lower sub-reaches are degraded, with bare ground and invasive grasses noted in many locations. The density of mature, large trees was also noted to decrease downstream, though improving near the Birrega Main Drain confluence. Verge vegetation (beyond the riparian zone) consists generally of bare ground with some scattered trees. There is a diversity of habitats along the reach, highlighted by DWER's river health condition assessment (Nov 2017) that noted signs of native fish species recruitment.
Weeds	Weeds were observed throughout the reach, particularly in the middle and downstream reaches where invasive grasses were prevalent on banks and within the channel. The common species observed were kikuyu and couch grass, with some buffalo grass near the homestead. Arum Lily, Bridal Creeper and Watsonia were noted throughout the reach, including on the fringe of Lowlands Reserve.
Erosion	Channel instability and lateral movement is a historical characteristic of this reach, demonstrated by the presence of paleo channels. Field inspections confirmed active erosion along the majority of the channel, corresponding with bed incising at the downstream end and bank retreat on meander bends (with trees undercut and exposed). The lack of understorey increases the potential for bank erosion. At the downstream end, channel incising has led to a deep main channel with flows unlikely to connect with fringing wetlands. Sediment deposition (with invasive grasses) was noted in the middle sub-reaches.
River Health Assessment	The preliminary results of the River Health Assessment (Centre for Sustainable Aquatic Ecosystems, 2020) indicated that this reach had the highest native species diversity, with 194 native fish identified at the two monitoring locations within Reach 1 (compared with 134 in Reach 2). There was also significantly more native crayfish than Reach 2.
Other Issues	Field measurements of electrical conductivity (EC) and dissolved oxygen (DO) were collected for this reach. The range of EC measurements was 360 µS/cm to 410 µS/cm; consistent with fresh water. There was a decreasing trend in DO downstream, with values consistently less than 5 mg/L downstream of the DWER Lowlands monitoring site. A DWER water quality assessment (Nov 2017) noted elevated phosphorus and

Feature	Comments
	turbidity in this reach, though Carters freshwater mussels were present which is a sign of good water quality.
Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. Landholders within this reach have farmed in this area for over a century, and highly value the river, not only for its important water source, but also for its beauty and the ecosystem services it provides. Before the Serpentine was dammed parts of the river here provided deep natural pools which were located near rock/riffle bars and were used as swimming holes for the community.

Table 5: Reach 1 Management Actions and Recommendations

Prioritised management actions recommended
• Continue to work with the landholders to improve fencing and limit stock access to the river; • Provide resources to the landholders to eradicate weed species, particularly Arum Lily, Bridal Creeper and Watsonia; • Consider localised bank protection to prevent erosion near Lowlands Reserve or where there is potential for healthy tree collapse; and, • Provide advice to the landholders on methods to identify erosion risk to allow for early intervention.
Long term management actions recommended
• Investigate the impact of instability from bed lowering at the confluence, including additional topographic survey and comparison with LIDAR data; • Based on the investigation, implement measures to stabilise this area, potentially including bank protection (soft and hard engineering); • Eradicate invasive grasses from the channel in conjunction with planting of native ground cover and shrubs to improve riparian vegetation; and, • Work with the landholders to provide anecdotal evidence on water quality and environmental water releases from the Serpentine Dam.

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 7 - Reach 1 Condition Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

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Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 8 - Reach 2 Location Map

Rockingham
City of Rockingham
Birriga Main Drain
2-1
2-2
2-3
2-4
Wilkinson Rd
MARDELLA
Hymus Creek
Maramanup Pool
2-5
2-6
Serpentine River Reach 2
Shire of Serpentine-Jarrahdale
2-8
Hymus Swamp
2-9
Serpentine Rd
2-10
Peel Main Drain
BALDIVIS
2-11
HOPELAND
2-12
Karnup Rd
2-13

Start/End Point
Serpentine River
Subreach Division
Waterways
Local Government Boundary

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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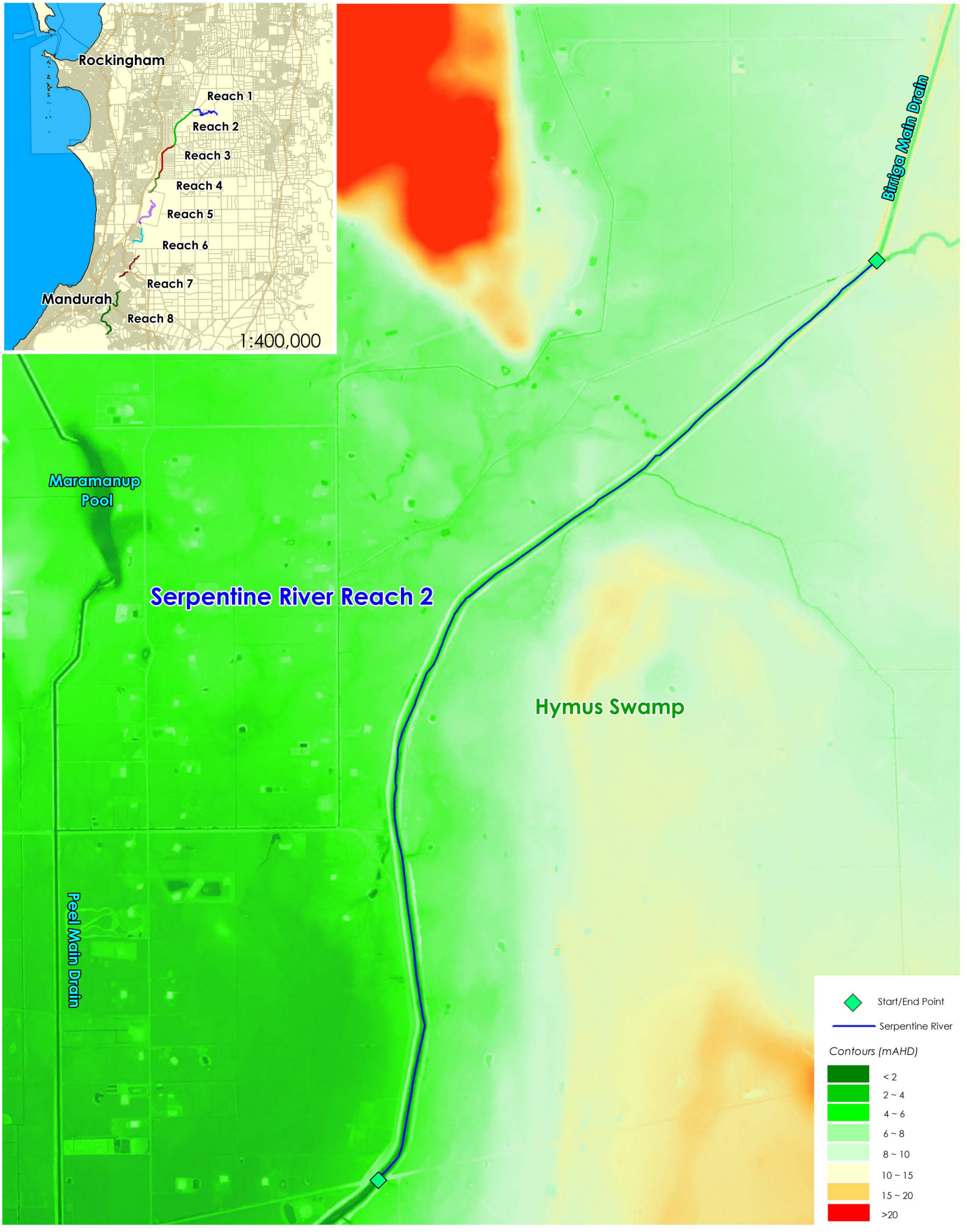
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 9 - Reach 2 Elevation Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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3.2 Reach 2

Reach 2 (5.2 km) extends from the Birrega Main Drain confluence to Karnup Road in the City of Rockingham (near the boundary with the Shire of Serpentine-Jarrahdale). Thirteen (13) sub-reaches were defined for this assessment (Figure 8). Unlike Reach 1 upstream, Reach 2 has been heavily modified from its natural form and now features artificial levee banks and a consistent, generally controlled form. The reach is bounded to the west by smaller private landholdings (across Serpentine and Wilkinson Roads), with rural land uses and Hymus Swamp (Bush Forever Site 372, managed by DBCA) to the east with the river contained within a 70-90 m wide reserve.

The levee banks are significantly elevated above the surrounding landscape (Figure 9) disconnecting the river from the surrounding wetlands and floodplain, particularly on the western side (SKM, 2009). Despite the constraints of the levee banks, there is variability in the vegetation and habitat condition of the river along the reach. Areas of active erosion were also observed. Most of the reach is fenced, although human and stock access was observed in fenced areas.


Small low flow channel


Upstream of gauging station


Dense typha


Limited riparian vegetation


Large trees within levee banks

Plate 3: Reach 2 Photos

Table 6: Reach 2 Description and Conditions

Feature	Comments
Landuse	The river is located within a 70-90 m wide reserve (unallocated Crown land), bounded immediately to the west by Serpentine Road (southern end) and Wilkinson Road (northern end), with smaller private landholdings beyond. Hymus Swamp (Bush Forever Site 372) is located to the east (middle sub-reaches), with private rural land to the north and south.
Fencing and Infrastructure	The levee banks on both sides of the river are fenced, with an internal access track on both levees. Access on the eastern side is restricted by a locked gate at the southern end. On the western side, vehicle, pedestrian and stock access is not restricted by the fences as they are of varying quality and there are several formal openings, particularly along Wilkinson Road. During field inspections, horse riding along the levee banks was observed. There was also evidence of vehicle tracks on the levees and marron pots and litter next to the river. The only infrastructure within the river is the DWER monitoring site at Dog Hill (614030).
Channel Form	Historically the channel would have been poorly defined, with a series of connected wetland areas. The current form is a significant departure, with large flood events generally contained within the levee banks, disconnected from the floodplain. Within the levee bank is a smaller low-flow channel (approximately 1 m deep) that has a meandering form and varying habitats. This lower channel is relatively active with erosion and sedimentation. North of Hymus Swamp there are three drains from adjacent paddocks that flow into the river, including Hymus Creek.
General Foreshore Condition	Channel condition is relatively consistent along the reach, varying only between B2-B3 (degraded and weed infested) to C2 (erosion prone and soil exposed). The lowest rating C2 occurs at upstream end near the confluence with the Birrega Main Drain where erosion was most prevalent, potentially associated with the bed incision described in Reach 1. The remainder of the Reach showed consistent characteristics with mostly stable banks, degraded riparian vegetation, weeds and low habitat quality.
Vegetation Cover and Stream Health	Riparian vegetation throughout Reach 2 is generally poor with scattered tree cover and a discontinuous canopy. The trees present are flooded gums and paperbark trees. There are considerable areas of bare ground on the levee banks and the majority of the reach features <50% understorey cover, indicative of the limited riparian vegetation. Rushes and sedges were prominent along the edge of the lower channel. A high proportion of the riparian vegetation present is invasive. Downstream of the DWER monitoring station a dense area of typha was noted in the main channel.
Weeds	The dominant weed species in this reach was watsonia, which was observed in most of the sub-reaches and in large clusters on the levee banks. Invasive ground covers identified in the field included kikuyu, couch grass and love grass. Other common weed species identified in this reach were wild oats, cotton bush, arum lily, lupin and veldt grass. Pig melon was observed in the downstream portions of the reach near Karnup Road.
Erosion	Bank stability varies within the reach as the lower channel is susceptible to erosion from flows, while the wider, higher levee banks are stable. The lower channel contains mobile sediment (potentially builders' sand) that is migrating through the reach downstream and large flow events can cause the lower channel form to be altered. Undercutting of the large banks and tree collapse into the channel were observed in the upstream sub-reaches.
River Health Assessment	The preliminary results of the River Health Assessment (Centre for Sustainable Aquatic Ecosystems, 2020) indicated fish totals are less than in Reach 1, with a significant difference based on the location. Upstream areas near the Birrega Main Drain confluence featured very few fish (18), whereas near the Dog Hill gauging station fish numbers (116) and diversity of species was higher (4 of 5 species). This is attributed to the improved habitat diversity behind the gauging station.

Other Issues	In-situ water quality testing was conducted along the reach to assess electrical conductivity (EC) and dissolved oxygen (DO). Readings of EC measurements ranged between 290 µS/cm to 860 µS/cm; with EC increasing downstream. These values indicate fresh water, but salinity is increasing downstream. Dissolved Oxygen was particularly low upstream of the weir at the Dog Hill monitoring station. Algae were also observed in these sub-reaches.
Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. The banks and levees of this reach are used by the community for hiking, camping and horse riding. This activity was possible due to gaps in the fencing on the western bank, and impacts (litter and erosion) were observed during the field assessment.

Table 7: Reach 2 Management Actions and Recommendations

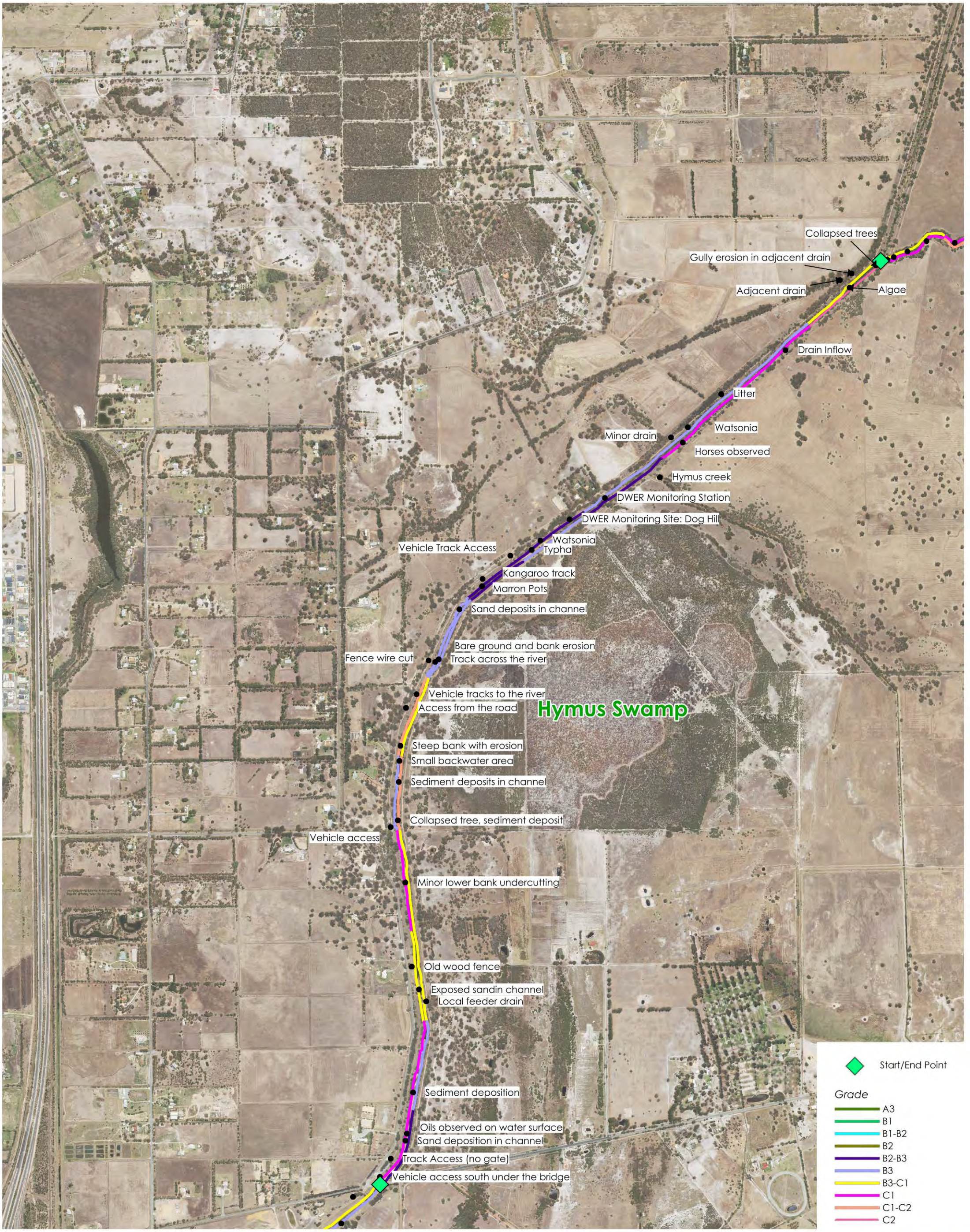
Prioritised management actions recommended

- Contact adjacent landholders and discourage equestrian access to the river;
- Work with landholders east of the river to improve vegetation and practices that contribute to nutrient inputs into Hymus Creek;
- Improve fencing, particularly at the downstream end, to restrict vehicle access to Reach 2 and under the Karnup Road bridge to Reach 3. Regular inspection and maintenance of this fence is required as cutting was noted;
- Fencing in the upstream ends includes several openings that allow for vehicle, equestrian and community access which should be closed;
- Remove aquatic weeds and consider thinning dense areas of typha; and,
- Undertake weed removal, bank stabilisation and restoration of riparian vegetation at high value areas as trials for wider restoration works. Potential sites include the Birrega confluence, upstream Hymus Swamp (confluence of Hymus Creek), downstream of Dog Hill monitoring station and Karnup Road.

Long term management actions recommended

- Bank instability in the upstream part of Reach 2 should be considered as part of investigation of bed lowering at the Birrega confluence for Reach 1;
- Establish education signage at the carpark on Karnup Road to outline restoration works and measures the community can undertake to improve water quality and weeds within the wider catchment;
- Improve riparian vegetation along the entire reach, based on trial areas lessons;
- Utilise Reach 2 to capture and extract sediment from the system to protect downstream lakes, pools and wetlands;
- Consider relocating fencing to the top of the levees and inside of existing tracks to allow for community use, but preventing direct river access;
- In conjunction with DBCA, investigate connection of Hymus Creek with Hymus Swamp and lowering of levee banks near Hymus Swamp to improve floodplain connectivity between the river and wetland; and,
- Work with landholders to establish a good quality habitat corridor between Hymus Swamp and Lowlands Reserve, potentially along the river.

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 10 - Reach 2 Condition Map



Data source: DOP, DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

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Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 11 - Reach 3 Location Map

Peel Main Drain
Karnup Rd
3-1
3-2
3-3
3-4
3-5
Shire of Serpentine-Jarrahdale
HOPELAND
3-6
Serpentine River Reach 3
3-7
3-8
Kwinana Freeway
BALDIVIS
KARNUP
City of Rockingham
3-9
3-10
3-11
Kerulup Pool

Start/End Point
Serpentine River
Subreach Division
Waterways
Local Government Boundary

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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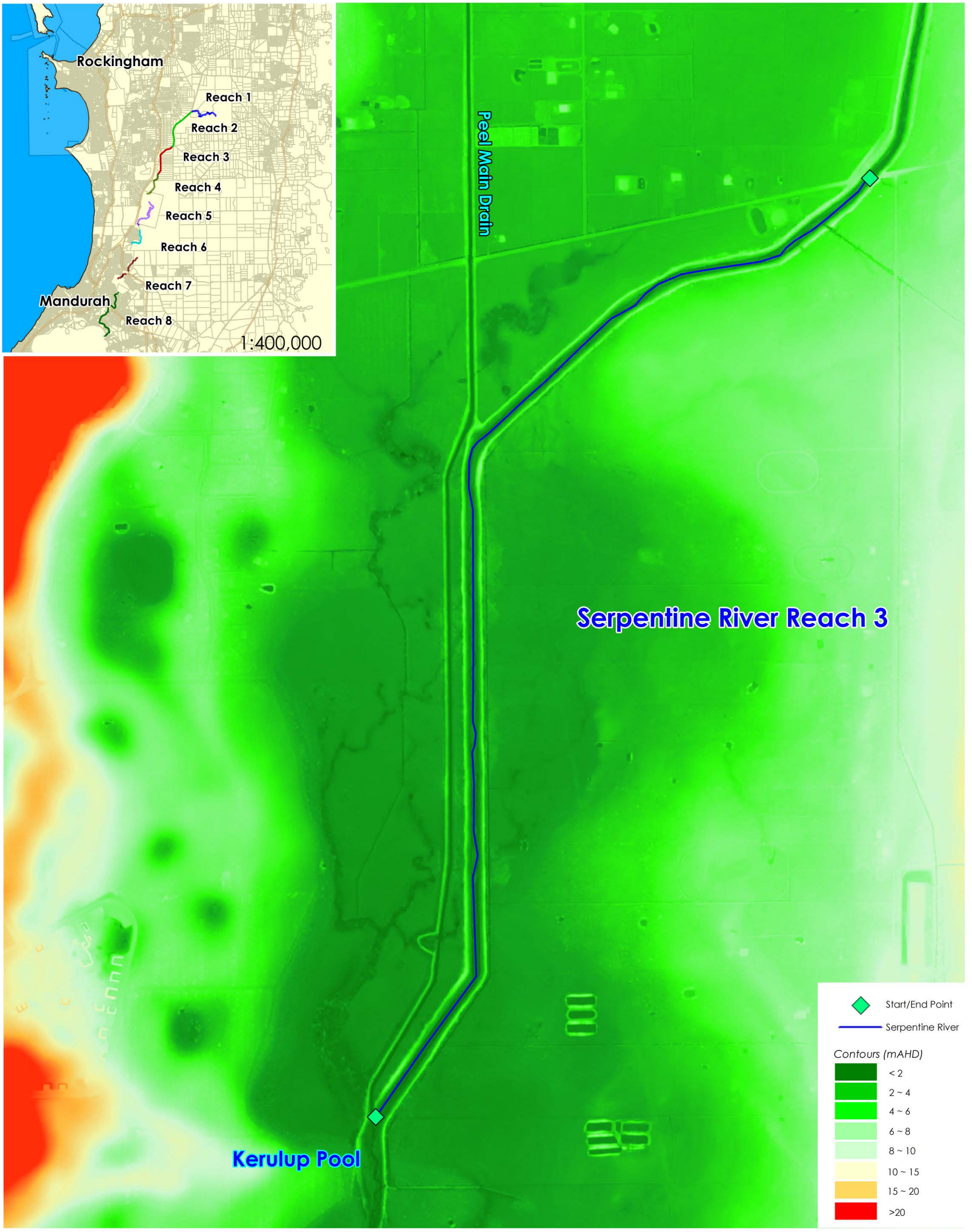
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 12 - Reach 3 Elevation Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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3.3 Reach 3

Reach 3 (4.3 km) extends from Karnup Road to the confluence with the Peel Main Drain in the City of Rockingham (near the boundary with the Shire of Serpentine-Jarrahdale). This reach was assessed with definition of 11 sub reaches, each being approximately 400 m in length (Figure 11). Like Reach 2, this reach has been significantly modified from a natural form through construction of artificial levees and straightening of the channel. The river is located within a 100 m reserve, between private landholdings on the eastern side, and a combination of private landholdings (northern sub-reaches) and Crown land to the west. The Peel Main drain flows parallel to the river through the Crown land (Figure 11), and the Kwinana Freeway is further west.

As shown in Figure 12, the levee banks are significantly higher than the surrounding low-lying landscape. Figure 12 also shows the presence of former channels and wetlands which reflects the pre-European form of the river through this area. The highly modified channel form is generally stable however there are extensive areas of bare ground with limited vegetation. Weeds were also identified on the levee banks and within the main channel.


Limited riparian vegetation


4WD Crossing


Dense typha


Car body and litter


Small meandering low flow channel

Plate 4: Reach 3 Photos

Table 8: Reach 3 Description and Conditions

Feature	Comments
Landuse	The channel sits within a 100 m reserve that runs south west from Karnup Road before flowing directly south to the Peel Main Drain confluence. The entire length of the eastern side of the river is private landholdings, containing mainly cleared land. Buildings within these lots are over 1 km from the river (close to River Road). West of the river, between Karnup Road and the Peel Main Drain are private landholdings. The remainder of the land to the west is Crown land.
Fencing and Infrastructure	Fencing on the western side of the river is restricted to the private landholdings. Fencing was not observed on the eastern side of the river during the field inspections though it may exist over the levee bank at the boundary of private property. No stock access into the river was observed suggesting that the fencing is effective. There are multiple tracks on the levee banks with unauthorised 4WD access common on this reach (accessed under Karnup Road). This access has led to damage on the levee banks, a number of informal crossings within the river and burnt out car bodies and litter. There is a rural drain flowing into the river near Karnup Road.
Channel Form	Like Reach 2, the current channel form consists of high levee banks and a smaller low-flow channel. Unlike Reach 2, the low-flow channel displays less variability with minimum habitat diversity. Floodplain modelling (SKM, 2010) indicates that the levee banks do not contain the 10yr ARI flood event, particularly to the east. This indicates a connection with the floodplain, though not to the extent of the pre-European channel form, which was a series of connected wetlands (visible in Figure 12, west of the river).
General Foreshore Condition	The channel condition is reasonably degraded with limited variability. Assessment scores range from C1 (degraded and weed infested) to C3 (eroded), with all sub-reaches scoring low for riparian vegetation, stream cover and habitat diversity. Bank stability scores were moderated with stability from the artificial levees, though areas of erosion were identified.
Vegetation Cover and Stream Health	The levee banks are generally cleared, with only scattered trees and limited canopy cover. More than any other reach on the Serpentine River the banks have bare ground and/or ground cover (grasses). A high proportion of the latter was invasive. Only 3 sub-reaches featured more than 10% tree cover (any size), mainly at the downstream end near the confluence with the Peel Main Drain. Verge vegetation on the eastern side of the upstream sub-reaches is relatively continuous, though located on the levee bank top.
Weeds	Consistent with Reach 2, watsonia was noted on all sub-reaches and the dominant ground cover was kikuyu and couch grass. Other weeds present include lovegrass, veldt grass and glaucous goosefoot. Large clusters of typha were observed within the main channel at the downstream end, particularly in backwater areas (behind sediment deposits within the channel).
Erosion	Erosion along this reach is generally localised and does not pose a significant threat to bank stability. The main areas of erosion occur at the upstream sub-reaches, particularly where the channel changes direction. There are several areas of sediment deposition along the reach where coarse sand forms constrictions and backwaters in the channel. These depositions are generally covered by kikuyu or couch grass. Where the channel is narrow from these deposits, 4WDs have created informal river crossings. 4WD access has also resulted in erosion, particularly where tracks are lower on the levee bank.
Other Issues	Water quality (in-situ) testing was undertaken along this reach to assess electrical conductivity (EC) and dissolved oxygen (DO). Readings of EC measurements ranged between 390 µS/cm and 770 µS/cm; with EC increasing downstream. These values indicate fresh water and they are lower than those measured in Reach 2, though testing occurred after 30 mm of rainfall in the preceding week. Similarly, DO was higher than reaches upstream. The other notable infrastructure near this reach is the constructed swale system on the Peel Main Drain to improve water quality discharging into the Serpentine River.

Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. Community value of this reach is limited by the lack of public access. The river is largely hidden from view from the Kwinana Freeway and only accessed (illegally) by 4WDs that have created erosion issues.

Table 9: Reach 3 Management Actions and Recommendations

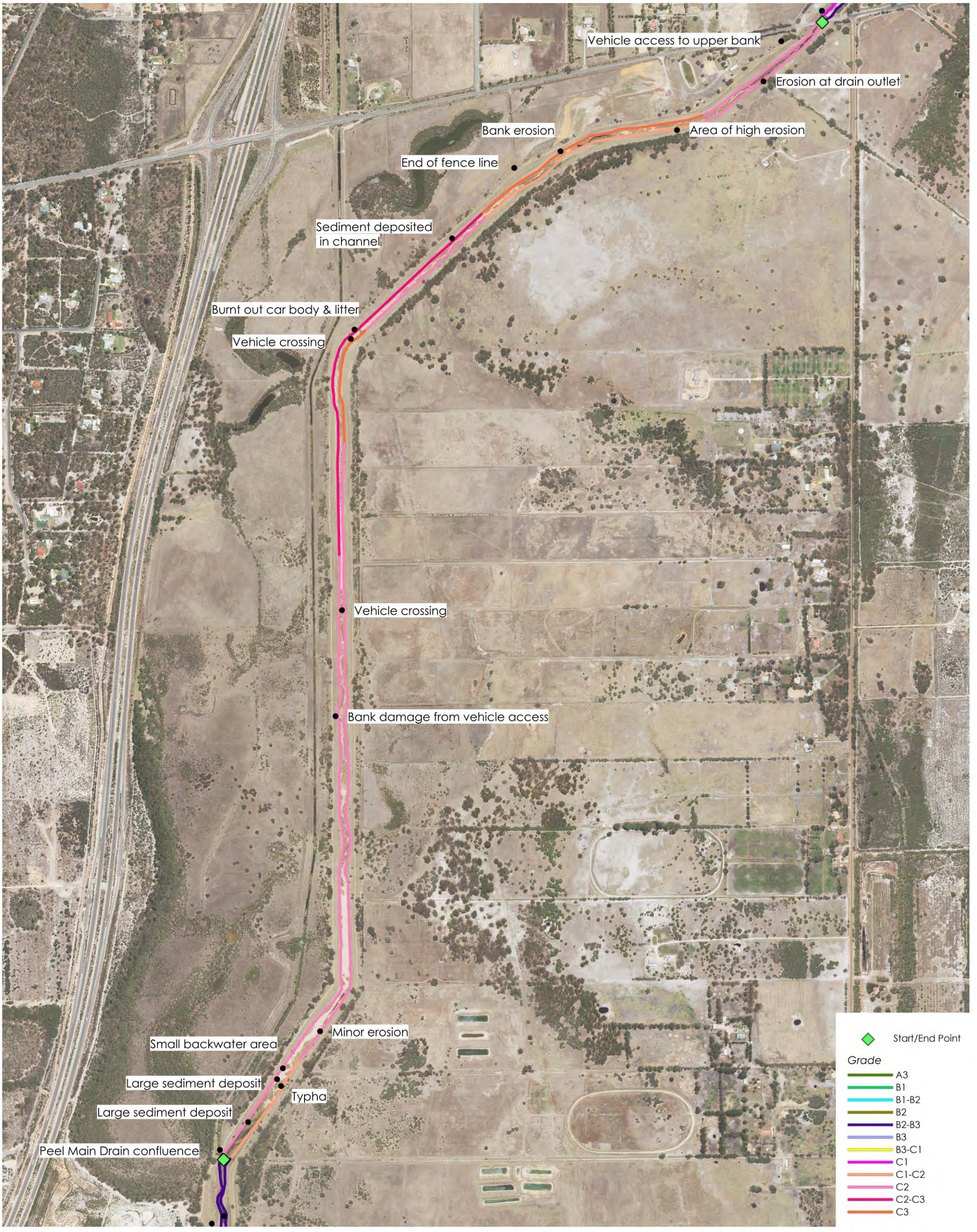
Prioritised management actions recommended

- Prevent vehicle access along this reach by improving gates at Karnup Road bridge and private landholdings east of the bridge;
- Encourage black cockatoo habitats by protect existing trees and plant additional trees: west of the river in formerly cleared areas and east of the river in private landholdings;
- Control feral animals;
- Remove car bodies along the reach to ensure no leaching of chemicals into the river;
- Remove aquatic weeds and consider thinning dense areas of typha; and,
- Monitor sediment within the channel to ensure flood capacity within the drain is sufficient, particularly at the confluence with the Peel Main Drain.

Long term management actions recommended

- Investigate modification of the levee system to increase connection to wetlands west of the channel (near Karnup Road) in conjunction with private landholders;
- Establish a vegetation corridor along the eastern bank and former floodplain, working with private landholders, to provide a continuous habitat towards Reach 2 (and Lowlands);
- Review the impact of DWER trials of Peel Main Drain flow and runoff diversion into large swales prior to discharge downstream. Similar systems can be considered along this reach with diversion of base-flows; and,
- Where modification of the levee system is not feasible, consider utilising the river and surrounding land use in this reach to protect downstream reaches and features by capturing and removing sediment.

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 13 - Reach 3 Condition Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

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Scale 1:10,000 @ A3

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Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 14 - Reach 4 Location Map

Peel Main Drain
4-1
Shire of Serpentine-Jarrahdale
KARNUP
4-2
HOPELAND
4-3
4-4
Kwinana Fwy
4-5
Serpentine River Reach 4
4-6
City of Rockingham
4-7
KERALUP
4-8
4-9
4-10
4-11
Punrak Drain
Lake Amarillo

Start/End Point
Serpentine River
Subreach Division
Waterways
Local Government Boundary

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
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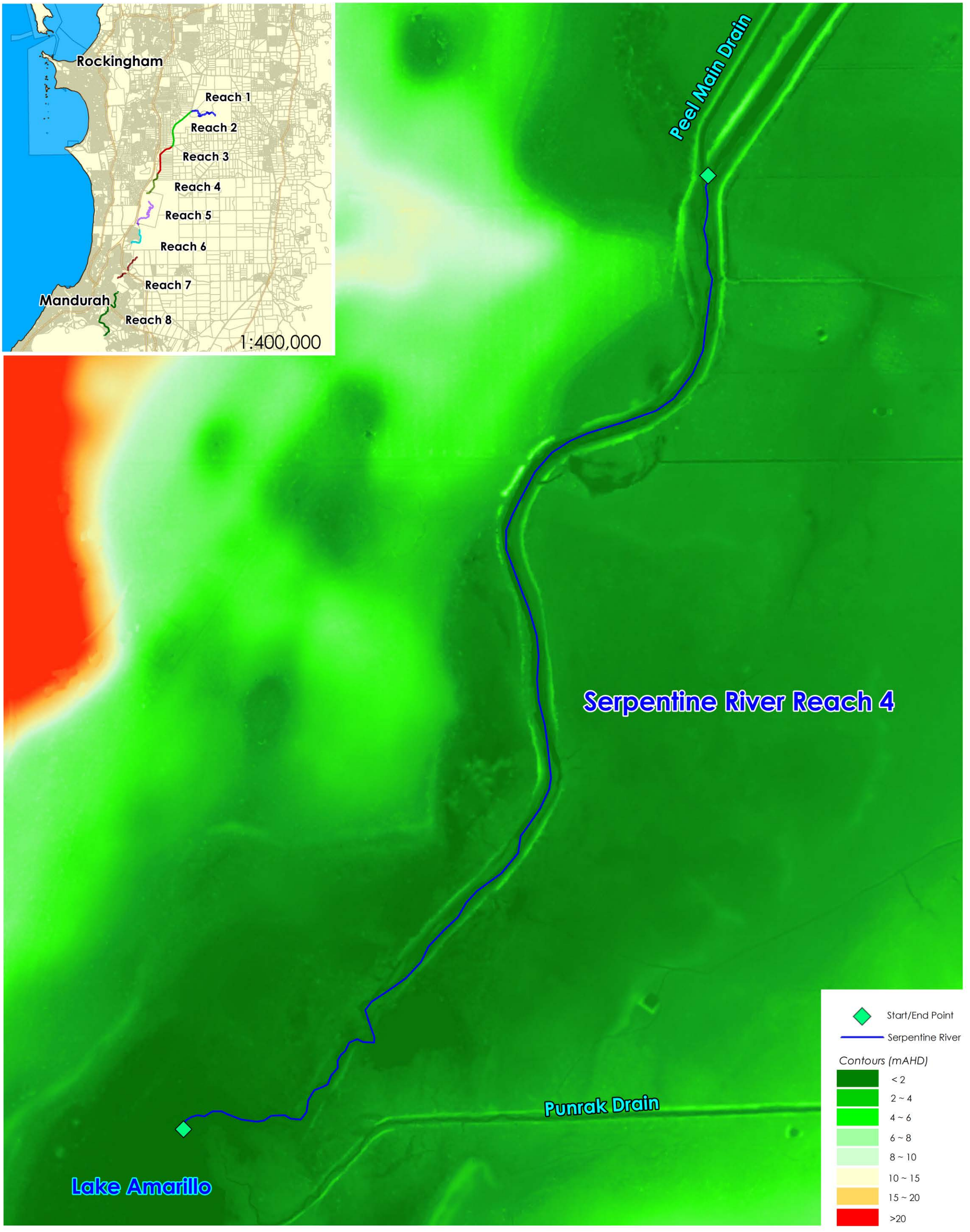
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 15 - Reach 4 Elevation Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:8,000 @ A3

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3.4 Reach 4

Reach 4 (3.1 km) extends from the confluence of the Peel Main Drain to Lake Amarillo in the City of Rockingham. This reach was assessed with definition of 11 sub-reaches, each being approximately 300 m in length (Figure 14). The majority of the reach is within the Department of Communities (DoC) Keralup landholdings, a 4,000 ha property that has been considered for development with residential and other land uses. Access in these areas is controlled through locked gates from the Kwinana Freeway and DoC land, though illegal access was noted particularly on the west of the river.

Reach 4 features a more natural meandering and vegetated form than compared with the bare, straightened channel in Reach 3. The transition occurs in the upstream sub-reaches of Reach 4 where artificial levee banks decrease in height towards a small wetland (Figure 15). The middle and downstream sub-reaches (and floodplains) of Reach 4 are classified as a Conservation Category Wetland, emphasising the presence of vegetation cover, including remnant trees providing a more continuous canopy. The entire reach and the floodplain (west to the Kwinana River) are Bush Forever (Site 394). Several weed species were identified in this reach.


Limited riparian vegetation


Red Water Fern


Dense typha


Narrow channel near Lake Amarilo


Lake Amarilo

Plate 5: Reach 4 Photos

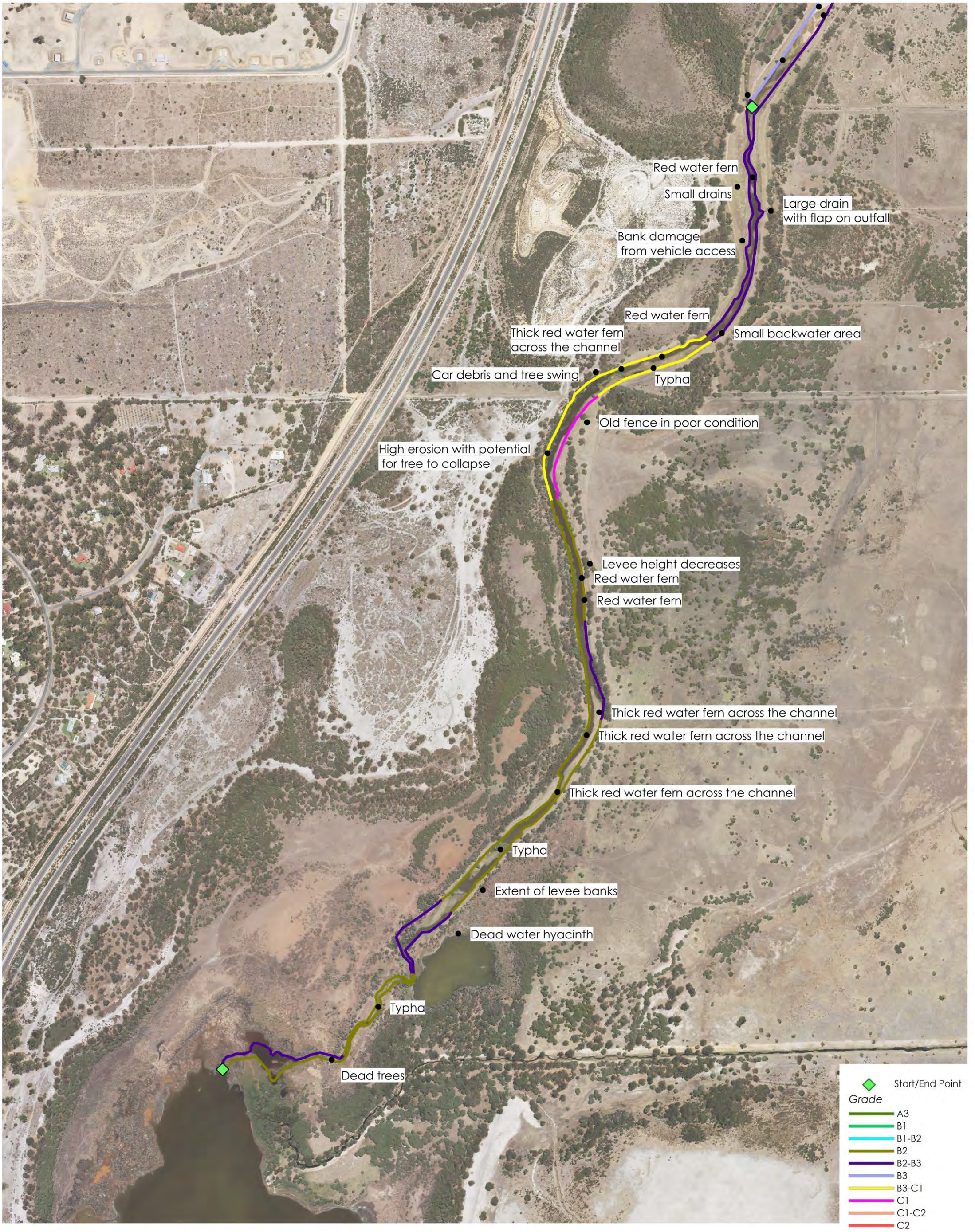
Table 10: Reach 4 Description and Conditions

Feature	Comments
Landuse	Land on either side of the river is owned and manged by the Department of Communities, with a small portion in the north vested with Department of Mines, Industry Regulation and Safety. Currently the land to the east is mostly cleared and used for cattle grazing. Land on the west of the river is constrained by the Kwinana Freeway and generally contains wetland areas and an area that was previously excavated for sand for the construction of the freeway. Future use of the Keralup site is subject to further planning, investigation and design.
Fencing and Infrastructure	There is no fence near the river on the Western side, with access controlled by fences and gates near the Kwinana Freeway. On the eastern side there are two fences; an older fence near the river that is in poor to moderate condition, and a newer fence (installed by DBCA and DoC) set back from the river banks that is in excellent condition. The fence runs outside of the small wetland at the downstream end of the reach. Despite the fences, field observations indicated the cattle and feral animals access from the eastern side of the river and vehicle access (including a burnt out car body) on the western side of the river.
Channel Form	The channel transitions from a wide, controlled channel with artificial banks to a narrow, meandering system with ill-defined banks near Lake Amarillo. The levee banks can be seen clearly in Figure 15, along with the increased connection with the floodplain. Within the levee banks there is a smaller low-flow channel that is up to 25 m wide with a lower bench to the levee banks. Towards Lake Amarillo the low-flow channel is around 5 m wide. A large rural drain flows into river at the upstream end (with a one-way flap at the outfall).
General Foreshore Condition	Scoring of the channel conditions improved downstream, with the upstream sub-reaches ranging from B2-B3 (degraded and weed infested) to C1 (erosion prone). The remainder of Reach 4 is consistently rated between B2 (degraded) and B2-B3 (degraded and weed infested) owing to the improved riparian and verge vegetation. Habitat diversity was consistently low for all sub-reaches given the relatively shallow low-flow channel, a lack of woody debris and limited backwater areas.
Vegetation Cover and Stream Health	The vegetation cover is significantly improved in comparison with Reach 3 however riparian vegetation is considerably reduced, particularly the ground and shrub layers. Tree cover was recorded as >50% on the eastern bank, between 10-49% on the western bank, with most trees <10 m (flooded gums and paperbark). Red water fern (native) extends across the entire low-flow channel in areas in some areas. Several dead trees were found near Lake Amarillo. DWER noted estuarine fish species near the confluence with Peel Main Drain.
Weeds	Several portions of the Reach were clogged by the presence of typha that have grown across the channel (Figure 16). Dead water hyacinth was observed with the small wetland and sub-reaches downstream near Lake Amarillo. Kikuyu and couch grass were noted, though less than in Reach 3. Other weeds identified during the field investigation include arum lily, goosefoot, veldt grass and cottonbush.
Erosion	The low-flow channel features deposited sediment that creates bars, islands and small backwater areas, similar to Reach 3. Erosion in Reach 4 is generally minor, with limited examples of bank undercutting beneath trees. On both banks there is a further risk of erosion associated with vehicle access, particularly from tracks that are near the low-flow channel.
Other Issues	Punrak Drain runs perpendicular to the Serpentine River and discharges into Lake Amarillo. The Punrak catchment and water quality impacts are discussed further in Reach 5. Lake Amarillo features seasonal variation in salinity from fresh (winter) to brackish to hypersaline (summer).
Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. Community value of this reach is limited by the lack of public access. The river is largely hidden from view from the Kwinana Freeway and only accessed (illegally) for camping and recreation.

Table 11: Reach 4 Management Actions and Recommendations

Prioritised management actions recommended
• Remove car bodies and material along the reach to ensure no leaching of chemicals into the river and remove tree swing to discourage recreational use of this reach; • Remove aquatic weeds and consider thinning dense areas of typha; • Control feral animals, particularly pigs; • Trial the importation of woody debris to improve habitat diversity; • Stabilise areas of high and severe erosion to protect healthy trees; and, • Investigate die-off of vegetation around Lake Amarillo and prevent stock and vehicle access in this area.
Long term management actions recommended
• The occurrence of red water fern indicates high nutrients within the river. Investigations of the contribution from respective tributaries (Peel Main Drain and local rural drains) should be undertaken to confirm respective contributions; • Improve riparian and floodplain vegetation, particularly areas with only ground cover or bare ground; • Work with land holders within the catchment to reduce nutrient application and improve water quality treatment (including Water Sensitive Urban Design) in established and proposed urban areas; and, • Advocate for the establishment of the Peel Regional Park from downstream of the Peel Main Drain confluence to protect the highest value waterway in conjunction with the State Government, Local Government, Water Corporation and local landholders.

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 16 - Reach 4 Condition Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

N

0 300
meters
Scale 1:8,000 @ A3

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Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 17 - Reach 5 Location Map

Vine Rd
Kwinana Fwy
KARNUP
5-1
5-2
5-3
5-4
5-5
5-6
5-7
5-8
5-9
5-10
5-11
5-12
5-13
Serpentine River Reach 5
City of Rockingham
KERALUP
Guananup Pool
Shire of Murray
Evergreen Loop
STAKE HILL

Start/End Point
Serpentine River
Subreach Division
Waterways
Local Government Boundary

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

N

0 600
meters
Scale 1:12,000 @ A3

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Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 18 - Reach 5 Elevation Map

Lake Amarillo

Paganoni Swamp Reserve

Serpentine River Reach 5

Guananup Pool

Start/End Point

Serpentine River

Contours (mAHD)

- < 2
- 2 ~ 4
- 4 ~ 6
- 6 ~ 8
- 8 ~ 10
- 10 ~ 15
- 15 ~ 20
- >20

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

N

0 600

meters

Scale 1:12,000 @ A3

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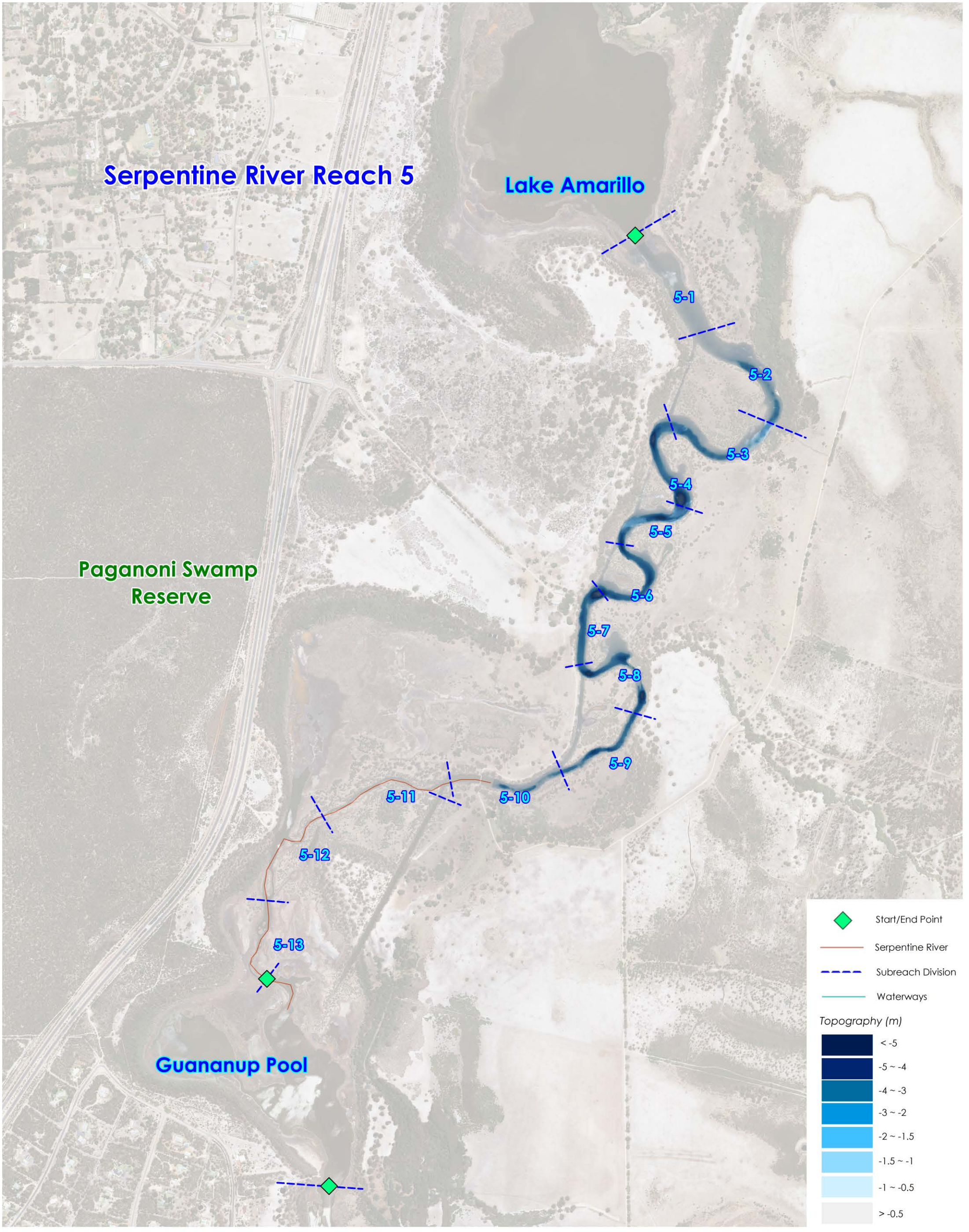
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 19 - Reach 5 Bathymetry Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:12,000 @ A3

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3.5 Reach 5

Reach 5 (5.3 km) extends from Lake Amarillo to the wetland system north of Stake Hill (Guananup Pool) in the City of Rockingham. This reach was assessed with definition of 13 sub reaches, each approximately 400 m in length (Figure 17). The main channel within Reach 5 has maintained a natural form however a number of high-flow bypass (straight) channels have been constructed to reduce surrounding flooding. The surrounding land is owned by the Department of Communities, including West Keralup which is zoned 'urban deferred' under the Metropolitan Region Scheme and East Keralup which is under investigation for non-residential land uses. At the downstream end of the reach, the Kwinana Freeway is 200m to the west, forming a border to Paganoni Swamp.

The channel form varies considerably from upstream reaches, with an approximately 30 m wide channel featuring a number of 3-4 m deep pools (Figure 19). There are examples of remnant vegetation along this reach in better condition that elsewhere, in particular in the large flooded gums on the eastern bank. The river and western floodplain are classified as Conservation Category Wetlands, whilst the eastern floodplain is classified as Multiple Use. Both floodplains and the river are within the Bush Forever (Site 394) area. Guananup Pool is a tidal flat with numerous dying trees.


Dying trees near Lake Amarilo


Meandering channel


Exposed tree roots


Algae on surface


Limited understorey

Plate 6: Reach 5 Site Photos

Table 12: Reach 5 Description and Conditions

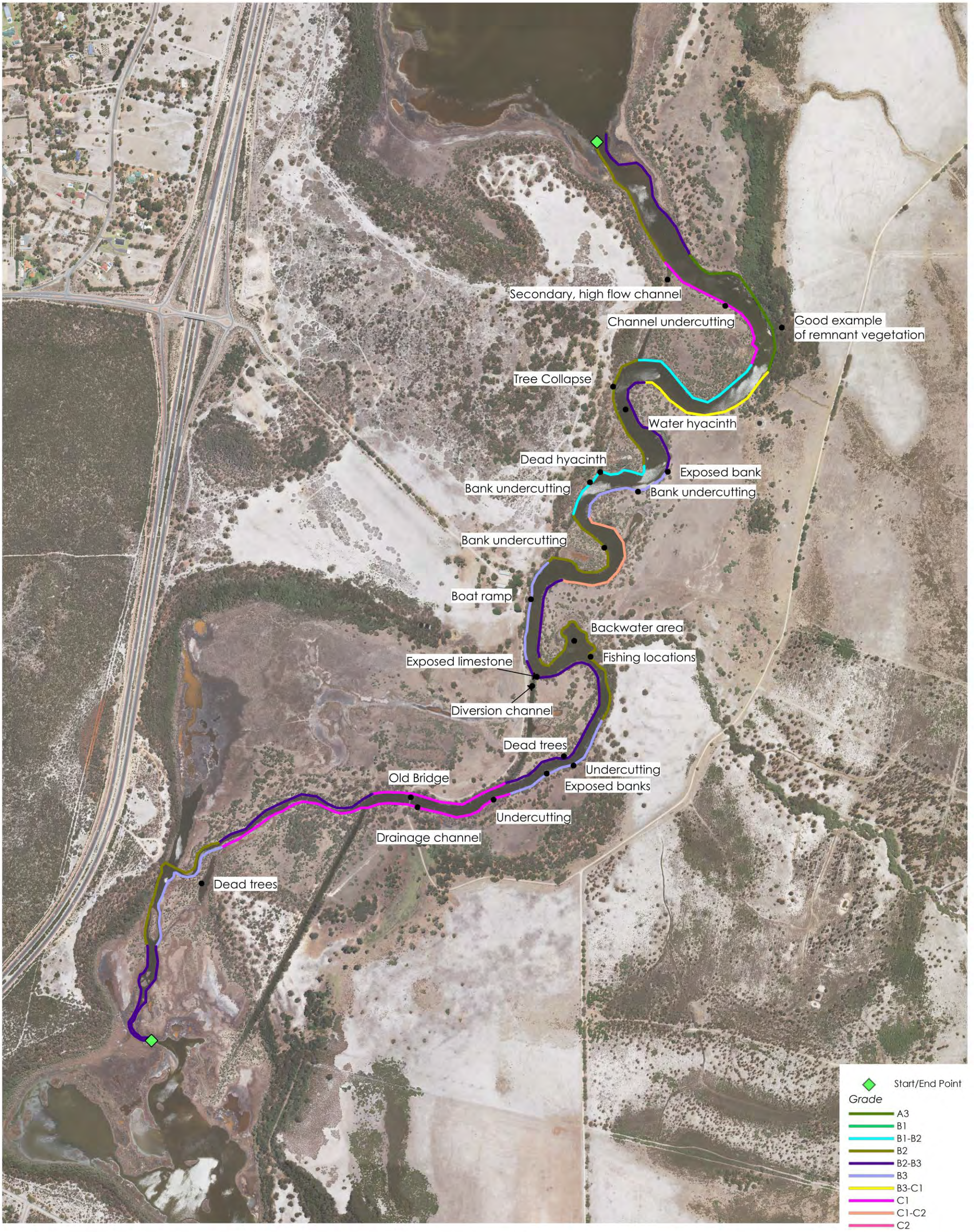
Feature	Comments
Landuse	The surrounding land is owned and managed by the Department of Communities. The land to the west of the river, bounded by the Kwinana Freeway, features large portions of cleared vegetation, a homestead and Conservation Category Wetlands associated with the floodplain. On the eastern side, land is generally cleared for stock grazing though several areas of remnant vegetation are intact.
Fencing and Infrastructure	No fences were observed on the western side of the river though there was no stock or damage given the isolated location. A recently constructed (by DBCA and DoC) fence on the eastern side of the river controls stock access, though minor damage from stock access was noted in several sub-reaches. It is unclear whether this may be attributed to stock access prior to the fence construction. Elsewhere along the reach is an old timber bridge, and an informal boat ramp and concrete structure adjacent to the homestead.
Channel Form	The main channel within Reach 5 has not been directly modified like upstream reaches. The channel features a meandering form with deep pools located on meander bends as shown in the bathymetry data collected by DWER (Figure 19). The pools are greater than 5 m deep in several locations, with an average channel depth typically greater than 2 m. The channel is typically 30 – 40 m wide, though it narrows at the downstream end. There are also several natural, shallow backwater areas associated with the meander bends. The system has been modified with the creation of straight high-flow channels that bypass meanders and reduce localised flooding. The longest of these channels is 960 m.
General Foreshore Condition	Foreshore condition along Reach 5 varies considerably from A3 (slightly disturbed) to C1-C2 (erosion prone and soil exposed) with the variation associated with riparian vegetation condition and bank erosion. The condition decreases downstream towards the wetland system where stock access and clearing, particularly on the eastern bank, has impacted the banks. Stream habitat and diversity is significantly improved compared with upstream reaches owing to the presence of the deep pools.
Vegetation Cover and Stream Health	The riparian vegetation cover is generally degraded, with several areas of bare ground and reduced shrubs and tree layers associated with impacts of past grazing uses. Dying trees were noted in several locations along the reach, both at the upstream and downstream ends. There is an area of remnant flooded gum and paperbark (sub-reach 5-2) that may be a reference area for future rehabilitation.
Weeds	Water hyacinth was identified generally in the upstream sub-reaches. Herbicide spraying was undertaken in early 2019 to control the spread of this weed, resulting in large clumps of dead plant matter in the main channel (behind baffles) and along banks. Other prominent weeds include watsonia (particularly dense in the middle sub-reaches), couch grass, kikuyu grass, fig trees and rumex (dock).
Erosion	Bank undercutting and tree collapse were noted throughout the reach. Areas of poor bank stability feature exposed soil and tree roots, near-vertical profile and undercutting from regular flows. These areas are generally associated with the outside of meander bends and reduce vegetation cover, particularly the shrub layer). Stock and human access (potentially historic) has also caused direct bank instability in many locations, including at the old timber bridge crossing.
Other Issues	Poor water quality was evident along the reach in the form of visible algae and foam on the surface. A potential source of nutrients within this reach is from Punrak drain that flows into system at Lake Amarillo (downstream from Reach 4). Punrak drain (including Karnet Brook and Dirk Brook) has a 134 km^2 catchment, extending to the Darling Scarp with approximately 30% of the catchment used for cattle. Water quality monitoring within the drain by DWER (2001-2016) has identified high levels of total nitrogen and total phosphorus with the waterway, including very high levels since 2013 (DWER, 2017). DWER are currently trialling the release of phosphorus-binding clay within the drain to improve water quality as part of the Regional Estuaries Initiative. The downstream area of Reach 5 is mapped as having a "moderate to high" risk of Acid Sulfate Soils occurring, consistent with the observed low-lying waterlogged soils. These soils may have been disturbed previously through the

	construction of straight high-flow channels in the area, posing a threat to the ecosystem health in Reach 5 and downstream.
Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. Community value of this reach is limited by the lack of public access. The river is largely hidden from view from the Kwinana Freeway and only accessed by adjacent residents.

Table 13: Reach 5 Management Actions and Recommendations

Prioritised management actions recommended
• Regularly inspect and maintain the fencing on the eastern bank to confirm no ongoing stock access; • Continue to monitor sediment build up in pools from the phosphorus-binding clay trials in Punrak Drain to prevent excessive build up; • Protect high-quality remnant vegetation on the upstream eastern bank, and survey and photograph vegetation in detail as a reference for other reaches; • Investigate dying trees at upstream and downstream extents, including the role of acid sulphate soils; and, • Rehabilitate severe bank erosion and undercutting to prevent mobilisation of sediment within this reach (and deposition into pools).
Long term management actions recommended
• Re-establish riparian vegetation along the reach, particularly on banks with bare ground to improve stability; • As with Reach 4, work with local landholders to reduce nutrient input in the catchment and improve water quality treatment of runoff; • Establish the Peel Regional Park and ensure rehabilitation and protection of this reach with any future changes in land use; and, • Consider closure and rehabilitation of high-flow bypass channels to increase connection with the floodplains and wetlands (dependent on impacts on surrounding flood levels for development).

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 20 - Reach 5 Condition Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:10,000 @ A3

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Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 21 - Reach 6 Location Map

City of Rockingham
KERALUP
Guananup Pool
Evergreen Loop
6-1
6-2
6-3
6-4
6-5
6-6
6-7
6-8
6-9
6-10
Shire of Murray
STAKE HILL
Serpentine Wy
Serpentine River Reach 6
Yalbanberup Pool

Start/End Point
Serpentine River
Subreach Division
Waterways
Local Government Boundary

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:8,000 @ A3

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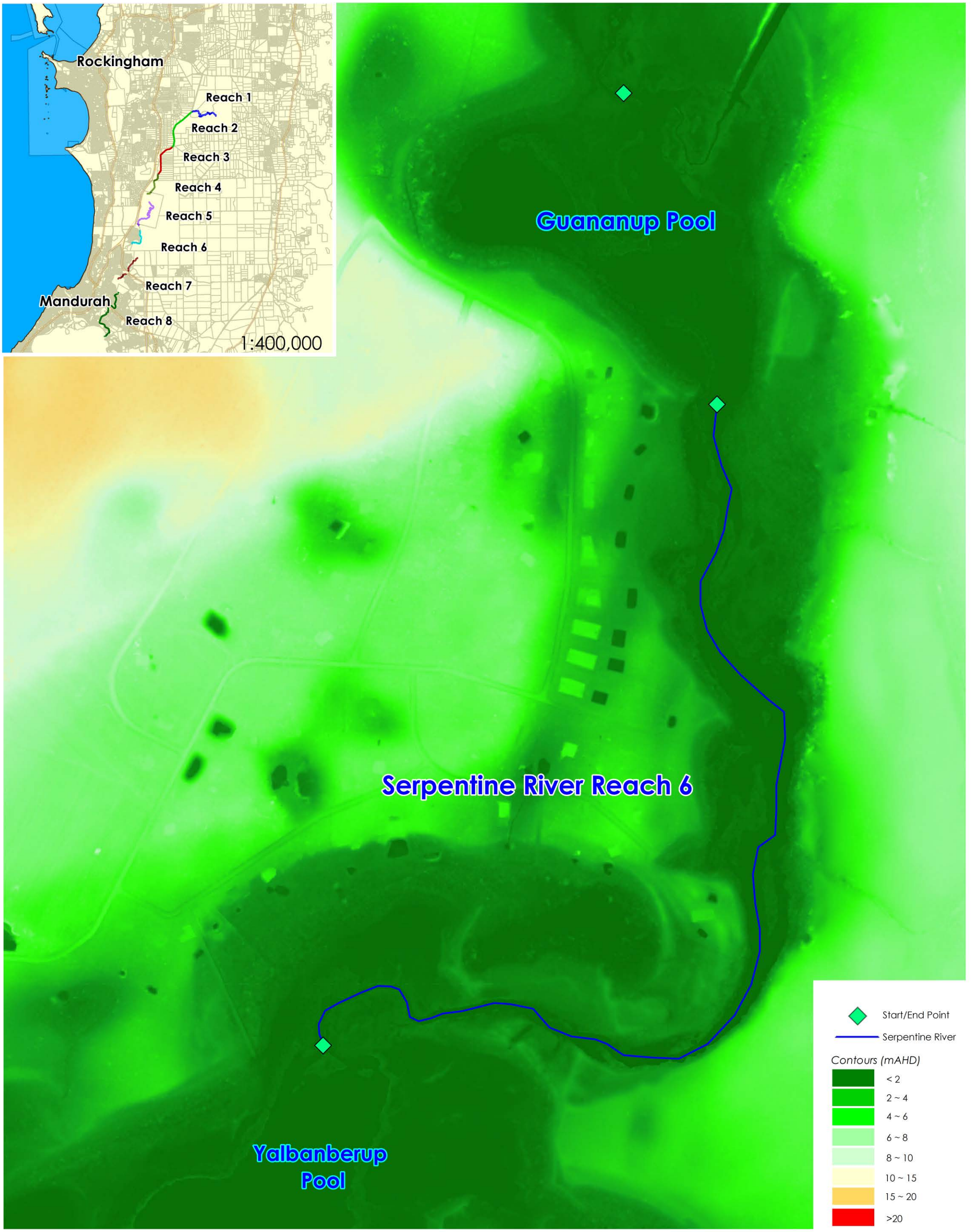
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 22 - Reach 6 Elevation Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:8,000 @ A3

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3.6 Reach 6

Reach 6 (3.1 km) extends from Guananup Pool to Yalbanberup Pool in the Shire of Murray. This reach was assessed with definition of 10 sub-reaches, each being approximately 300 m in length (Figure 21). Limited access in late autumn and winter (dense vegetation and/or waterlogged ground) prevented a field inspection of the reach, with data below based on desktop analysis. Key datasets include a helicopter-based aerial photography of the banks in December 2018 and recent aerial imagery of the wider floodplain.

This reach is within the southern end of the Department of Communities Keralup landholdings. West of the river is Stake Hill, a rural residential development constructed in the 1990s. The river and western floodplain are classified as a Conservation Category Wetland, recognising the presence of vegetation cover on both banks, including remnant trees providing a near-continuous canopy. The channel is generally wide with a combination of small backwater areas and islands and bars providing a variety of habitats.

Table 14: Reach 6 Description and Conditions

Feature	Comments
Landuse	Reach 6 is located in a combination of crown land and Department of Communities landholding, with the boundary often intersecting the main channel. Land to the east is used for stock grazing and vegetation beyond 100 m from the river is low-lying and generally cleared. The Stake Hill development west of the site features rural residential lots, with some houses within 100 m of the river. Most lots, including those adjacent to the river feature small dams.
Fencing and Infrastructure	Public access to the river in this reach is generally limited by private properties and dense vegetation on the west, and low-lying (water logged) land on the east. There is a fence along the northern end of Evergreen Loop which is the closest point for public access to the river. There is a small private access track at the upstream end of the reach. Stock access to the east is controlled by the fence installed by DBCA and DoC.
Channel Form	The river is a single meandering channel with mid-channel islands and bars, and a low-lying floodplain forming backwater areas (visible within Figure 22). The channel is up to 150 m wide, though narrows considerably to 25 m at the downstream end. There are no obvious channel modifications within this reach. The tidal influence is evident where tidal flats are located on both sides of the river near Yalbanberup Pool.
General Foreshore Condition	The foreshore condition varies between B1 (degraded) and B2-B3 (degraded – weed dominated), with the main factor being the riparian and verge vegetation quality. Clearing of vegetation on both sides of the river (particularly within the verge zone) for development and stock grazing resulted in the degraded rating for this reach. Bank stability and habitat diversity were scored reasonably consistently owing to the low-lying floodplain, shallow banks and the abundance of variety in channel form.
Vegetation Cover and Stream Health	Aerial images indicate dense tree cover on both banks with a continuous canopy, apart from tidal flat areas. The more detailed helicopter photos show that many of the trees are dead or dying, with minimal understorey and bare ground. The tidal flats are generally devoid of vegetation. Vegetation has been cleared within 20 m of the eastern side of the river, while vegetation has been reduced on the western bank, south of the residential areas.
Weeds	Site inspections in this area were not possible, so specific weeds could not be identified. Aerial images indicate there are no in-channel weeds

	such as water hyacinth that were noted upstream.
Erosion	Aerial imagery (Figure 21) and LIDAR data (Figure 22) suggests that there would be limited erosion throughout the reach. Reach 7 (downstream) has a similar channel form and erosion was associated with human access only. The vegetation and land ownership limits this potential in Reach 6.
Other Issues	During a separate inspection in 2019, a dead Rakali was identified in the downstream section.
Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. Community value of this reach is limited by the lack of public access. Although there is increased access opportunities compared within upstream reaches, recreation generally consists of kayaking.

Table 15: Reach 6 Management Actions and Recommendations

Prioritised management actions recommended
• Review and maintain fencing on the eastern bank to confirm no ongoing stock or vehicle access; • Work with landholders on the western bank to control access to the river and minimise the risk of bank erosion; and, • Investigate dying trees along the reach.
Long term management actions recommended
• Re-establish riparian vegetation along the reach, particularly on the eastern bank damaged previously by stock grazing; • As with Reach 4, work with local landholders to reduce nutrient input in the catchment and improve water quality treatment of runoff; and, • Establish the Peel Regional Park and ensure rehabilitation and protection of this reach with any future changes in land use.

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 23 - Reach 6 Condition Map

Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

0 400
meters
Scale 1:8,000 @ A3

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Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 24 - Reach 7 Location Map

Yalbanberup Pool
7-1
7-2
7-3
7-4
7-5
7-6
7-7
7-8
7-9
7-10
Goegrup Lake
Serpentine River Reach 7
Woodland Parade
Kwinana Fwy
Marginata Rd
Shire of Murray
STAKE HILL
City of Mandurah
PARKLANDS
Red Rd
Lakes Rd East
Lakes Rd
Osprey Link

Start/End Point
Serpentine River
Subreach Division
Waterways
Local Government Boundary

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

N

0 500
meters
Scale 1:10,000 @ A3

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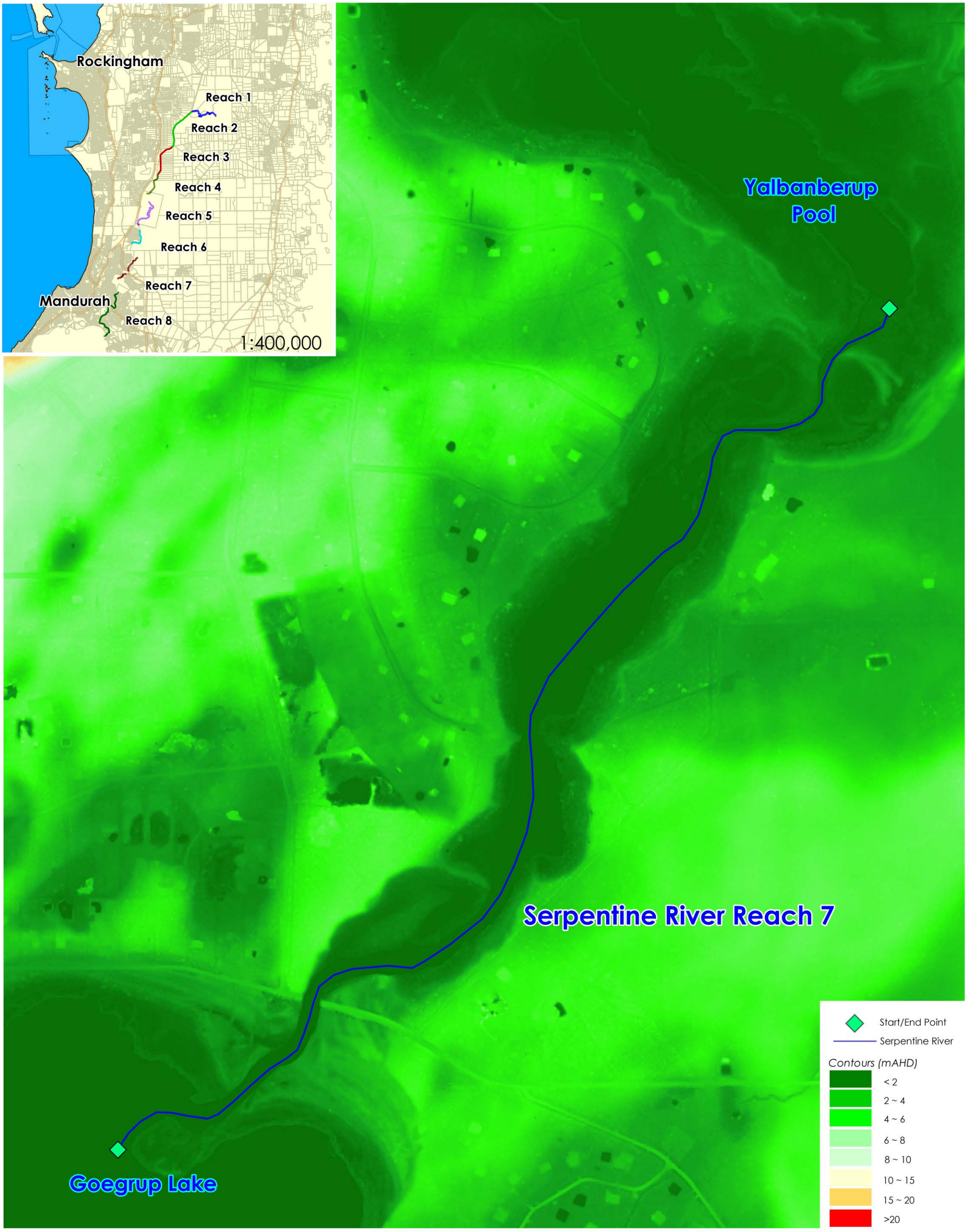
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 25 - Reach 7 Elevation Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:10,000 @ A3

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3.7 Reach 7

Reach 7 (3.7 km) extends from Yalbanberup Pool to Goegrup Lake in the Shire of Murray (near the boundary with the City of Mandurah south of Lakes Road). This reach was assessed with definition of 10 sub-reaches, approximately 350 m in length (Figure 24). Field inspection of this reach was undertaken by boat, with sub-reaches 7-1 to 7-3 completed from desktop analysis. Reach 7 is south of the Department of Communities Keralup project with private landholdings on the eastern side of the river. West of the river are private rural lots, part of the southern Stake Hill development. The Kwinana Freeway and Lakes Road cross the river towards Lake Goegrup. The entire reach is classified as a Conservation Category Wetland.

The river has not been significantly modified historically apart from the Kwinana Freeway construction. The upstream and downstream sub-reaches are relatively narrow and meandering, while the middle sub-reaches are approximately 200 m wide. As shown in Figure 25, the banks and immediate floodplain are low-lying, with tidal flats at the upstream end. There are multiple informal access points to the river, demonstrating the recreation value of this reach in particular kayaking.


Limited vegetation on banks


Large trees near Lakes Rd


Varying canopy cover


Algae on surface


River up to 200 m wide

Plate 7: Reach 7 Site Photos

Table 16: Reach 7 Description and Conditions

Feature	Comments
Landuse	The middle and downstream sub-reaches of the river are within Crown land that also includes a portion of the floodplain and the Yalbanderup Pool. The northern meandering sub-reaches are within freehold land zoned Regional Open Space. Land west of the river is predominantly rural residential lots. Land use on the eastern side of the river varies between rural residential (north and south of Kwinana Freeway) and a large land holding previously used for stock grazing.
Fencing and Infrastructure	The major infrastructure in this reach are two bridges (Kwinana Freeway and Lakes Road) and a Water Corporation pipeline that crosses the river. Fencing along this reach that was visible was off varying quality depending on upkeep by the adjacent landowners. The river is accessed by the community at several informal locations along the river (Figure 26), including at Lakes Road and the end Woodland Parade in Stake Hill. These access points are not controlled, and public access has led to localised erosion.
Channel Form	The channel form is largely unmodified from historical mapping. The upstream sub-reaches meander from Yalbanberup Pool to the middle reaches that feature a 200 m wide (unnamed) pool. There are tidal flats and backwater areas in the upstream meandering system. Downstream of the Kwinana Freeway the channel resumes a meandering form though only a single channel. For the majority of the reach, the banks are shallow apart from the western bank upstream of Kwinana Freeway where there is a steeper section.
General Foreshore Condition	The lack of historical intervention in the river has resulted in sub-reaches with high assessment scores and better conditions than other reaches that were assessed. The sub-reaches range from A3 (slightly disturbed) to B2 (degraded) owing to the extent of the riparian vegetation and lack of severe erosion. The reach has good habitat diversity amongst all sub-reaches with a variety of channel depths and woody debris present. Algae in the water column were observed in most sub-reaches, with flecks of oil noted downstream.
Vegetation Cover and Stream Health	Riparian vegetation in Reach 7 contains predominantly native vegetation, with invasive ground cover noted in many sub-reaches. Large trees were noted along the entire reach providing a continuous canopy, disrupted only by the bridges, crossings and access points. A large number of dying sheoaks between the Kwinana Freeway and Lakes Road were observed on the northern bank. Understorey was heavily reduced downstream of Lakes Road on private properties, and upstream associated with grazing.
Weeds	Few invasive species were observed during the field inspection. Love-grass and kikuyu were noted in several sub-reaches. Turf was also observed near the homestead upstream of Kwinana Freeway.
Erosion	Limited and minor erosion was noted through this reach, reflecting the shallow banks, low-lying floodplain and lack of boating. Local areas of erosion and bank damage were associated with access points. The bridges and river crossing featured rock protection and/or timber boards to limit erosion. Collapsed trees were noted downstream of Lakes Road.
Other Issues	Gull Road Drain flows into Yalbanberup Pool, upstream of this reach. DWER monitoring in this reach identified the drain as having the highest total nitrogen and phosphorus concentration at any of the 13 sites sampled in the Peel-Harvey Catchment (DWER, 2017b). These high concentrations were previously linked to the Wandalup Farm's piggery which has now closed.
Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. Community value of this reach is high owing to the increased access to this reach and the ability to view it from public spaces and bridges. This reach is used for recreation (kayaks and boating) and many private properties have facilities facing the river (particularly downstream of Lakes Road).

Table 17: Reach 7 Management Actions and Recommendations

Prioritised management actions recommended
• Work with respective local governments to create formal access points to the river for recreation, south of Lakes Road (City of Mandurah) and Woodland Parade (Shire of Murray); • Repair gates and fences along Fowler Road to prevent vehicle access to the river; • Work with landholders on the eastern bank near Yalbanberup Pool to restrict stock and vehicle access and improve connection between riparian vegetation and remnant vegetation with the floodplain; and, • As with upstream reaches, investigate dying trees, particularly near the Kwinana Freeway.
Long term management actions recommended
• Work with landholders to improve land use practices and reduce nutrient inputs in the catchment; and, • Consider the access point south of Lakes Road as an education site with signage (similar to Reach 2) to outline recreational and natural values of this reach and measures the community can undertake to improve water quality and weed control within the wider catchment.

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 26 - Reach 7 Condition Map

Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:10,000 @ A3

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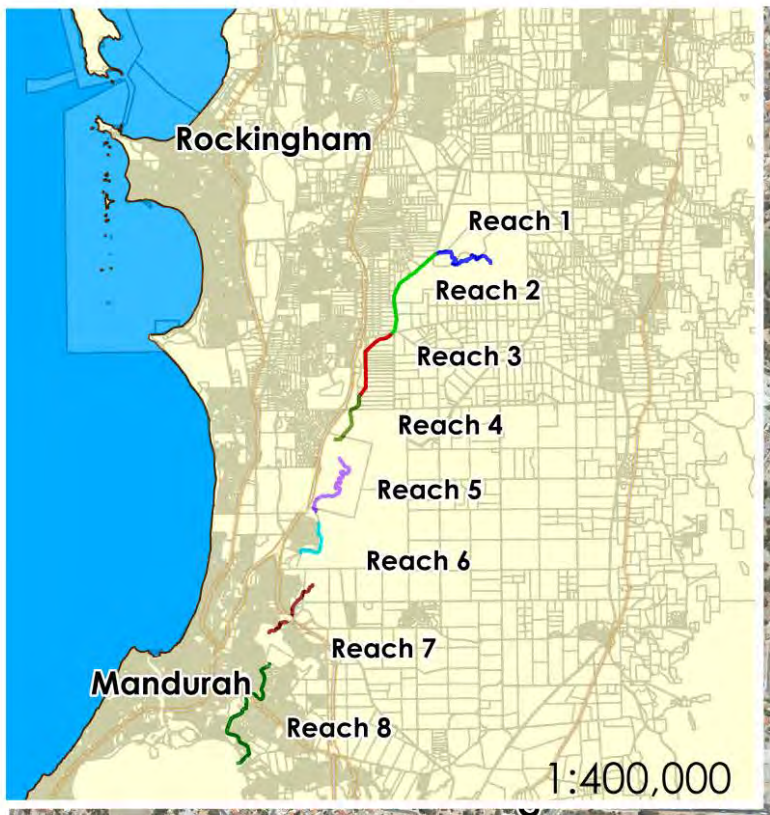
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 27 - Reach 8 Location Map



Goegrup Lake
8-1
8-2
8-3
8-4
8-5
8-6
8-7
8-8
8-9
8-10
8-11
8-12
8-13
8-14
8-15
8-16
8-17
8-18
Pinjarra Rd
City of Mandurah
COODANUP
Barragup Island
Wanjeep St
Roy Rd
Watson Dr
Furnissdale Rd
Serpentine River Reach 8
Shire of Murray
FURNISSDALE
John St

Start/End Point
Serpentine River
Subreach Division
Local Government Boundary

Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

N

0 800
meters
Scale 1:16,000 @ A3

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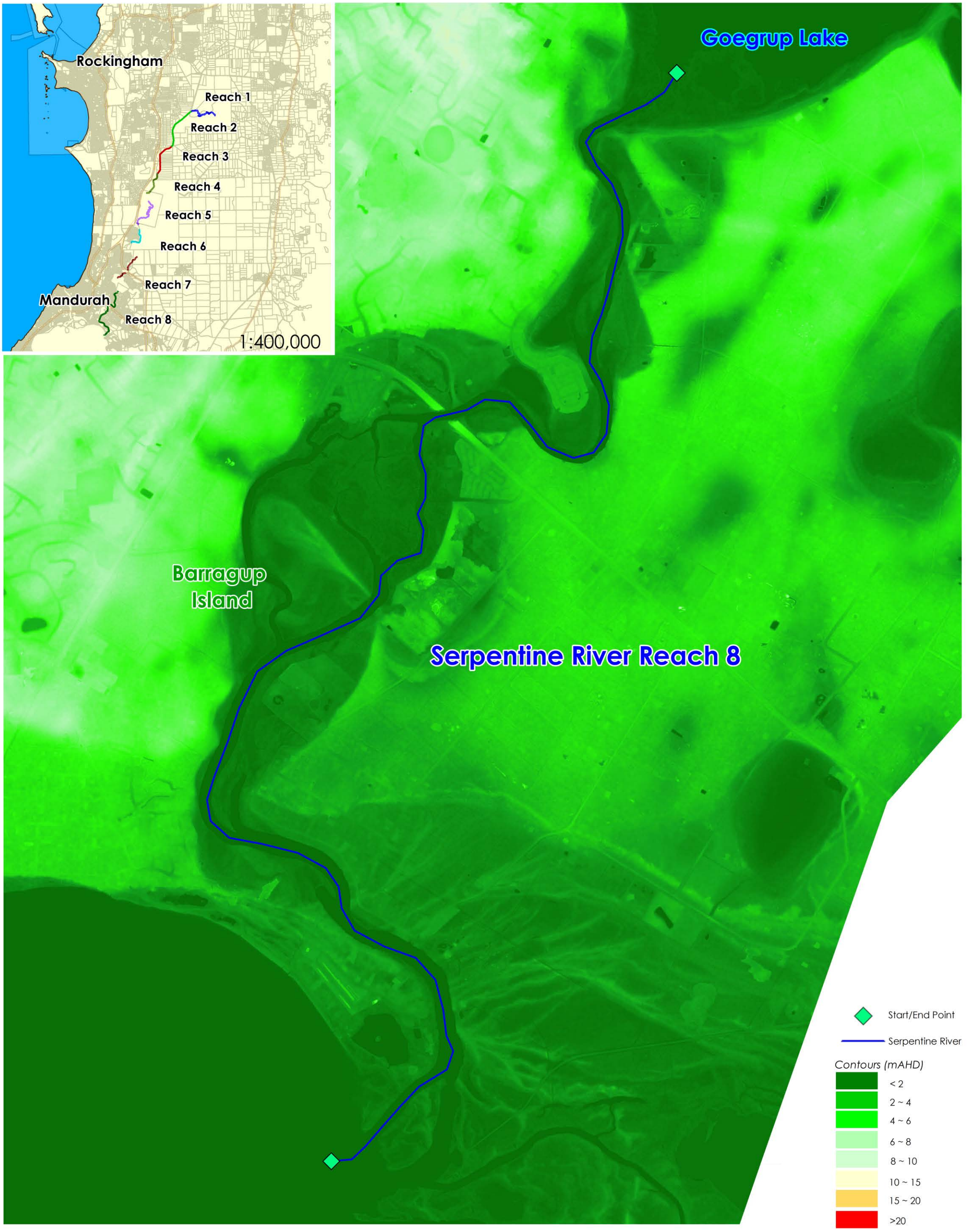
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 28 - Reach 8 Elevation Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:16,000 @ A3

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3.8 Reach 8

Reach 8 (8.2 km) extends from Goegrup Lake to the Peel-Harvey Estuary outlet. This reach was assessed with definition of 18 sub-reaches, each being approximately 450 m in length (Figure 24). Field inspection of this reach was undertaken by boat. The Serpentine River forms the boundary between the City of Mandurah (west) and the Shire of Murray (east). The river is within an area zoned Regional Open Space (by both local governments), providing a buffer to residential and rural residential properties. The Pinjarra Road Bridge crosses the river, connecting development on the east and west. This reach has previously been assessed in detail (City of Mandurah, 2007) and findings are incorporated in this assessment and recommendations.

This reach is estuarine, meandering from the lake to the estuary with a number of connected tidal flats. Typically the river is 60 – 80 m wide though the tidal flat area downstream of Pinjarra Road is approximately 700 m wide. Erosion and reduced vegetation cover was observed along this reach, associated with the urban surroundings and increased access and recreation use compared with upstream.


Severe bank erosion


Private jetties


Boards to prevent erosion


Abundant birdlife


Dying trees

Plate 8: Reach 8 Site Photos

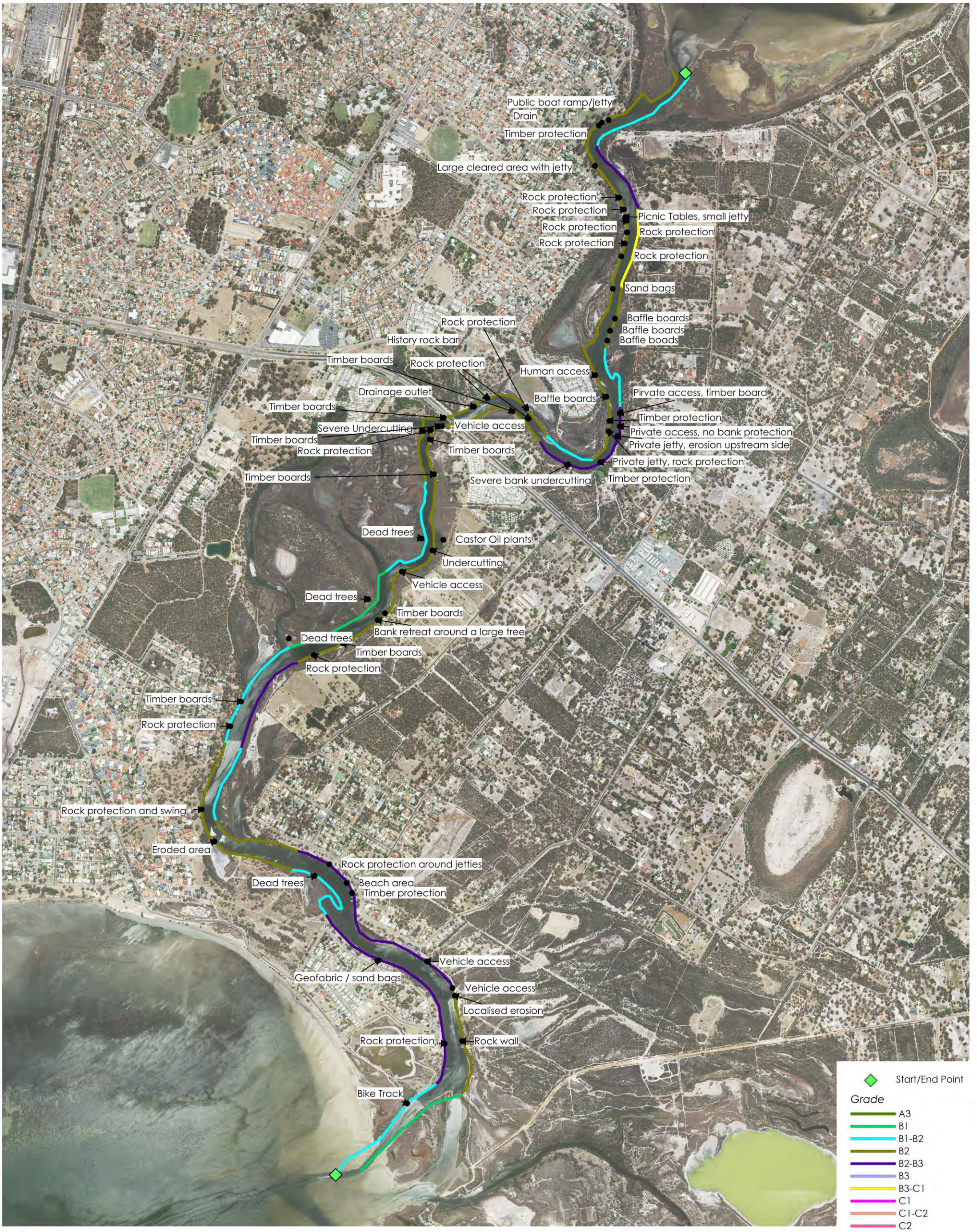
Table 18: Reach 8 Description and Conditions

Feature	Comments
Landuse	The channel sits within Crown land, zoned Regional Open Space. On the eastern side of the river (Shire of Murray), the most common land use is rural and rural residential, with residential areas in Furnissdale downstream of Pinjarra Road. Residential areas west of the river (City of Mandurah) are generally established, and include the suburbs of Greenfields and Coodanup. These suburbs were built from the 1980s and feature drainage pipes that discharge directly into the river.
Fencing and Infrastructure	The majority of the reach is not fenced, allowing access from public and private land. Fencing is restricted to areas of remnant vegetation. There are several paths and walkways along the river, particularly on the western bank, north of the Pinjarra Road Bridge. Riverside Drive (Furnissdale) and Bertram Road (Coodanup) run parallel to the river and provide a buffer to residential areas. There are small jetties and moorings along the entire reach along with several boat ramps (Figure 29).
Channel Form	The channel is estuarine with shallow banks, a low-lying floodplain and a meandering form that widens slightly downstream. There are large tidal flats, associated secondary channels and smaller backwater areas through the reach. At the downstream end, the river has multiple channels around Jennala Island, near the outlet from the Murray River.
General Foreshore Condition	Foreshore condition along Reach 8 varies from B1 (degraded) to B3-C1 (degraded – erosion prone) with the variation associated with riparian vegetation condition and bank erosion. In comparison with upstream estuarine reach 7, scores are lower due to increased bank instability and access from urban areas. Higher scores on the western bank are associated with improved bank stability, attributed to the location of meander bends and previous works to control erosion.
Vegetation Cover and Stream Health	Riparian and verge vegetation on both sides of the river have been impacted by rural and residential land uses, past and present. There are large flooded gums along the river in the upstream reaches, but limited understorey. Casuarina is the dominant tree of the downstream sub-reaches with some marri and jarrah identified. Dead trees were noted along these sub-reaches, particularly within the tidal flats. The majority of the banks (apart from those impacted by access or clearing) features rushes and sedges. Samphire was also recorded, including upstream of Pinjarra Road.
Weeds	Annual grasses and turf grass was noted along the reach, the latter associated with parklands in residential areas. Other weeds identified were wild oats (sub-reach 8-9), castor oil (sub-reach 8-10) and palm trees (sub-reach 8-18).
Erosion	Bank erosion is evident along the reach likely resulting from community access, boat wake and larger riverine flows. The erosion noted included minor bank scouring and undercutting, exposed surfaces, tree collapse and severe undercutting. The more severe erosion was observed on the outside of meander bends along the reach. Efforts to control erosion within the reach have included the installation of baffle boards, logs strapped to banks, pine revetment, bank matting and rock wall protection. The baffle boards (timber boards offset from the river bank) are particularly extensive north of Pinjarra Road with limited effectiveness. Erosion behind these boards was regularly observed. Rock protection on the western bank is more successful in stabilising the banks.
Other Issues	N/A
Community and Cultural Values	Local Bindjareb Noongar Elders and Representatives will provide knowledge and advice on each site, its cultural significance and values. Please refer to section 2.3 of this document to ensure all processes and procedures are followed. Community interaction with this reach is the highest of those assessed. There are numerous examples of access for boating and recreation, including private jetties and moorings. There are also several public open spaces and tracks that are used frequently by the community.

Table 19: Reach 8 Management Actions and Recommendations

Prioritised management actions recommended
• Eradicate clusters of weeds observed along the reach, including castor oil and wild oats; • Encourage landowners to plant local native plants and remove invasive species away from the river and waterways; • Install erosion control measures at areas of severe undercutting to prevent bank collapse and retreat; • Work with Department of Transport to enforce a 5-knot speed limit in this reach; • Provide local residents with advice and resources to define/control access points to the river; • Close unnecessary tracks and access points along the river; • Monitor new development in Coodanup to ensure no sediment is mobilised and suitable water quality discharges to the river; and, • As with upstream reaches, investigate dying trees, particularly near the large tidal flat downstream from Pinjarra Road.
Long term management actions recommended
• Review local drainage catchments to identify high-risk urban pollution sources and investigate retrofitting drainage systems to ensure water quality treatment prior to discharge into the Serpentine River; • Replace ineffective erosion control structures (e.g. baffle boards, pine revetment) with soft (matting, logs and woody debris) or hard (rock-pitching) engineering bank protection; and, • Work with landholders to restore riparian vegetation.

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 29 - Reach 8 Condition Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

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meters
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4 RECOMMENDATIONS

A summary of the recommended actions are provided in Table 20, grouped to address the aims of the PHCC and Alcoa Foundation's *Connecting Corridors and Communities: Restoring the Serpentine River* project. It is envisioned that these actions are adapted based on findings from further investigations, identification of other issues and threats, or following remediation work. Funding is required for recommended actions to be successfully undertaken.

Abbreviations for the various agencies in Table 20 are provided below:

- CoR: City of Rockingham
- CoM: City of Mandurah
- DBCA: Department of Biodiversity, Conservation and Attractions
- DFES: Department of Fire and Emergency Services
- DMIRS: Department of Mines, Industry Regulation and Safety
- DoC: Department of Communities
- DoT: Department of Transport
- DPLH: Department of Planning, Lands and Heritage
- DPLH-AA: Department of Planning, Lands and Heritage (Aboriginal Affairs)
- DWER: Department of Water and Environmental Regulation
- SoM: Shire of Murray
- SSJ: Shire of Serpentine Jarrahdale
- Private: Private Landholders
- PHCC: Peel Harvey Catchment Council
- WC: Water Corporation

Table 20: Priority Actions and Recommendations

Item	Priority	Location	Action	Owner	Manager	Stakeholders
1-1	Short term	Reaches 1 to 7	Provide further controls to the river to prevent stock and vehicle access that is responsible for bank damage and vegetation degradation. Significant access points that require control are: - Reach 2 eastern and western banks (illegal vehicles) - Reaches 2 and 3 under Karnup Road - Reach 4 on the western bank (vehicles) - Reach 4 near Lake Amarillo (stock and feral animals) - Reach 5 on the eastern bank (stock) - Reach 7 on the eastern bank (vehicles) With regards to vehicle access points, regular inspection of gates and fences is required to ensure they are not cut or otherwise damaged.	Private (R1-R4, R7) DPLH (R1-R7) DMIRS (R4) DoC (R4,R5)	DBCA (R2-R7) DWER WC (R1-R4) DoT (R7) DFES (R1-R2)	SSJ (R1, R2) CoR (R2-R5) SoM (R6,R7) DPLH-AA
1-2	Short term	Reach 2	Undertake weed removal, bank stabilisation and restoration of riparian vegetation at high value areas as trials for wider restoration works. Potential sites in Reach 2 include upstream of the Serpentine River and Birrega confluence and upstream Hymus creek and Serpentine River confluence, and downstream of Dog Hill monitoring station and Karnup Road.	Private DPLH	DBCA DWER WC	CoR SSJ DPLH-AA PHCC
1-3	Short term	Reaches 3 and 4	Car bodies, bulk litter and informal recreation facilities (fire pits, tree swings) along these reaches should be removed to ensure no leaching of chemicals into the river and discourage use.	Private DPLH DMIRS (R4)	DBCA DWER WC	CoR DPLH-AA
1-4	Short term	Reaches 2 to 4	Continue to control aquatic weeds such as water hyacinth and consider thinning of other invasive aquatic species such as typha and red water fern.	Private DoC (R4) DMIRS (R4) DPLH	DBCA DWER WC	CoR SSJ (R2) DPLH-AA
1-5	Short term	Reaches 1, 2, 4, 5 and 8	Implement localised bank protection to prevent erosion near Lowlands and in the remaining reaches where there is potential for bank erosion and collapse of healthy trees.	Private (R1,R2,R4) DoC (R4,R5) DPLH DMIRS (R4)	DBCA (R2,R4,R5,R8) DWER WC (R1,R2,R4) DoT (R8)	CoR (R2,R4,R5) SSJ (R1, R2) SoM (R8) CoM (R8) DPLH-AA
1-6	Short term	Reach 4	Trial the importation of woody debris to improve habitat diversity.	Private	DBCA	CoR

Item	Priority	Location	Action	Owner	Manager	Stakeholders
				DoC DPLH DMIRS	DWER WC	DPLH-AA
1-7	Short term	Reach 5	Continue to monitor sediment build up in pools from the phosphorus-binding clay trials in Punrak Drain to prevent excessive build up.	DoC DPLH	DBCA DWER	CoR DPLH-AA
1-8	Long term	Reaches 1 and 2	Investigate the impact of instability from bed lowering at the confluence with the Birrega Main Drain, including additional topography survey and comparison with LIDAR data. Based on the investigation, implement measures to stabilise this area, potentially including bank protection (soft and hard engineering). Multiple uncontrolled drains from paddocks on the eastern bank should also be investigated.	Private DPLH	DBCA (R2) DWER WC	DPLH-AA
1-9	Long term	Reach 2	Consider relocation of the fence on the western bank to inside of the track to allow community use, but preventing direct access.	Private DPLH	DBCA DWER WC	CoR DPLH-AA
1-10	Long term	Reaches 2 and 3	Utilise Reaches 2 and 3 to buffer and protect downstream lakes, pools and wetlands through sediment trapping and removal.	Private DoC DPLH	DBCA DWER WC	CoR SSJ DPLH-AA
1-11	Long term	Reach 3	Review the impact of DWER trials of Peel Main Drain flow and runoff diversion into large swales prior to discharge downstream. Similar systems can be considered along this reach with diversion of base-flows.	Private DoC DPLH	DBCA DWER WC	CoR DPLH-AA
1-12	Long term	Reach 4	The occurrence of red water fern (native) indicates high nutrients within the river. Investigations of the contribution from respective tributaries (Peel Main Drain and local rural drains) should be undertaken to confirm respective contributions.	Private DoC DPLH DMIRS	DBCA DWER WC	CoR DPLH-AA
1-13	Long term	Reach 8	Review local drainage catchments to identify high-risk urban pollution sources and consider retrofitting drainage systems to ensure water	DPLH	CoM DBCA	CoM SoM

Item	Priority	Location	Action	Owner	Manager	Stakeholders
			quality treatment prior to discharge into the Serpentine River.		DWER DoT	DPLH-AA
1-14	Long term	Reach 8	Replace ineffective erosion control structures (e.g. baffle boards, pine revetment) with soft (matting, logs and woody debris) or hard (rock-pitching) engineering bank protection.	DPLH	CoM DBCA DWER DoT	CoM SoM DPLH-AA
2-1	Short term	Reach 2	Contact landholders and discourage equestrian access to the river.	Private DPLH	DBCA DWER WC	CoR SSJ DPLH-AA
2-2	Long term	Reaches 2 and 7	The majority of the river is inaccessible to the public. Education sites should be established for the community to view the river, understand the Aloca/PHCC project and view restoration efforts. Two prominent locations are the carpark north of Karnup Road (downstream end of Reach 2) and south of Lakes road (Reach 7). Signage in each location is recommended.	Private DPLH	DBCA DWER WC (R2) DoT (R7)	CoR (R2) SSJ (R2) SoM (R7) DPLH-AA PHCC
3-1	Short term	Reach 5	Protect high-quality remnant vegetation on the upstream eastern bank, and survey and photograph vegetation in detail as a reference for other reaches.	DoC DPLH	DBCA DWER	CoR DPLH-AA
3-2	Short term	Reach 3 & 4	Protect existing trees and plant additional trees: west of the river in formerly cleared areas and east of the river in private landholdings.	Private DPLH	DBCA DWER WC	CoR DPLH-AA
3-3	Long term	Reaches 1 to 3	Work with landholders to establish a good quality habitat corridor between Hymus Swamp and Lowlands Reserve, potentially along the river.	Private DPLH	DBCA (R2,R3) DWER WC	SSJ (R1, R2) CoR (R2,R3) DPLH-AA
3-4	Long term	Reach 1	Work to replace invasive grasses from the channel with planting of native ground cover and shrubs to improve riparian vegetation.	Private DPLH	DWER WC	DPLH-AA
3-5	Long term	Reaches 4 to 6	Improve riparian and floodplain vegetation, particularly areas with only ground cover or bare ground.	Private (R4) DoC DPLH DMIRS (R4)	DBCA DWER WC(R4)	CoR (R4,R5) SoM (R6) DPLH-AA

Item	Priority	Location	Action	Owner	Manager	Stakeholders
4-1	Short term	All	Work with the local Bindjareb Noongar Community, DPLH and the Native Title proponents to identify and build opportunities for training and employment linked to working on country.	Private (R1-4, R7) DPLH (R1-R7) DMIRS (R4) DoC (R4,R5)	CoM (R8) DBCA (R2 R7) DWER WC (R1-R4) DoT (R7-R8)	CoR (R2-R5) SSJ (R1, R2) SoM (R6-R7) CoM (R8) DPLH-AA
4-2	Short term	All	Work with the local Bindjareb Noongar Community, DPLH and the Native Title proponents to ensure due diligence is followed in implementing consultation, engagement and on-ground works under the Native Title Act.	Private (R1-4, R7) DPLH (R1-R7) DMIRS (R4) DoC (R4,R5)	CoM (R8) DBCA (R2 R7) DWER WC (R1-R4) DoT (R7-R8)	CoR (R2-R5) SSJ (R1, R2) SoM (R6-R7) CoM (R8) DPLH-AA
4-3	Short term	All	Work with the local Bindjareb Noongar Community, DPLH and the Native Title proponents to ensure due diligence is followed in implementing consultation, engagement and on-ground works under the Native Title Act.	Private (R1-4, R7) DPLH (R1-R7) DMIRS (R4) DoC (R4,R5)	CoM (R8) DBCA (R2 R7) DWER WC (R1-R4) DoT (R7-R8)	CoR (R2-R5) SSJ (R1, R2) SoM (R6-R7) CoM (R8) DPLH-AA
4-2	Long term	All	Identify and implement related skills based training opportunities for the local Bindjareb Noongar community linked to working on country to increase procurement opportunities.	Private (R1-4, R7) DPLH (R1-R7) DMIRS (R4) DoC (R4,R5)	CoM (R8) DBCA (R2 R7) DWER WC (R1-R4) DoT (R7-R8)	CoR (R2-R5) SSJ (R1, R2) SoM (R6-R7) CoM (R8) DPLH-AA
5-1	Short term	Reach 8	Work with Department of Transport to enforce 5 knot limit to prevent erosion from boat wakes.	DPLH	DBCA DWER DoT	CoM SoM DPLH-AA
5-2	Long term	Reaches 4 to 7	Advocate for the establishment of the Peel Regional Park from downstream of the Peel Main Drain confluence to protect the highest value waterway in conjunction with the State Government, Local Government, Water Corporation and local landholders.	Private (R4,R7) DoC DPLH DMIRS (R4)	DBCA DWER WC (R4) DoT (R7)	CoR (R4,R5) SoM (R6,R7) DPLH-AA
6-1	Short term	Reaches 1 and 8	Provide resources to the landholders to identify and eradicate weed species, including Arum Lily, Bridal Creeper and Watsonia (Reach 1) and Castor Oil and Wild Oats (Reach 8).	Private DPLH	CoM (R8) DWER	SSJ (R1) CoM (R8)

Item	Priority	Location	Action	Owner	Manager	Stakeholders
					WC	DPLH-AA
6-2	Short term	Reaches 3 and 4	Landholders should be encouraged to control feral animals, particularly pigs to protect banks and riparian vegetation.	Private DPLH DMIRS (R4)	DBCA DWER WC	CoR DPLH-AA
6-3	Short term	Reach 1	Provide advice to the landholder on methods to identify erosion risk to allow for early intervention.	Private DPLH	DWER WC	SSJ DPLH-AA
6-4	Short term	Reach 8	Monitor new development in Coodanup to ensure no sediment is mobilised and suitable water quality discharges to the river.	DPLH	CoM DBCA DWER	CoM SoM DPLH-AA
6-5	Long term	All	Encourage land holders within the catchment to reduce nutrient application and improve water quality treatment (including Water Sensitive Urban Design) in established and proposed urban areas.	Private (R1-R4, R7) DPLH DMIRS (R4) DoC (R4,R5)	DBCA (R2-R8) DWER WC (R1-R4) DoT (R7,R8)	SSJ (R1, R2) CoR (R2-R5) SoM (R6-R8) DPLH-AA
6-6	Long term	Reaches 1 and 6 to 8	Encourage landowners to plant local, native plants with the riparian zone and remove invasive species away from the river and waterways.	Private (R1,R7) DPLH DoC (R6)	CoM (R8) DBCA (R6,R7,R8) DWER WC (R1) DoT (R7,R8)	SSJ (R1, R2) SoM (R6,R7,R8) CoM (R8) DPLH-AA
7-1	Short term	Reaches 4 to 8	Investigate die-off of trees that was observed between Lake Amarillo to the Peel-Harvey Estuary to determine the causes and measures to protect remaining trees, including any impacts from Acid Sulfate Soils.	Private (R4,R7) DoC DPLH DMIRS (R4)	CoM (R8) DBCA DWER WC (R4) DoT (R7,R8)	CoR (R4,R5) SoM (R6,R7) CoM (R8) DPLH-AA
7-2	Long term	Reaches 2, 3 and 5	Investigate the reversal of river training that has occurred previously to increase connection with fringing wetlands and offset lower groundwater levels predicted under drying-climate scenarios. Potential locations for this are: - Reach 2: Hymus Swamp; - Reach 3: Fringing wetlands near Karnup Road; and, - Reach 5: Closure of bypass channels.	Private (R2,R3) DoC DPLH	DBCA DWER WC (R2,R3)	CoR SSJ DPLH-AA

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APPENDIX 1: DATA ANALYSIS METHODOLOGY

The methodology for collating and assessing the data is adapted from *River Restoration – Foreshore condition assessment in farming areas of south-west Western Australia* (WRC, 1999). For consistency with previously prepared RAPs, the detailed foreshore criteria was prepared considering grades between A (pristine) and D (drain). The detailed assessment allows for 3 sub-categories and therefore 12 categories overall. Assigning a category is generally a subjective exercise, matching observation with descriptions for each category.

In order to provide a more objective, repeatable approach, key parameters are assessed and scored based on the data breakdown provided below. Table 21 (WRC, 1999) provides a scoring system to calculate overall stream health and has been adapted to score foreshore conditions. For the Serpentine RAP, each bank within each sub-reach has been assessed with this scoring system, noting that habitat diversity refers to conditions within the channel, and therefore is the same for both banks.

Table 21: Stream Health Scoring (WRC, 1999)

	Floodway and bank vegetation	Verge vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity
Excellent	- Healthy undisturbed native vegetation - No Weeds **(15 points)**	- Healthy undisturbed native vegetation - Verges more than 20m wide **(8 points)**	-Abundant cover: shade, overhanging vegetation - Snags, leaf litter, rocks and/or aquatic vegetation in stream **(8 points)**	- No erosion or subsidence or sediment deposits - Dense vegetation cover on banks and verge - No disturbance **(8 points)**	- Three or more habitat types - Some permanent water **(6 points)**
Good	- Mainly healthy undisturbed native vegetation - Some weeds - No recent disturbances **(12 points)**	- Mainly healthy undisturbed native vegetation - Verges less than 20m wide **(6 points)**	- Abundant shade and overhanging vegetation - Some cover in the stream **(6 points)**	- No significant erosion, subsidence or sediment deposits in floodway or on lower banks - May be some soil exposure and vegetation thinning on upper bank and verge **(6 points)**	- Two habitat types - Some permanent water **(4 points)**
Moderate	- Good vegetation cover but a mixture of native and exotic species - Localised clearing - Little recent disturbance **(6 points)**	- Good vegetation cover but a mixture of native and exotic species - Verges 20m wide or more **(4 points)**	- Some permanent shade and overhanging vegetation - Some instream cover **(4 points)**	- Good vegetation cover - Only localised erosion, bank collapse and sediment heaps - Verges may have sparse vegetation cover **(4 points)**	- Mainly one habitat type with permanent water, or a range of habitats with no permanent water **(2 points)**
Poor	- Mainly exotic ground cover - Obvious site disturbance **(3 points)**	- Narrow verges only (<20m wide) - Mainly exotic vegetation **(2 points)**	- Channel mainly clear - Little permanent shade or instream cover **(2 points)**	- Extensive active erosion and sediment heaps - Bare banks and verges common - Banks may be collapsing **(2 points)**	- Mainly one habitat type with no permanent water **(1 point)**
Very Poor	- Mostly bare ground or exotic ground cover (i.e. pasture gardens or weeds but no trees) **(0 points)**	- Mostly bare ground or exotic ground cover (i.e. pasture gardens or weeds but no trees) **(0 points)**	- Virtually no shade or instream cover **(0 points)**	- Almost continuous erosion - Over 50% of banks collapsing - Sediment heaps line or fill much of the floodway - Little or no vegetation cover **(0 points)**	- Stream channelized - No pools, riffles or meanders - The stream forms a continuous channel **(0 points)**

Scores from each bank were determined from an analysis of key parameters, described further below. The scores from this analysis were then equated to the foreshore condition, based on the scoring system outlined in Table 22. Assignment of a rating is based on the total score for all the categories. Where total score falls between two ratings, additional categories are applied. For example, a score of 28 would be assigned B1-B2. Manual adjustments to the final condition category were then applied based on a review of field photography, water quality data and other data sets.

Table 22: Foreshore Category Scoring

	Score					
	Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Rating
A1	15	8	8	8	6	45
A2	12	8	8	8	6	42
A3	12	6	8	6	4	36
B1	12	4	6	6	4	32
B1-B2	-	-	-	-	-	28
B2	6	4	4	6	4	24
B2-B3	-	-	-	-	-	20.5
B3	3	2	4	6	2	17
B3-C1	-	-	-	-	-	16
C1	3	4	2	4	2	15
C1-C2	-	-	-	-	-	13
C2	3	2	2	2	2	11
C2-C3	-	-	-	-	-	9
C3	3	0	0	2	2	7
D1	3	2	0	0	0	5
D2	3	0	0	0	0	3
D3	0	0	0	0	0	0

Floodway and Bank Vegetation

Floodway and bank vegetation represents the largest category (by score). The key indicators (used to determine scores) and other considerations (for adjustment) are provided in Table 23.

Table 23: Floodway and Bank Vegetation Indicators

Key indicators	Other considerations
Streamside Zone Vegetation: Bare Ground	Riparian Layer: Ground Layer (rushes/sedges)
Streamside Zone Vegetation: Turf Grass	Riparian Layer: Shrub Layer
Streamside Zone Vegetation: Ground Cover	Riparian Layer: Tree Layer
Streamside Zone Vegetation: Shrubs	Width of Riparian Zone
Streamside Zone Vegetation: Trees <10 m	Dominant Riparian Species
Streamside Zone Vegetation: Trees >10 m	Riparian Zone Absent or Reduced Factors
Streamside Zone Vegetation: Turf Grass % Exotic	Streamside Zone Vegetation: Trees <10 m % Exotic
Streamside Zone Vegetation: Ground Cover % Exotic	Streamside Zone Vegetation: Trees >10 m % Exotic
Streamside Zone Vegetation: Shrubs % Exotic	

The scoring for the floodway and bank vegetation is outlined in Table 24.

Table 24: Floodway and Bank Vegetation Scoring

Rating	Score	Description	Indicator Assessment
Excellent	15 points	- Healthy undisturbed native vegetation - No Weeds	- No bare ground - No weeds - Shrub or Tree Cover >50%
Good	12 points	- Mainly healthy undisturbed native vegetation - Some weeds - No recent disturbances	- No bare ground - Weeds <10% - Shrub or Tree Cover >50%
Moderate	6 points	- Good vegetation cover but a mixture of native and exotic species - Localised clearing - Little recent disturbance	- Bare ground <10% - Weeds 10%-49% - Shrub and Tree Cover 10-49%
Poor	3 points	- Mainly exotic ground cover - Obvious site disturbance	- Bare ground 10-49% - Exotic Ground Cover 10%-49% - Turf Grass 10-49%
Very Poor	0 points	- Mostly bare ground or exotic ground cover (i.e. pasture gardens or weeds but no trees)	- Bare ground >50% - Exotic Ground Cover >50% - Turf Grass >50%

Verge Vegetation

Verge vegetation is the surrounding vegetation from the river. The condition of the verge vegetation influences the stability of the banks, livestock access and general encroachment in the riparian environment. The key indicators (used to determine scores) and other considerations (for adjustment) are provided in Table 25.

Table 25: Verge Vegetation Indicators

Key indicators	Other considerations
Beyond the Streamside Zone: Dominant Feature 10-49m	Beyond the Streamside Zone: Dominant Feature >100m
Beyond the Streamside Zone: Dominant Feature 50-99m	

The scoring for the floodway and bank vegetation is outlined in Table 26. The average between the 10-49m and 50-99m scores were used for the foreshore.

Table 26: Verge Vegetation Scoring

Rating	Score	Description	Indicator Assessment
Excellent	8 points	- Healthy undisturbed native vegetation - Verges more than 20m wide	Forest
Good	6 points	- Mainly healthy undisturbed native vegetation - Verges less than 20m wide	Remnant Vegetation
Moderate	4 points	- Good vegetation cover but a mixture of native and exotic species - Verges 20m wide or more	Plantation
Poor	2 points	- Narrow verges only (<20m wide) - Mainly exotic vegetation	Weeds/Grasses/Crops
Very Poor	0 points	- Mostly bare ground or exotic ground cover (i.e. pasture gardens or weeds but no trees)	Minimal vegetation

Stream Cover

Stream cover provides a measure of the vegetation within and overhanging the stream. The key indicators are outlined in Table 27, along with the other factors that are considered in the assessment.

Table 27: Stream Cover Indicators

Key indicators	Other considerations
Stream Cover overhanging banks %	Bank vegetation draped in water
Tree overhanging %	Tree overhang
Aquatic plants & macro cover %	Stream width
Emergent proportion %	Shrub overhanging %
Submerged proportion %	
Woody debris	

The scoring for the stream cover is outlined in Table 28. Unlike other categories, the key indicators are generally independent of each other and therefore a weighted approach is undertaken. Each indicator is scored separately then weighted to provide a final stream cover score.

Table 28: Stream Cover Scoring

Rating	Score	Stream Cover Overhanging banks %	Tree Overhanging %	Aquatic plants & macro cover %	Emergent proportion %	Submerged proportion %	Woody debris
Weighting		**100%**	**50%**	**50%**	**50%**	**25%**	**75%**
Excellent	8 pts	50-100%	>80%	>50%	>70%	<20%	Dense
Good	6 pts	-	>60%	>30%	>50%	<40%	Moderate
Moderate	4 pts	10-49%	>50%	>20%	>40%	<60%	Sparse
Poor	2 pts	1-9%	>25%	>10%	>25%	<80%	None
Very Poor	0 pts	0%	0%	0%	0%	<100%	-

Bank Stability and Erosion

Whilst erosion is a natural process for river systems, accelerated or wide-spread erosion is indicative on an unstable system. The key indicators (used to determine scores) and other considerations (for adjustment) are provided in Table 29.

Table 29: Bank Stability and Erosion Indicators

Key indicators	Other considerations
Erosion %	Bank Shape
Erosion Severity	Bank Slope
	Bank Depth

The scoring for the bank stability and erosion is outlined in Table 30 and is a combination of erosion extent and the severity of erosion. Bank dimensions are considered also as steep banks with extensive or severe erosion require intervention more than gentle banks with the same score.

Table 30: Bank Stability and Erosion Scoring

Rating	Score	Description	Indicator Assessment
Excellent	8 points	- No erosion or subsidence or sediment deposits - Dense vegetation cover on banks and verge - No disturbance	- 0-4% erosion & minor rating
Good	6 points	- No significant erosion, subsidence or sediment deposits in floodway or on lower banks - May be some soil exposure and vegetation thinning on upper bank and verge	- 0-4% erosion & low-moderate rating; or - 5-19% erosion & minor rating
Moderate	4 points	- Good vegetation cover - Only localised erosion, bank collapse and sediment heaps - Verges may have sparse vegetation cover	- 0-4% erosion & high to severe rating; or - 5-19% erosion & low-moderate rating
Poor	2 points	- Extensive active erosion and sediment heaps - Bare banks and verges common - Banks may be collapsing	- 5-19% erosion & high to severe rating; or - 20-49% erosion & minor or low-moderate rating
Very Poor	0 points	- Almost continuous erosion - Over 50% of banks collapsing - Sediment heaps line or fill much of the floodway - Little or no vegetation cover	- 20-49% erosion & high to severe rating; or - >50% erosion with any rating

Aquatic Habitat

Aquatic habitat is determined from assessment of the channel itself rather than each bank. Therefore the aquatic habitat score is applied to both the left and right banks for any sub-reach. The key indicators (used to determine scores) and other considerations (for adjustment) are provided in Table 31.

Table 31: Aquatic Habitat Indicators

Key indicators	Other considerations
Habitat % Channel	Water Odours
Habitat % Pool	Water Oils
Habitat % Riffle	Turbidity
Habitat % Reach	Tannin Staining
	Algae in Water Column
	Algae on Substrate
	Sediment Plume
	Sediment Oils
	Sediment Odours

The scoring for the aquatic habitat is outlined in Table 32. Diversity in habitat is required for an excellent rating.

Table 32: Aquatic Habitat Scoring

Rating	Score	Description	Indicator Assessment
Excellent	6 points	- Three or more habitat types - Some permanent water	- Pool habitat >20% and Riffle habitat >20%
Good	4 points	- Two habitat types - Some permanent water	- Pool habitat >20% or Riffle habitat >20%
Moderate	2 points	- Mainly one habitat type with permanent water, or a range of habitats with no permanent water	- Pool habitat >10% or Riffle habitat >10%
Poor	1 points	- Mainly one habitat type with no permanent water	- Pool habitat >5% or Riffle habitat >5%
Very Poor	0 points	- Stream channelized - No pools, riffles or meanders - The stream forms a continuous channel	- No Pool or Riffle habitat

APPENDIX 2: REACH SCORING SUMMARY

Reach	Sub-reach	Left Bank (South/East)							Right Bank (North/West)						
		Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Total Score	Rating	Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Total Score	Rating
1	1	9	7	6.00	4	4	**30.00**	**B1**	9	7	6.00	3	4	**29.00**	**B1**
1	2	6	2	6.00	6	4	**24.00**	**B2**	10	6	6.00	6	4	**32.00**	**B1**
1	3	5	2	5.00	5	2	**19.00**	**B2-B3**	5	5	5.00	2	2	**19.00**	**B2-B3**
1	4	6	2	5.00	2	3	**18.00**	**B2-B3**	6	4	5.00	7	3	**25.00**	**B1-B2**
1	5	6	2	5.00	2	3	**18.00**	**B2-B3**	6	2	6.00	4	3	**21.00**	**B2**
1	6	5	3	4.00	6	3	**21.00**	**B2**	5	3	4.00	6	3	**21.00**	**B2**
1	7	5	2	4.43	6	2	**19.43**	**B2-B3**	5	2	4.43	6	2	**19.43**	**B2-B3**
1	8	5	1	3.86	4	3	**16.86**	**B3**	5	2	3.86	2	3	**15.86**	**B3-C1**
1	9	5	1	3.86	2	2	**13.86**	**C1**	5	1	3.86	4	2	**15.86**	**B3-C1**
1	10	4	1	4.50	3	2	**14.50**	**C1**	4	1	4.00	3	2	**14.00**	**C1**
1	11	4	1	4.00	3	2	**14.00**	**C1**	4	1	3.57	2	2	**12.57**	**C1-C2**
1	12	3	1	3.71	2	2	**11.71**	**C1-C2**	3.5	1	3.71	7	2	**17.21**	**B2-B3**
1	13	4	1	3.00	3	2	**13.00**	**C1-C2**	4	1	3.50	2	2	**12.50**	**C1-C2**
1	14	3	1	2.57	2	2	**10.57**	**C2**	3	2	3.00	4	2	**14.00**	**C1**
1	15	2.5	1	3.86	2	2	**11.36**	**C1-C2**	2.5	1	3.86	3	2	**12.36**	**C1-C2**
1	16	4	2	4.71	1	2	**13.71**	**C1**	4.5	1	4.00	2	2	**13.50**	**C1**
1	17	2.5	1	3.50	4	1	**12.00**	**C1-C2**	3.5	1	4.43	5	1	**14.93**	**C1**
1	18	3.5	1	4.86	3	2	**14.36**	**C1**	3.5	1	4.86	4	2	**15.36**	**B3-C1**
2	1	2.5	2.5	2.50	2	1	**10.50**	**C2**	2.5	3	1.57	7	1	**15.07**	**B3-C1**
2	2	1.5	2	1.86	7	2	**14.36**	**C1**	3	3	1.86	7	2	**16.86**	**B3**
2	3	2.5	1	2.29	7	1.5	**14.29**	**C1**	3	3	2.29	7	1.5	**16.79**	**B3**
2	4	3.5	3	3.00	6	2	**17.50**	**B2-B3**	4	2.5	3.50	5	2	**17.00**	**B3**
2	5	3	6	2.00	4	2	**17.00**	**B3**	4.5	3	2.00	7	2	**18.50**	**B2-B3**
2	6	2.5	3	4.00	7	2.5	**19.00**	**B2-B3**	4	1	4.00	7	2.5	**18.50**	**B2-B3**
2	7	2	3	3.00	7	2	**17.00**	**B3**	3.5	3	3.50	5	2	**17.00**	**B3**
2	8	1.5	4.5	2.00	6	1.5	**15.50**	**B3-C1**	2.5	3	2.00	4	1.5	**13.00**	**C1-C2**
2	9	2.5	2	2.57	3.5	2	**12.57**	**C1-C2**	3	2	2.57	7	2	**16.57**	**B3**
2	10	2.5	3	3.00	6	1.5	**16.00**	**B3-C1**	2.5	3	3.00	4	1.5	**14.00**	**C1**
2	11	2	3	2.43	6	2.5	**15.93**	**B3-C1**	1.5	2	2.43	7	2.5	**15.43**	**B3-C1**
2	12	2.5	4	2.71	5	2	**16.21**	**B3**	2.5	3	2.43	5	2	**14.93**	**C1**
2	13	3	4	2.00	7	1.5	**17.50**	**B2-B3**	2.5	1.5	2.00	6	1.5	**13.50**	**C1**
3	1	1.5	2.5	2.00	3	2	**11.00**	**C2**	1.5	1	2.00	3	2	**9.50**	**C2**
3	2	1.5	7	1.50	3	0	**13.00**	**C1-C2**	1.5	1	1.50	3	0	**7.00**	**C3**
3	3	1.5	5	1.50	3	1	**12.00**	**C1-C2**	0	1	1.50	3	1	**6.50**	**C3**
3	4	1.5	4	1.50	3	1	**11.00**	**C2**	1.5	2	1.50	3	1	**9.00**	**C2-C3**
3	5	1.5	3	1.00	2	1	**8.50**	**C2-C3**	1.5	2	1.00	2	1	**7.50**	**C2-C3**
3	6	1.5	3	1.00	4	0	**9.50**	**C2**	1.5	2	1.00	4	0	**8.50**	**C2-C3**
3	7	1.5	2	2.00	3	1	**9.50**	**C2**	1.5	2	2.00	4	1	**10.50**	**C2**
3	8	1.5	2	2.00	3	1	**9.50**	**C2**	1.5	2.5	2.00	3	1	**10.00**	**C2**
3	9	1.5	3	1.00	3	1	**9.50**	**C2**	1.5	3	1.00	4	1	**10.50**	**C2**
3	10	1.5	4	1.00	3	1	**10.50**	**C2**	1.5	2	1.00	4	1	**9.50**	**C2**
3	11	1.5	5	1.00	4	1	**12.50**	**C1-C2**	1.5	4	1.00	3	1	**10.50**	**C2**

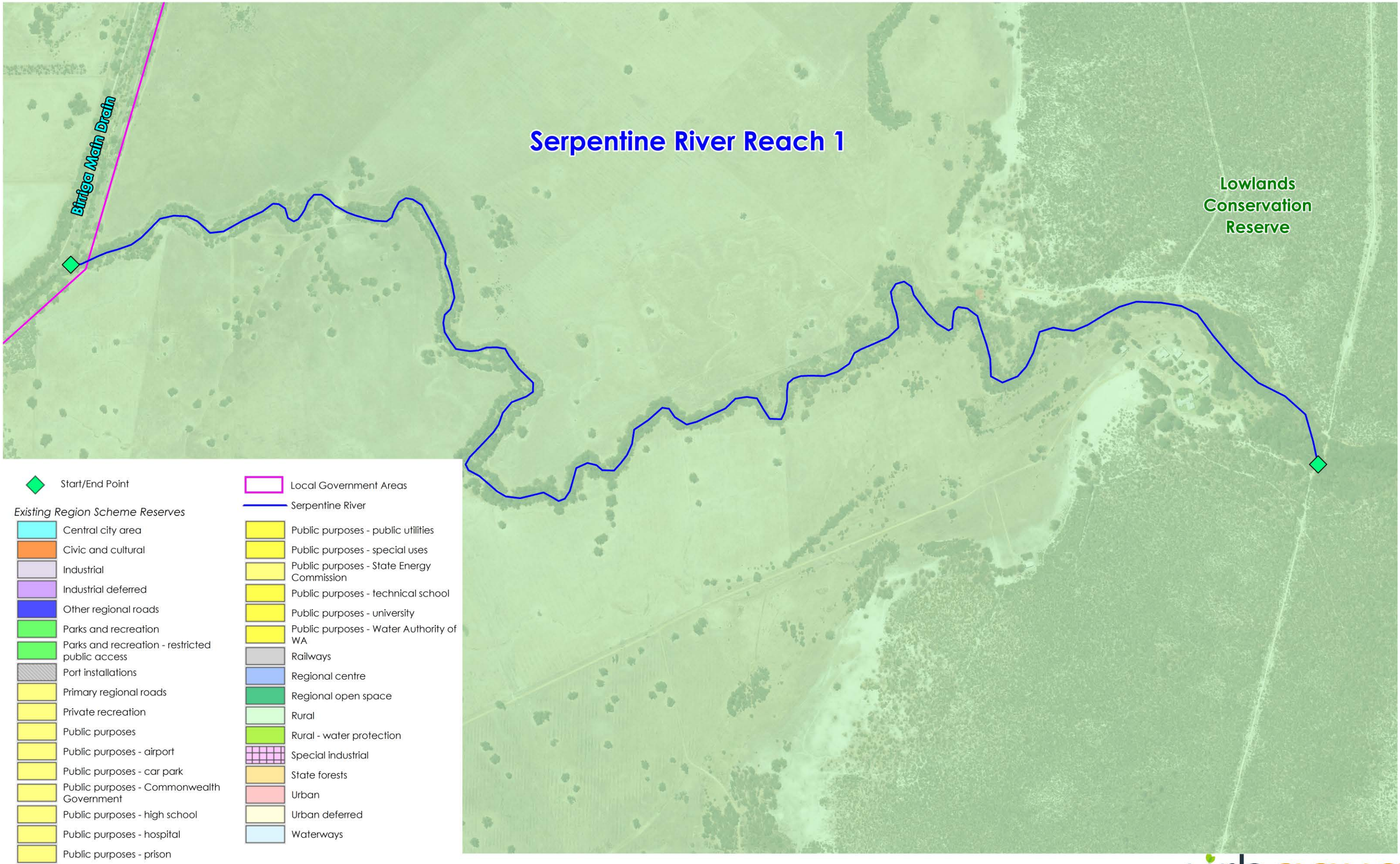
Reach	Sub-reach	Left Bank (South/East)							Right Bank (North/West)						
		Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Total Score	Rating	Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Total Score	Rating
4	1	3	6	2.43	7	1	**19.43**	**B2-B3**	3	4	2.43	7	1	**17.43**	**B2-B3**
4	2	3	6	2.14	6	1	**18.14**	**B2-B3**	3	4	2.14	7	1	**17.14**	**B2-B3**
4	3	3	5	2.00	5	1	**16.00**	**B3-C1**	3	4	2.00	6	1	**16.00**	**B3-C1**
4	4	3	2	2.00	7	1	**15.00**	**C1**	6	4	2.00	3	1	**16.00**	**B3-C1**
4	5	6	5	2.00	7	1	**21.00**	**B2**	6	6	2.00	6	1	**21.00**	**B2**
4	6	6	4	2.00	7	1	**20.00**	**B2-B3**	6	6	2.50	6	1	**21.50**	**B2**
4	7	6	6	2.00	7	1	**22.00**	**B2**	6	6	2.00	7	1	**22.00**	**B2**
4	8	6	6	2.00	7	1	**22.00**	**B2**	6	6	2.00	7	1	**22.00**	**B2**
4	9	3	6	2.00	7	1	**19.00**	**B2-B3**	3	6	2.00	7	1	**19.00**	**B2-B3**
4	10	6	6	2.29	7	1	**22.29**	**B2**	6	6	2.29	7	1	**22.29**	**B2**
4	11	6	6	1.71	7	1	**21.71**	**B2**	3	6	1.71	7	1	**18.71**	**B2-B3**
5	1	5	2	2.50	7	2	**18.50**	**B2-B3**	5	6	2.50	8	2	**23.50**	**B2**
5	2	10	8	5.00	6	4	**33.00**	**A3**	3	1.5	2.00	3	4	**13.50**	**C1**
5	3	2	3	3.00	3	4.5	**15.50**	**B3-C1**	7	4	4.14	7	4.5	**26.64**	**B1-B2**
5	4	4	2.5	3.20	5	5	**19.70**	**B2-B3**	6	5	3.50	2	5	**21.50**	**B2**
5	5	3	3	4.14	2	4.5	**16.64**	**B3**	6	6	3.86	4	4.5	**24.36**	**B1-B2**
5	6	2	1.5	3.00	1.5	3.5	**11.50**	**C1-C2**	5.5	5	4.00	3.5	3.5	**21.50**	**B2**
5	7	3	2	4.43	4	4.5	**17.93**	**B2-B3**	3.5	2	4.00	2.5	4.5	**16.50**	**B3**
5	8	4	5	3.00	4	5.5	**21.50**	**B2**	2	4	3.00	3	5.5	**17.50**	**B2-B3**
5	9	3	5	3.00	3	3	**17.00**	**B3**	4	5	4.10	4	3	**20.10**	**B2-B3**
5	10	3	5	3.50	1.5	2	**15.00**	**C1**	3	3	4.50	2.5	2	**15.00**	**C1**
5	11	2.5	5	2.50	3	2	**15.00**	**C1**	4	4	4.00	4	2	**18.00**	**B2-B3**
5	12	2	5	1.50	4	4	**16.50**	**B3**	5	6	3.50	4	4	**22.50**	**B2**
5	13	1.5	5	1.00	6	4	**17.50**	**B2-B3**	1.5	6	1.00	6	4	**18.50**	**B2-B3**
6	1	4	6	1.50	6	5	**22.50**	**B2**	5	5	3.00	7	5	**25.00**	**B1-B2**
6	2	3	6	1.00	6	4	**20.00**	**B2-B3**	5	4	2.00	6	4	**21.00**	**B2**
6	3	8	3	4.50	7	5	**27.50**	**B1-B2**	6	3	3.00	7	5	**24.00**	**B2**
6	4	8	2	4.50	7	6	**27.50**	**B1-B2**	7	3	3.50	7	6	**26.50**	**B1-B2**
6	5	9	3	4.50	7	5	**28.50**	**B1**	5	1.5	3.50	6	5	**21.00**	**B2**
6	6	6	2	4.00	6	3.5	**21.50**	**B2**	4	3	3.50	4	3.5	**18.00**	**B2-B3**
6	7	7	2	4.00	5	4	**22.00**	**B2**	3.5	3	2.50	5	4	**18.00**	**B2-B3**
6	8	3	4	2.50	4	4	**17.50**	**B2-B3**	3	5	2.50	4	4	**18.50**	**B2-B3**
6	9	3	4	2.50	4	4	**17.50**	**B2-B3**	3	4	2.50	3	4	**16.50**	**B3**
6	10	4	6	2.50	5	5	**22.50**	**B2**	4	6	2.50	6	5	**23.50**	**B2**

Reach	Sub-reach	Left Bank (South/East)							Right Bank (North/West)						
		Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Total Score	Rating	Floodway and Bank Veg	Verge Vegetation	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Total Score	Rating
7	1	4	6	2.50	6	5	**23.50**	**B2**	7	6	4.00	6	5	**28.00**	**B1-B2**
7	2	4	6	2.50	8	4	**24.50**	**B1-B2**	7	6	4.00	7	4	**28.00**	**B1-B2**
7	3	4	6	3.00	3	5	**21.00**	**B2**	8	6.5	4.00	7	5	**30.50**	**B1**
7	4	8	6	3.71	8	7.5	**33.21**	**A3**	8	6.5	4.29	8	7.5	**34.29**	**A3**
7	5	8	7	4.29	8	6	**33.29**	**A3**	8	7	4.29	8	6	**33.29**	**A3**
7	6	7	6.5	4.00	8	6	**31.50**	**B1**	6	6.5	4.00	6	6	**28.50**	**B1**
7	7	9	5	3.50	6	4	**27.50**	**B1-B2**	6	6	2.86	6	4	**24.86**	**B1-B2**
7	8	8	6	3.14	5	4	**26.14**	**B1-B2**	8	5	2.86	6	4	**25.86**	**B1-B2**
7	9	6	3	4.00	6	4	**23.00**	**B2**	7	6	4.00	4	4	**25.00**	**B1-B2**
7	10	9	6	3.14	7	4	**29.14**	**B1**	8	5	3.50	7	4	**27.50**	**B1-B2**
8	1	6	5	2.50	6	6	**25.50**	**B1-B2**	4	4	3.10	4	6	**21.10**	**B2**
8	2	4	3	3.14	5	4	**19.14**	**B2-B3**	5	3	3.43	6	4	**21.43**	**B2**
8	3	5	3	2.00	2	4	**16.00**	**B3-C1**	6	3	3.10	7	4	**23.10**	**B2**
8	4	6	5	3.57	3	5	**22.57**	**B2**	6	5	3.57	4	5	**23.57**	**B2**
8	5	7	6	3.43	6	5	**27.43**	**B1-B2**	7	4	3.14	3	5	**22.14**	**B2**
8	6	6	4	3.40	3	4	**20.40**	**B2-B3**	7	5	3.00	4	4	**23.00**	**B2**
8	7	7	4	3.00	1	4	**19.00**	**B2-B3**	8	6	3.00	6.5	4	**27.50**	**B1-B2**
8	8	6	4.5	2.00	6	4	**22.50**	**B2**	6	5	2.50	6	4	**23.50**	**B2**
8	9	6	3.5	1.50	6	5	**22.00**	**B2**	4	6	1.43	5	5	**21.43**	**B2**
8	10	6	5	2.43	5	5	**23.43**	**B2**	9	6.5	1.00	6	5	**27.50**	**B1-B2**
8	11	7	3.5	2.00	3	6	**21.50**	**B2**	9.5	6.5	1.40	6	6	**29.40**	**B1**
8	12	7	3	1.14	3	6	**20.14**	**B2-B3**	6	4	2.50	6	6	**24.50**	**B1-B2**
8	13	7.5	5	2.00	6	4	**24.50**	**B1-B2**	6	3	2.50	6.5	4	**22.00**	**B2**
8	14	6.5	2	2.50	5	6	**22.00**	**B2**	7	4	2.00	4	6	**23.00**	**B2**
8	15	3	2	2.00	6	6	**19.00**	**B2-B3**	7	6	2.00	6	6	**27.00**	**B1-B2**
8	16	5	2	3.14	4	4	**18.14**	**B2-B3**	4	2	3.00	6	4	**19.00**	**B2-B3**
8	17	6	6	2.00	5	5	**24.00**	**B2**	5	2.5	1.50	6	5	**20.00**	**B2-B3**
8	18	10	6	0.86	7	5	**28.86**	**B1**	9	6	0.86	7	5	**27.86**	**B1-B2**

	Score					
	Floodway and Bank Veg	Verge Veg	Stream Cover	Bank Stability and Erosion	Habitat Diversity	Rating
A1	15	8	8	8	6	45
A2	12	8	8	8	6	42
A3	12	6	8	6	4	36
B1	12	4	6	6	4	32
B1-B2	-	-	-	-	-	28
B2	6	4	4	6	4	24
B2-B3	-	-	-	-	-	20.5
B3	3	2	4	6	2	17
B3-C1	-	-	-	-	-	16
C1	3	4	2	4	2	15
C1-C2	-	-	-	-	-	13
C2	3	2	2	2	2	11
C2-C3	-	-	-	-	-	9
C3	3	0	0	2	2	7
D1	3	2	0	0	0	5
D2	3	0	0	0	0	3
D3	0	0	0	0	0	0

APPENDIX 3: LAND USE MAPPING

Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 30 - Reach 1 Land Use Map



Data source: DOP, PHCC, Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:8,000 @ A3

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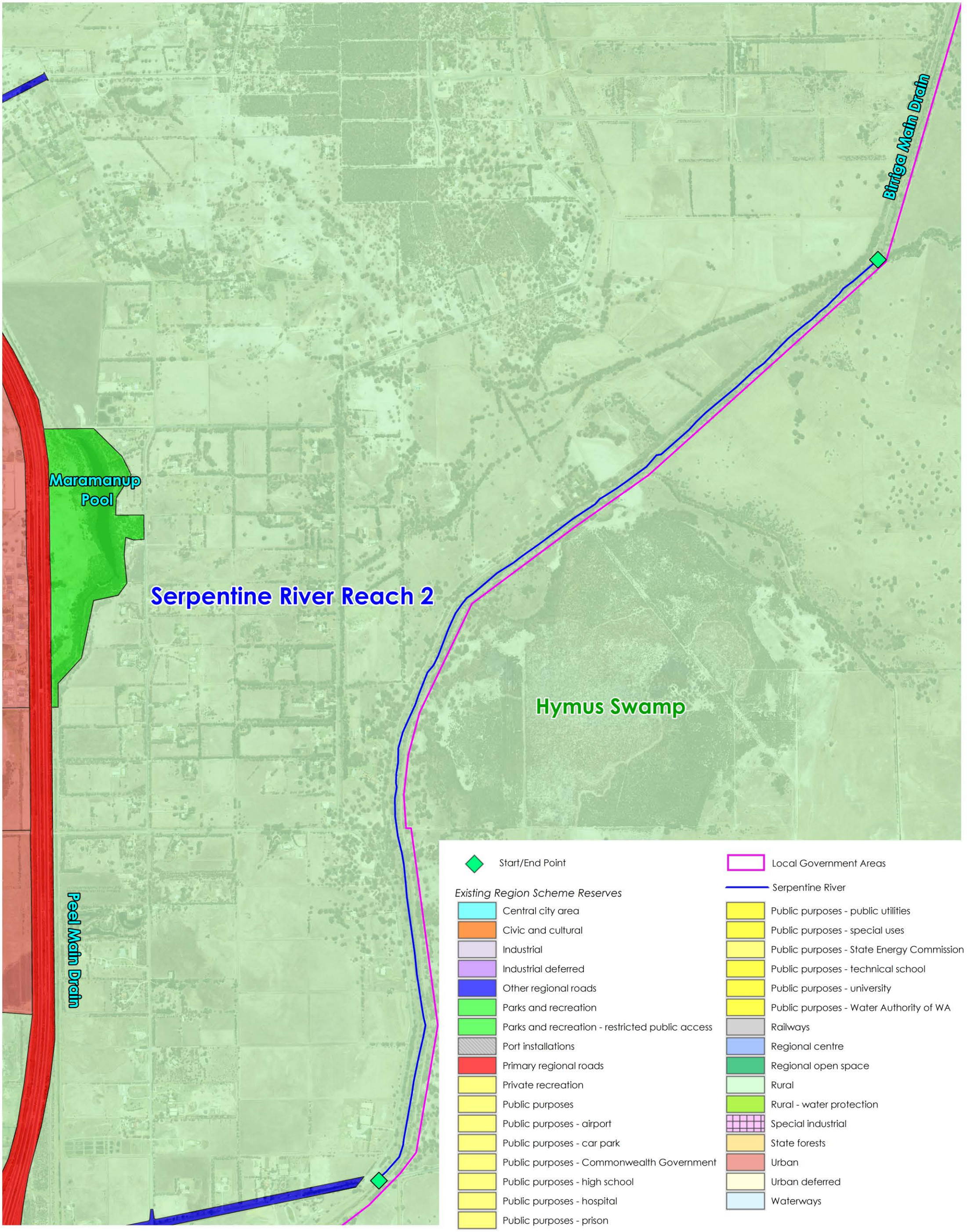
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 31 - Reach 2 Land Use Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

0 1,000
meters
Scale 1:15,000 @ A3

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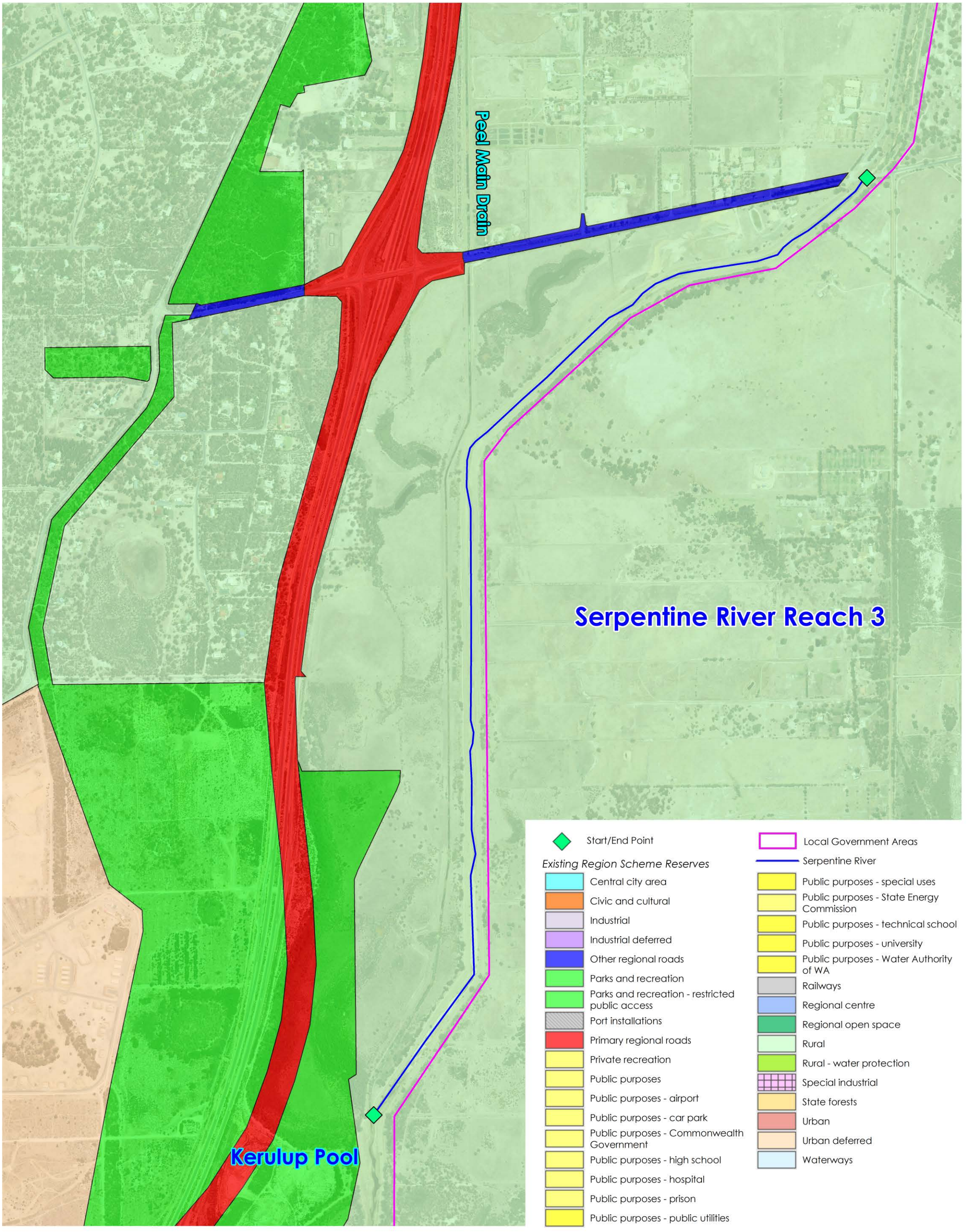
Figure 32 - Reach 3 Land Use Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:12,000 @ A3

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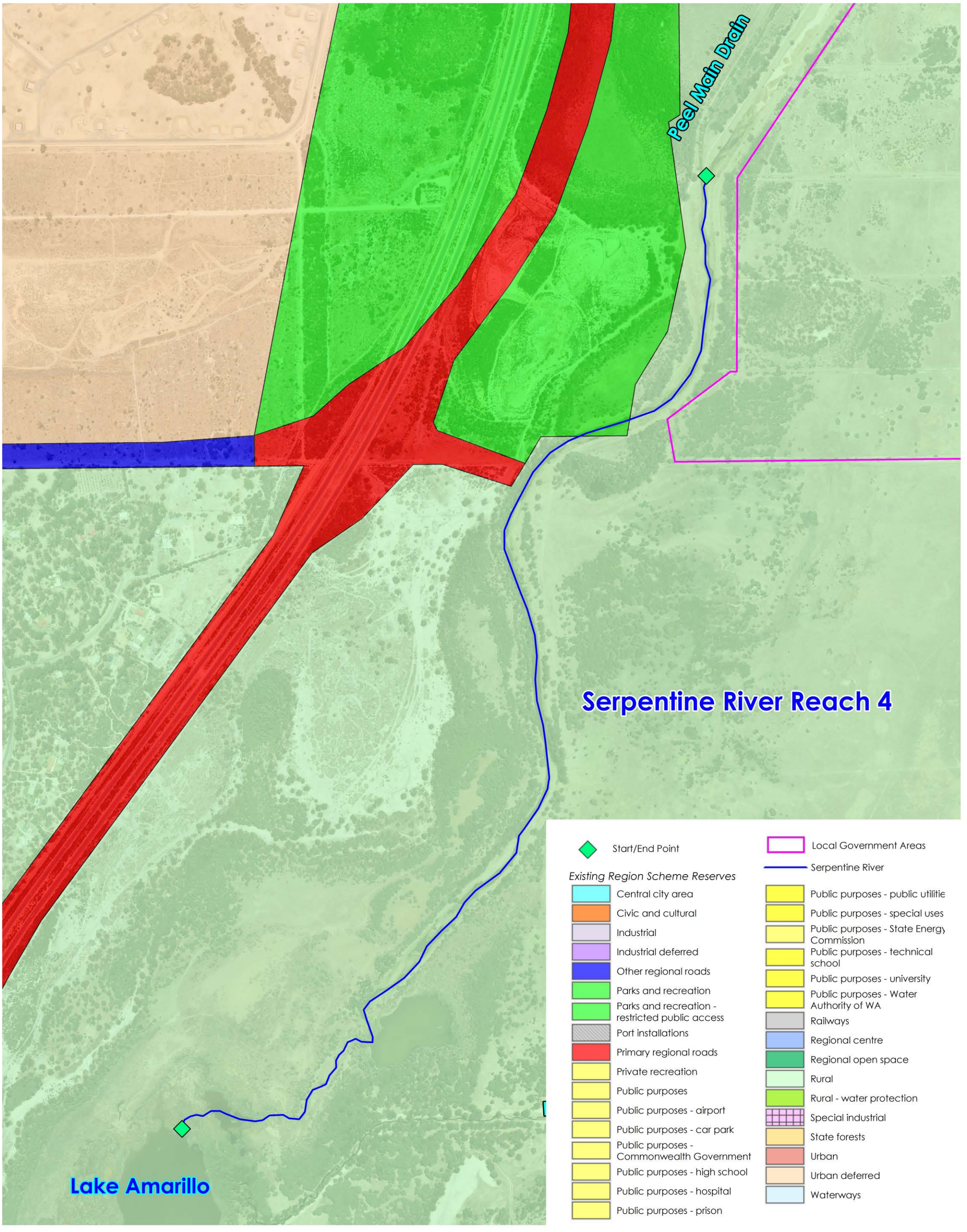
Figure 33 - Reach 4 Land Use Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:8,000 @ A3

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Figure 34 - Reach 5 Land Use Map

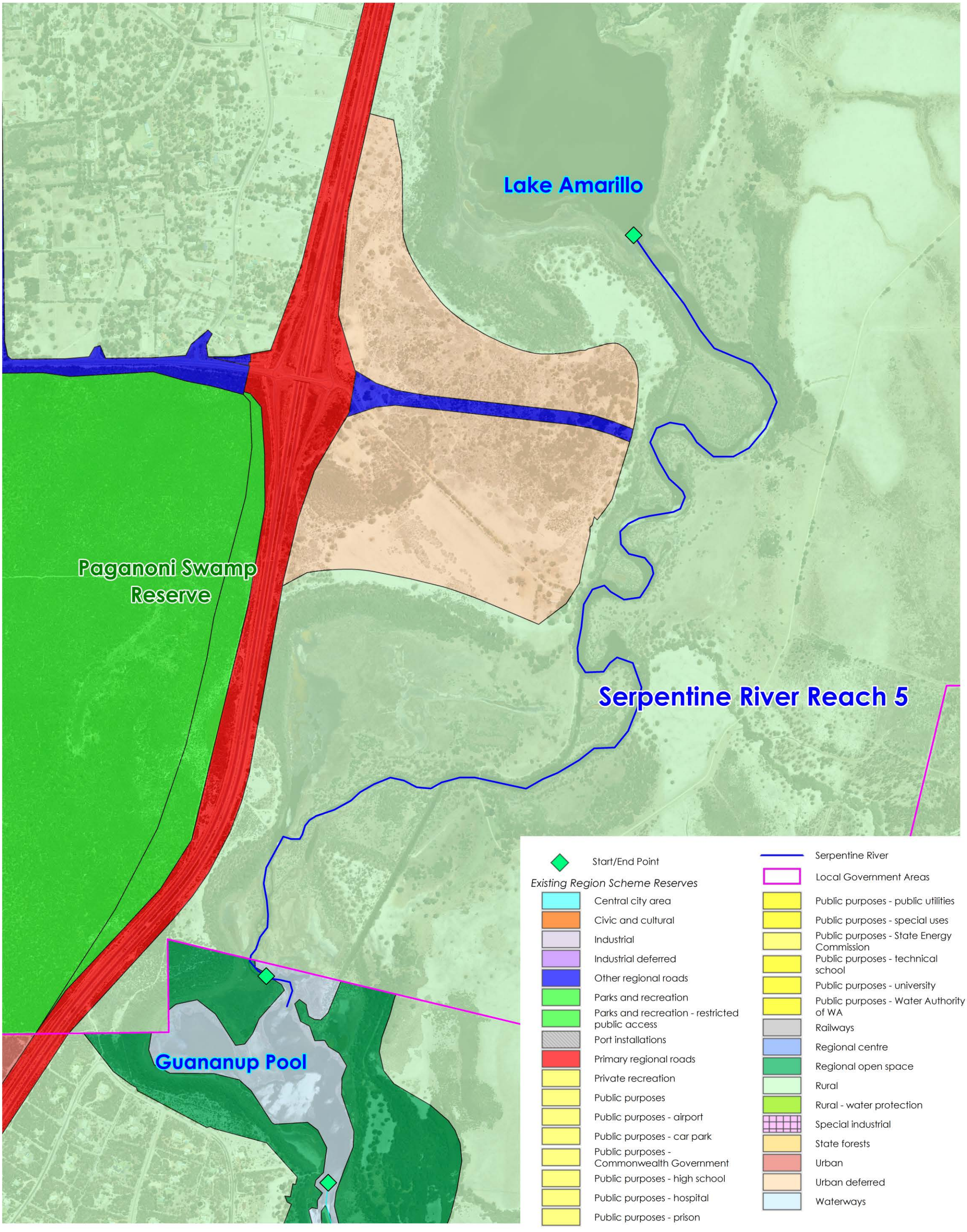

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Figure 35 - Reach 6 Land Use Map

Start/End Point

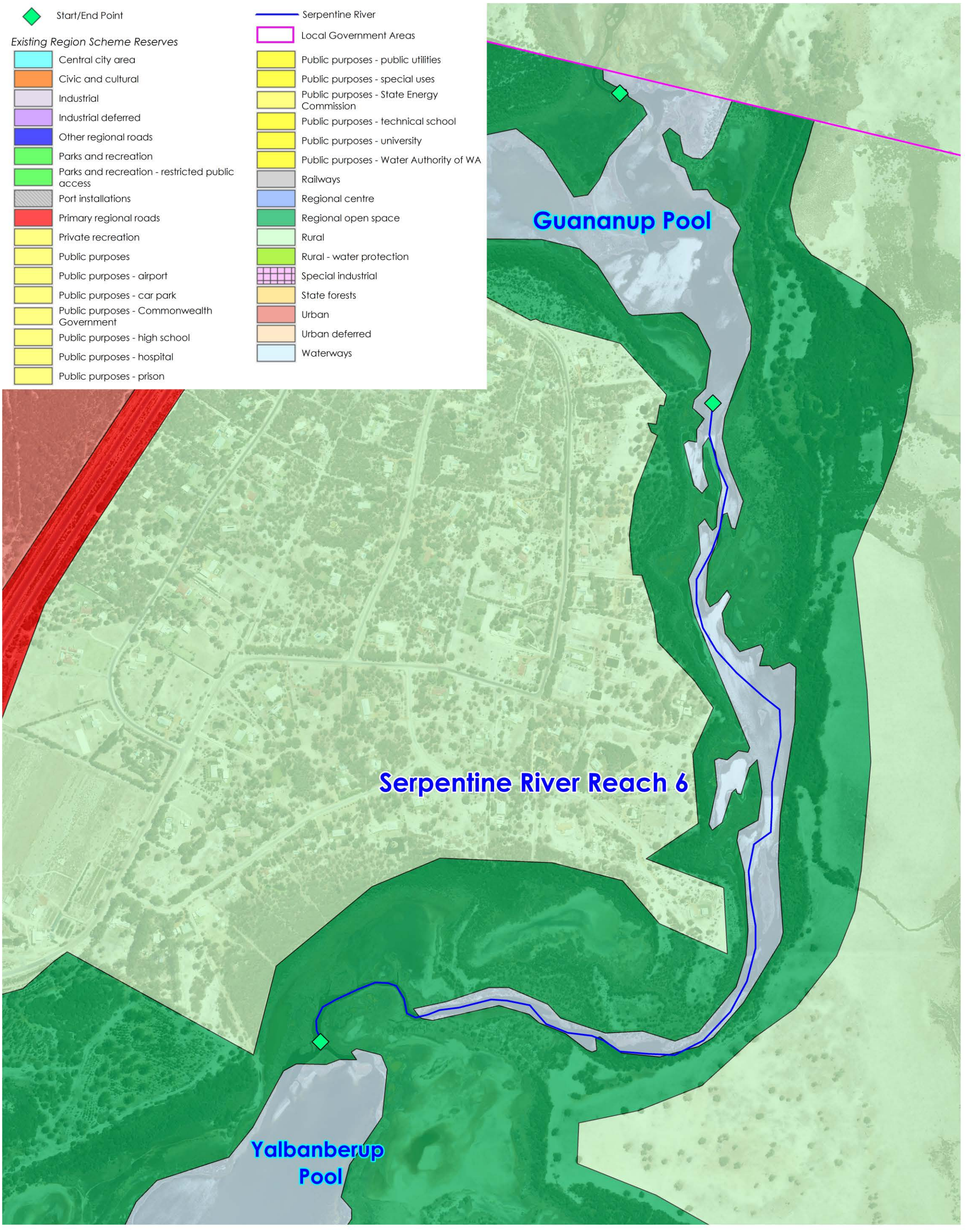
Existing Region Scheme Reserves

- Central city area
- Civic and cultural
- Industrial
- Industrial deferred
- Other regional roads
- Parks and recreation
- Parks and recreation - restricted public access
- Port installations
- Primary regional roads
- Private recreation
- Public purposes
- Public purposes - airport
- Public purposes - car park
- Public purposes - Commonwealth Government
- Public purposes - high school
- Public purposes - hospital
- Public purposes - prison

Serpentine River

Local Government Areas

- Public purposes - public utilities
- Public purposes - special uses
- Public purposes - State Energy Commission
- Public purposes - technical school
- Public purposes - university
- Public purposes - Water Authority of WA
- Railways
- Regional centre
- Regional open space
- Rural
- Rural - water protection
- Special industrial
- State forests
- Urban
- Urban deferred
- Waterways



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:8,000 @ A3

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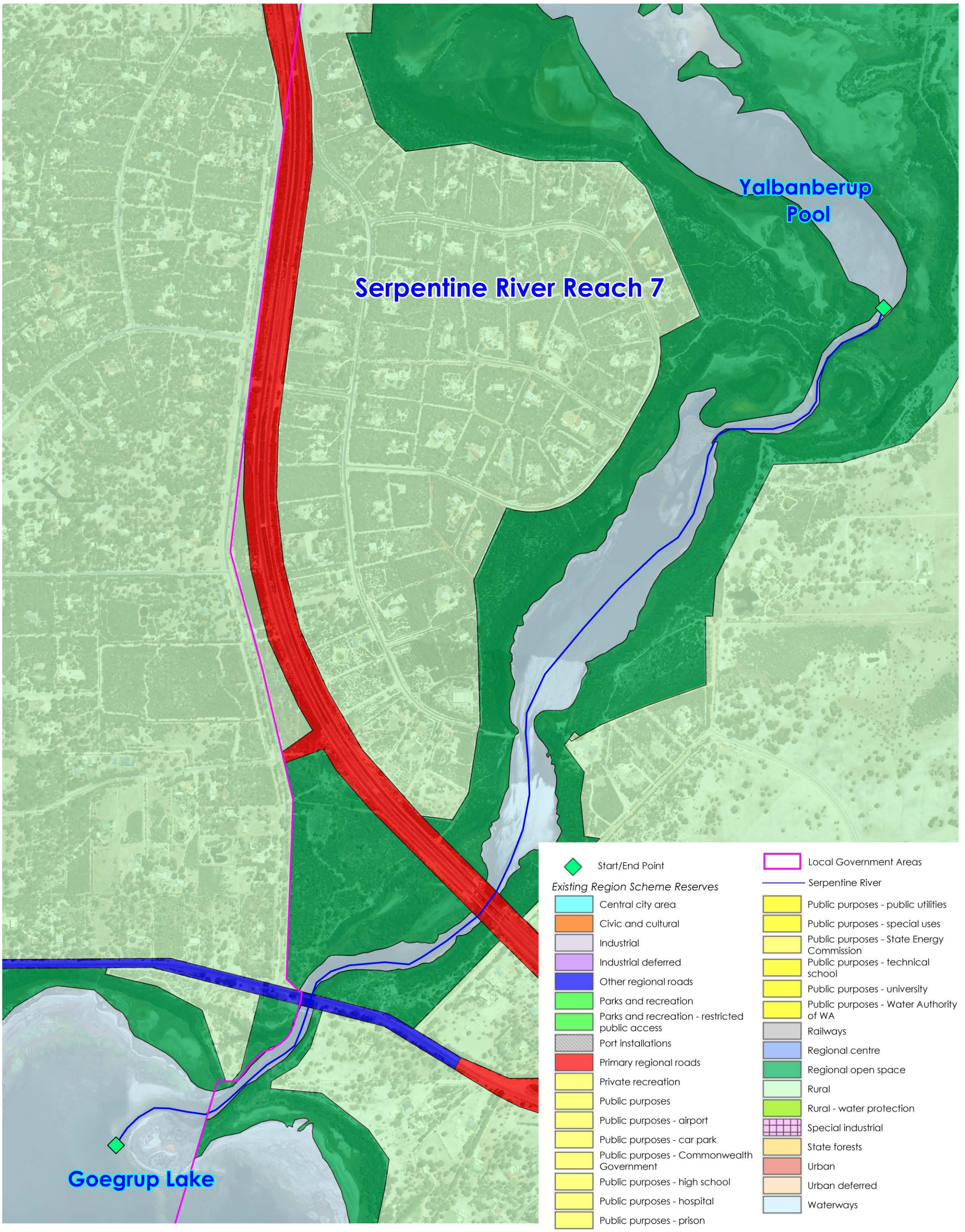
Figure 36 - Reach 7 Land Use Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

0 500

meters

Scale 1:10,000 @ A3

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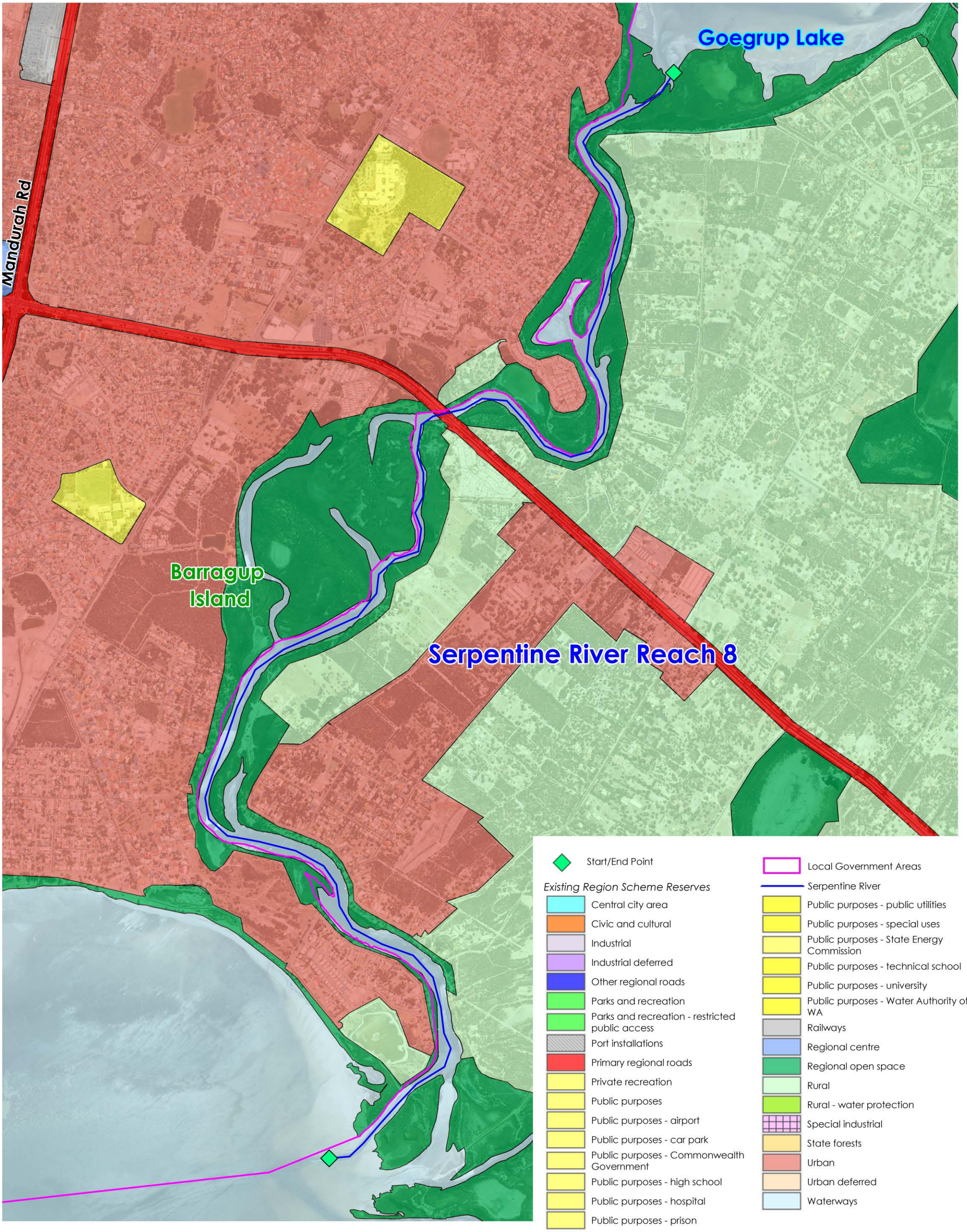
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 37 - Reach 8 Land Use Map



Data source: DOP, PHCC. Created by: YY Projection: MGA: zone 50.

0 800
meters
Scale 1:16,000 @ A3

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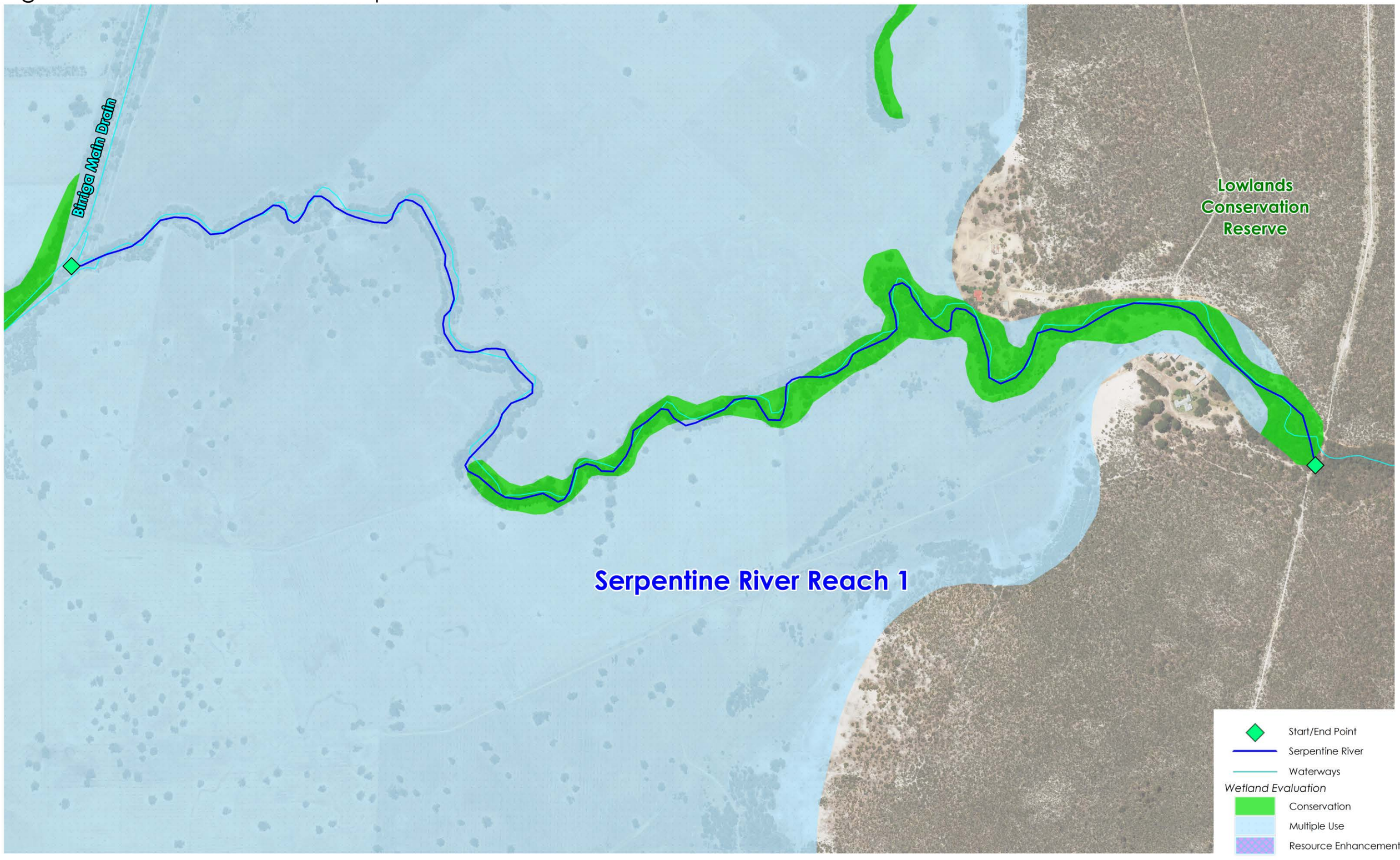
APPENDIX 4: WETLAND MAPPING

Peel Harvey Catchment Council - Serpentine River Action Plan

Figure 38 - Reach 1 Wetland Map



Data source: DOP,.DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

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meters

Scale 1:8,000 @ A3

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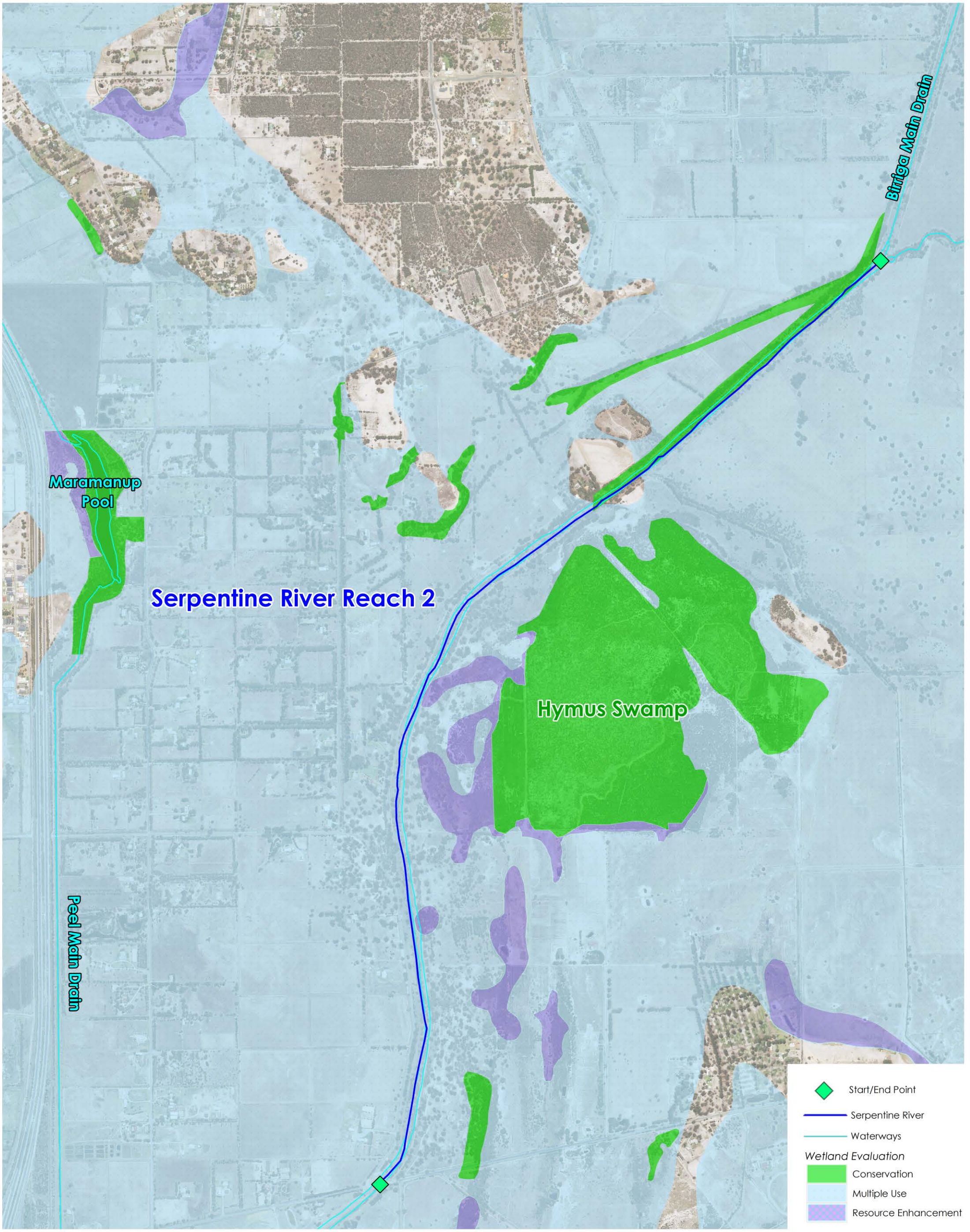
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 39 - Reach 2 Wetland Map



Data source: DOP, DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:15,000 @ A3

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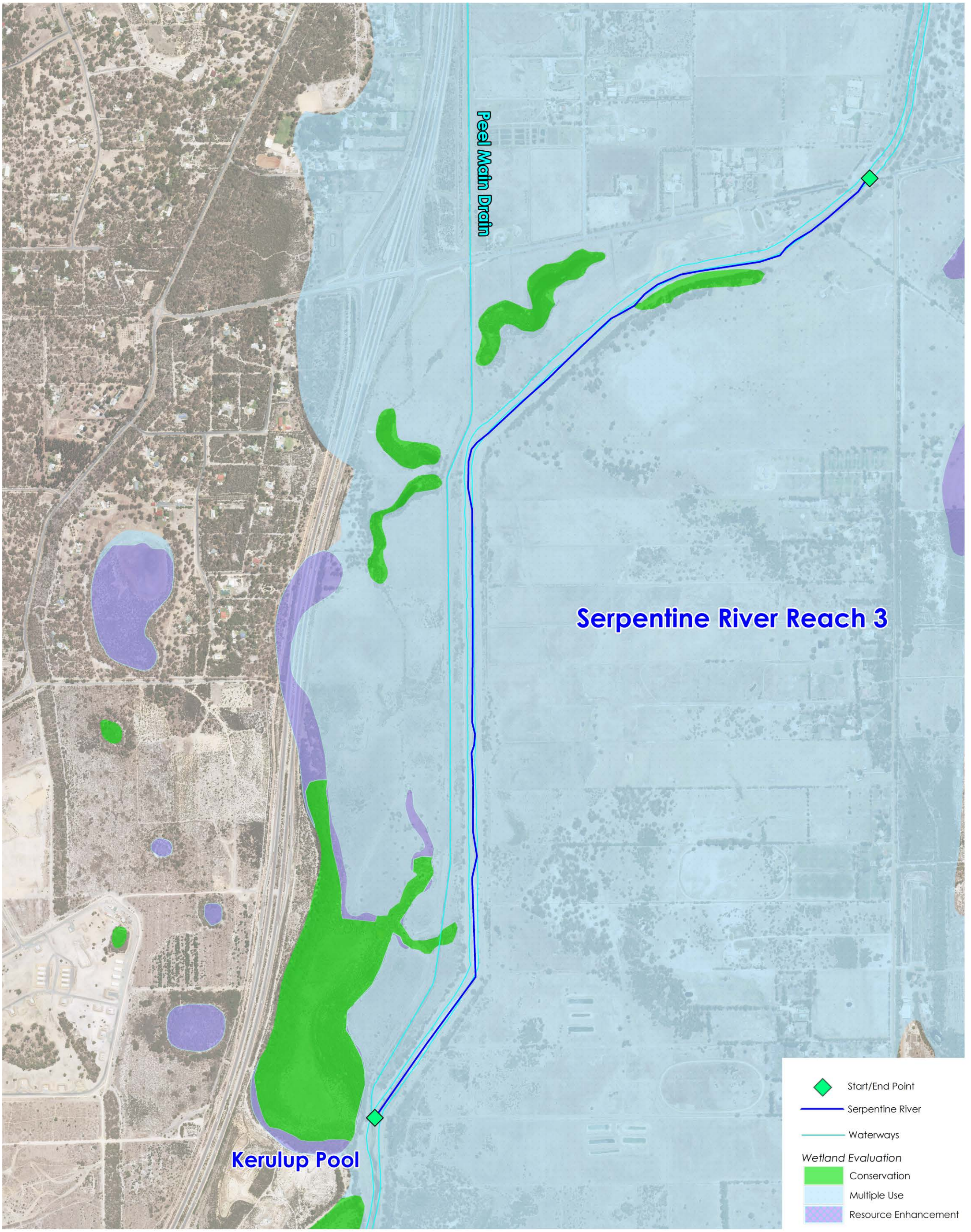
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 40 - Reach 3 Wetland Map



Data source: DOP,DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:12,000 @ A3

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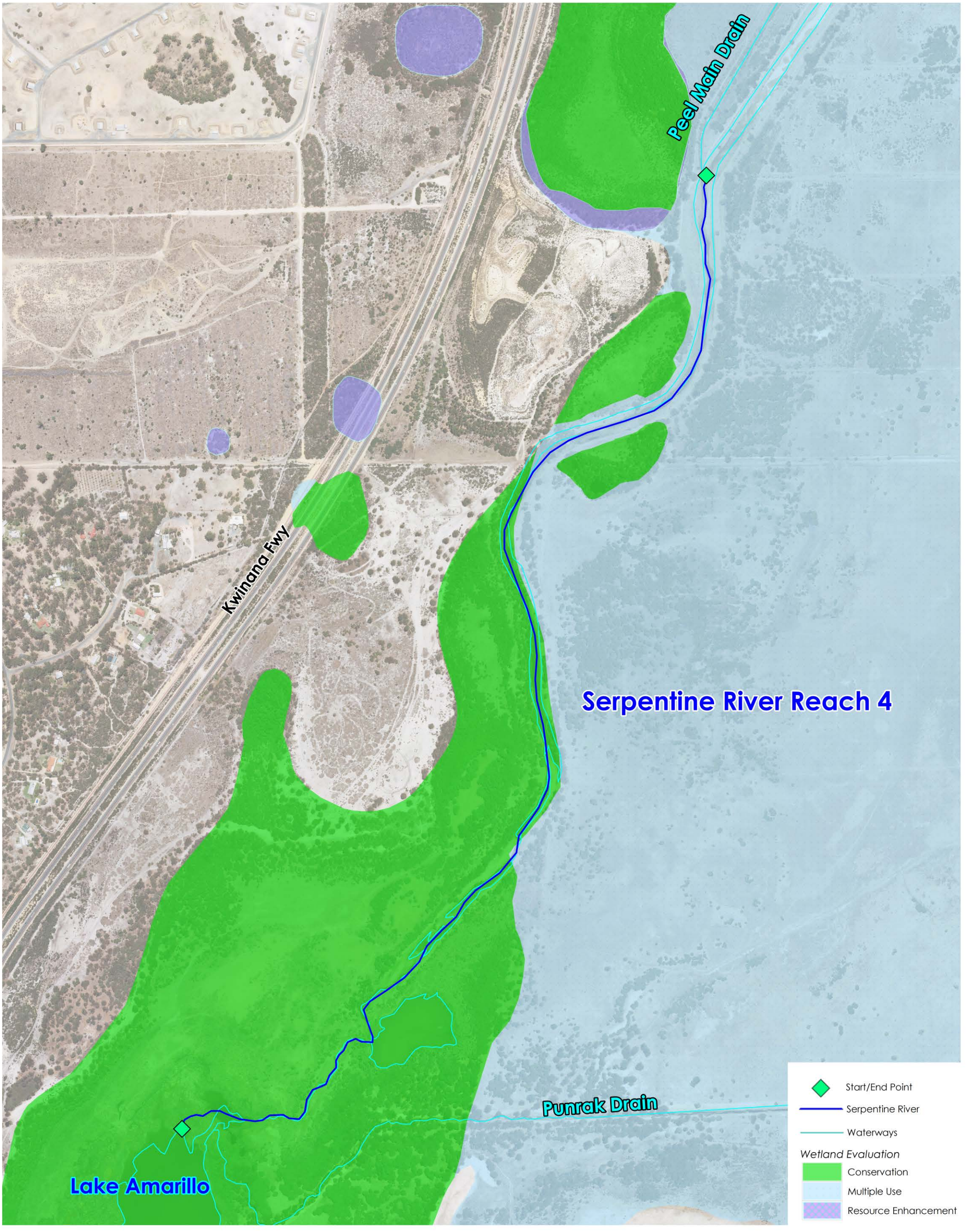
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 41 - Reach 4 Wetland Map



0 500
meters
Scale 1:8,000 @ A3

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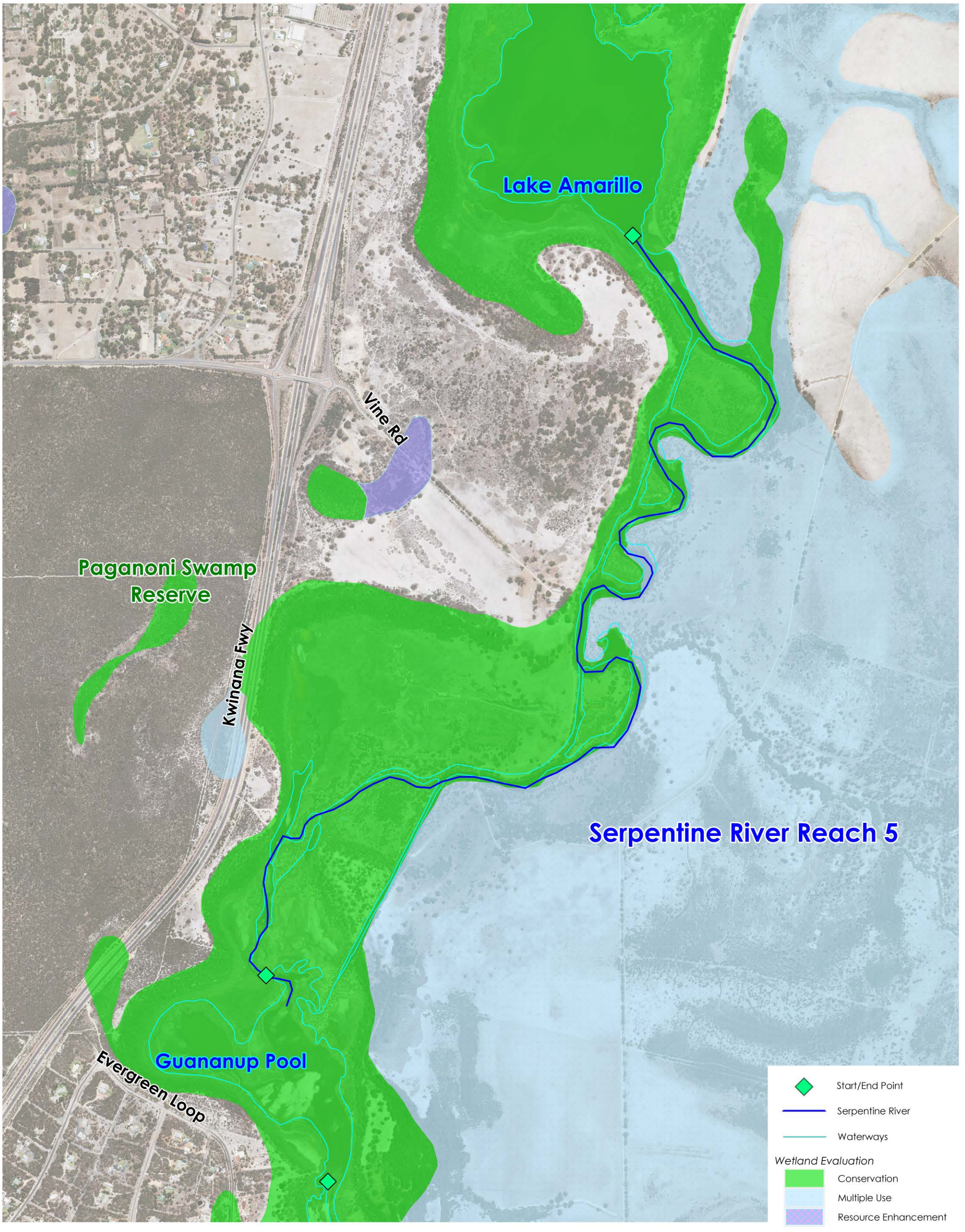
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 42 - Reach 5 Wetland Map



Data source: DOP,DBCA, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:12,000 @ A3

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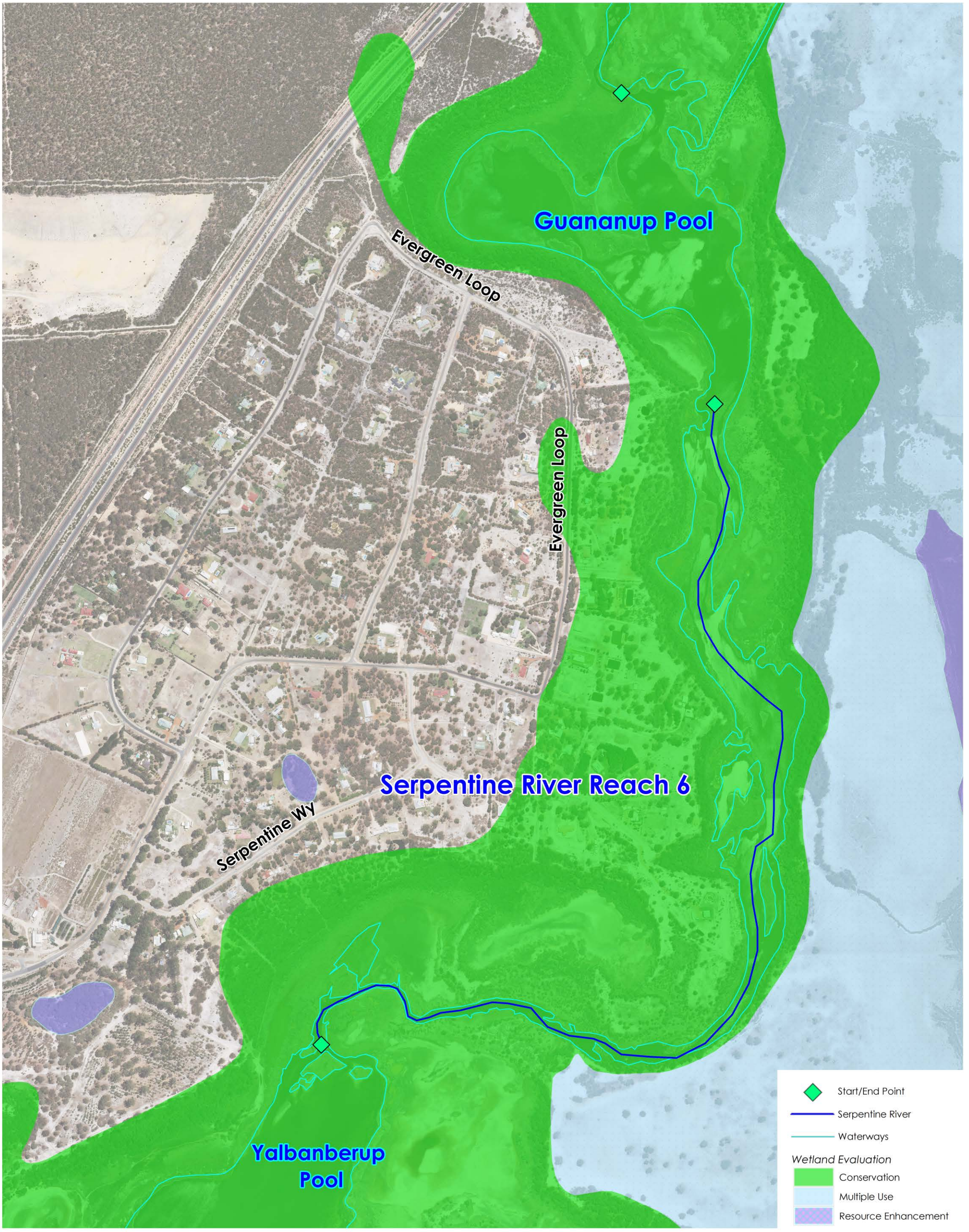
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 43 - Reach 6 Wetland Map



Data source: DOP, DBCA, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:8,000 @ A3

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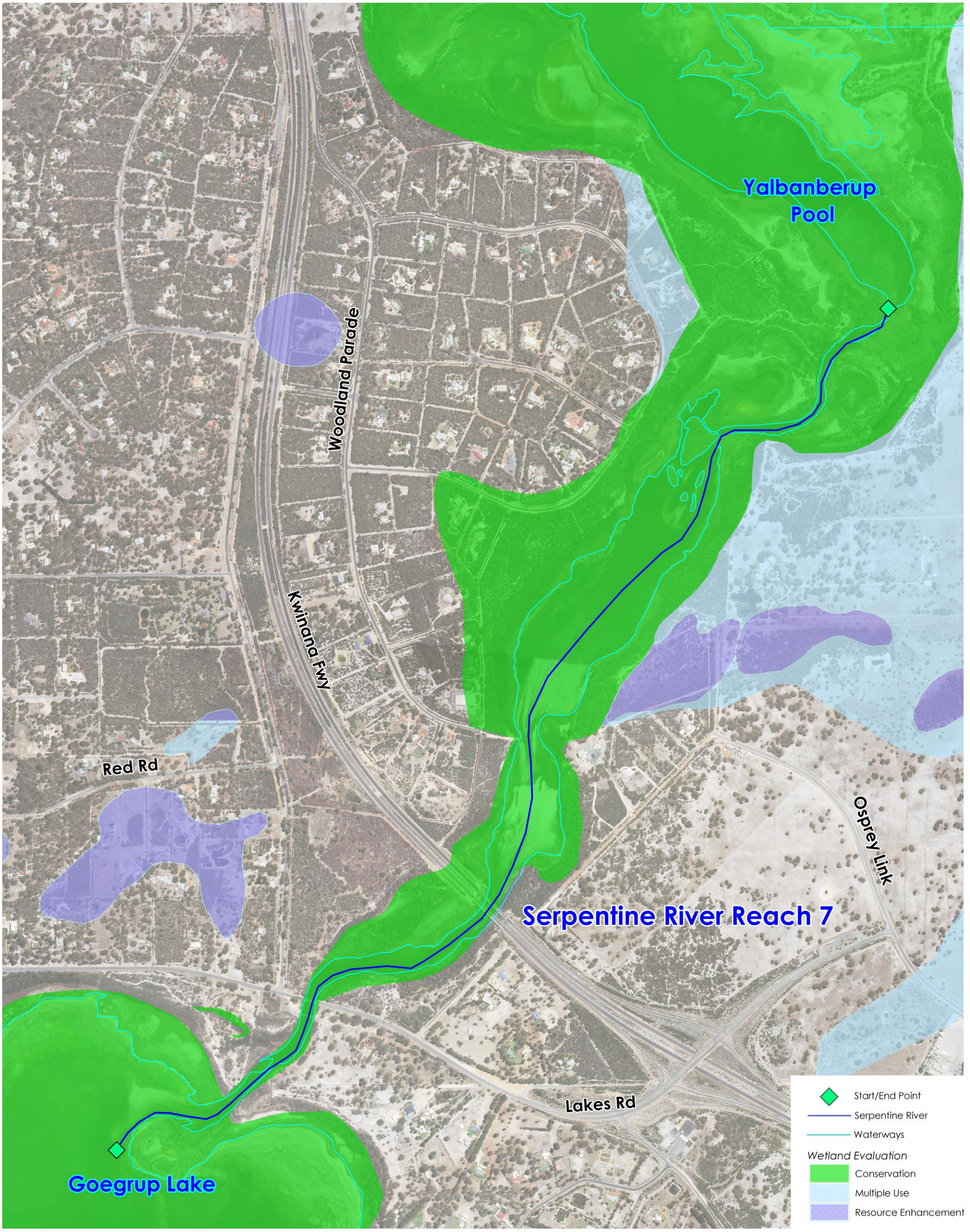
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 44 - Reach 7 Wetland Map



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meters
Scale 1:10,000 @ A3

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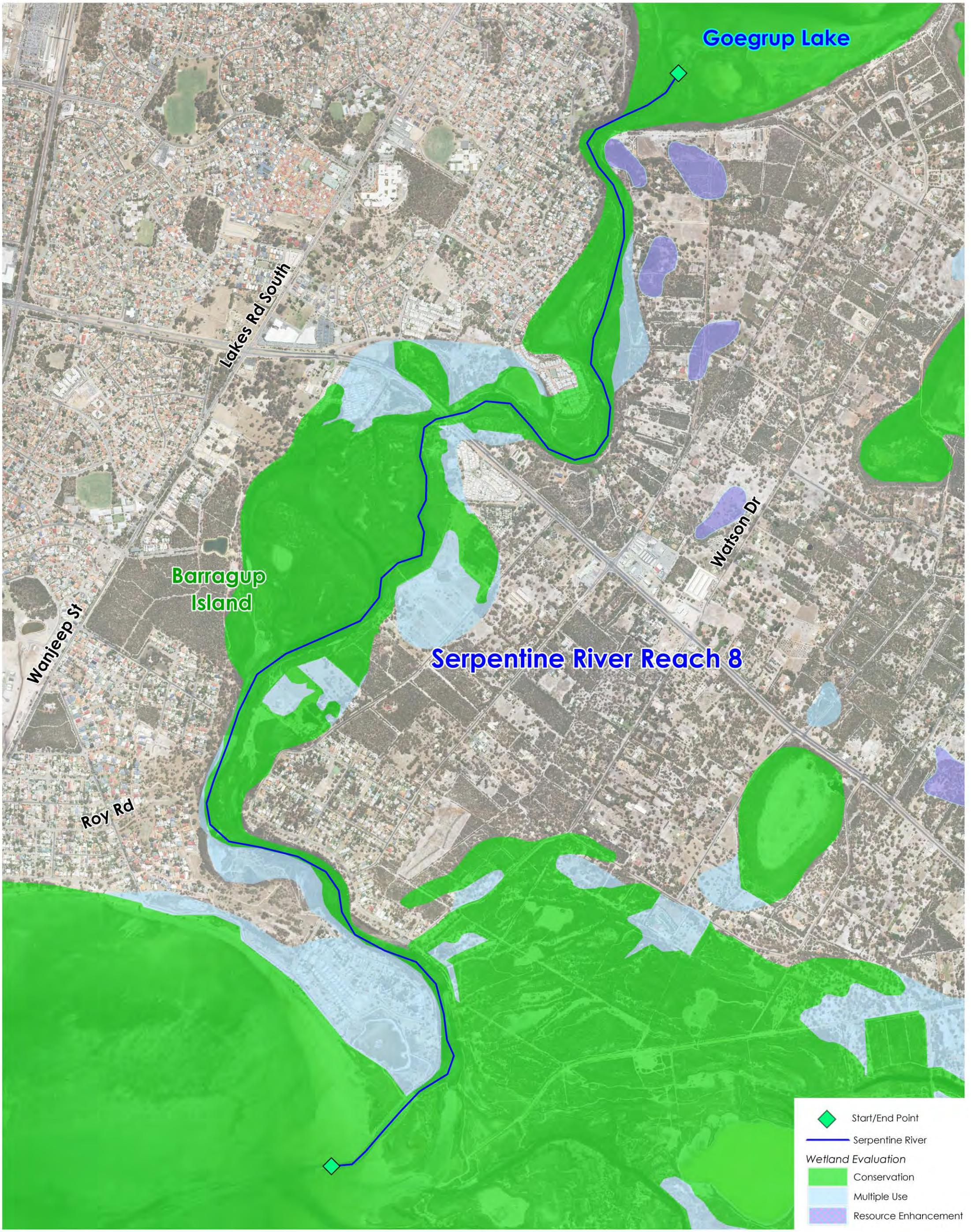
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 45 - Reach 8 Wetland Map



Data source: DOP, DBCA, PHCC. Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:16,000 @ A3

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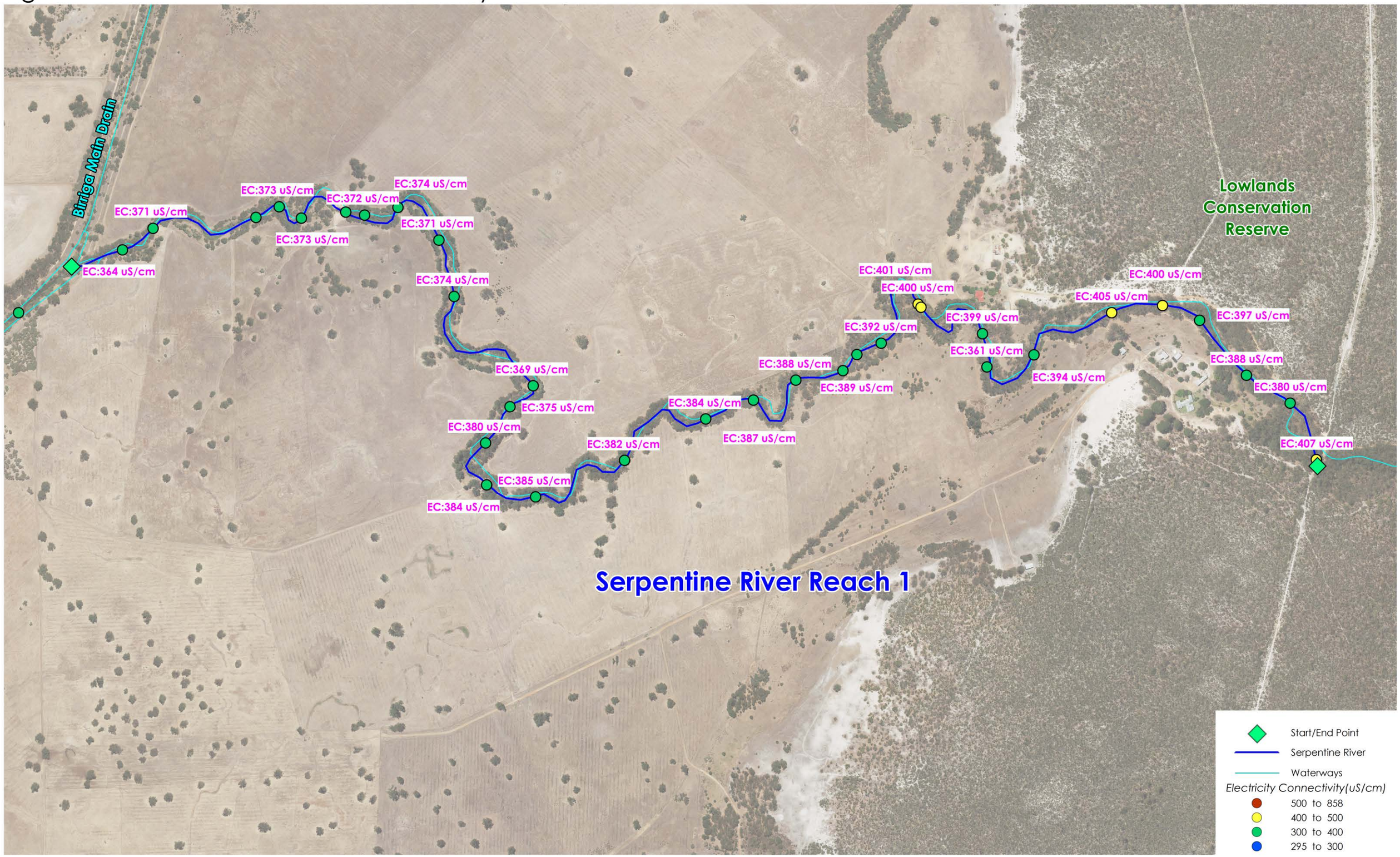
APPENDIX 5: WATER QUALITY SUMMARY

Peel Harvey Catchment Council - Serpentine River Action Plan

Figure 46 - Reach 1 Electrical Conductivity



Data source: DOP,.DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:8,000 @ A3

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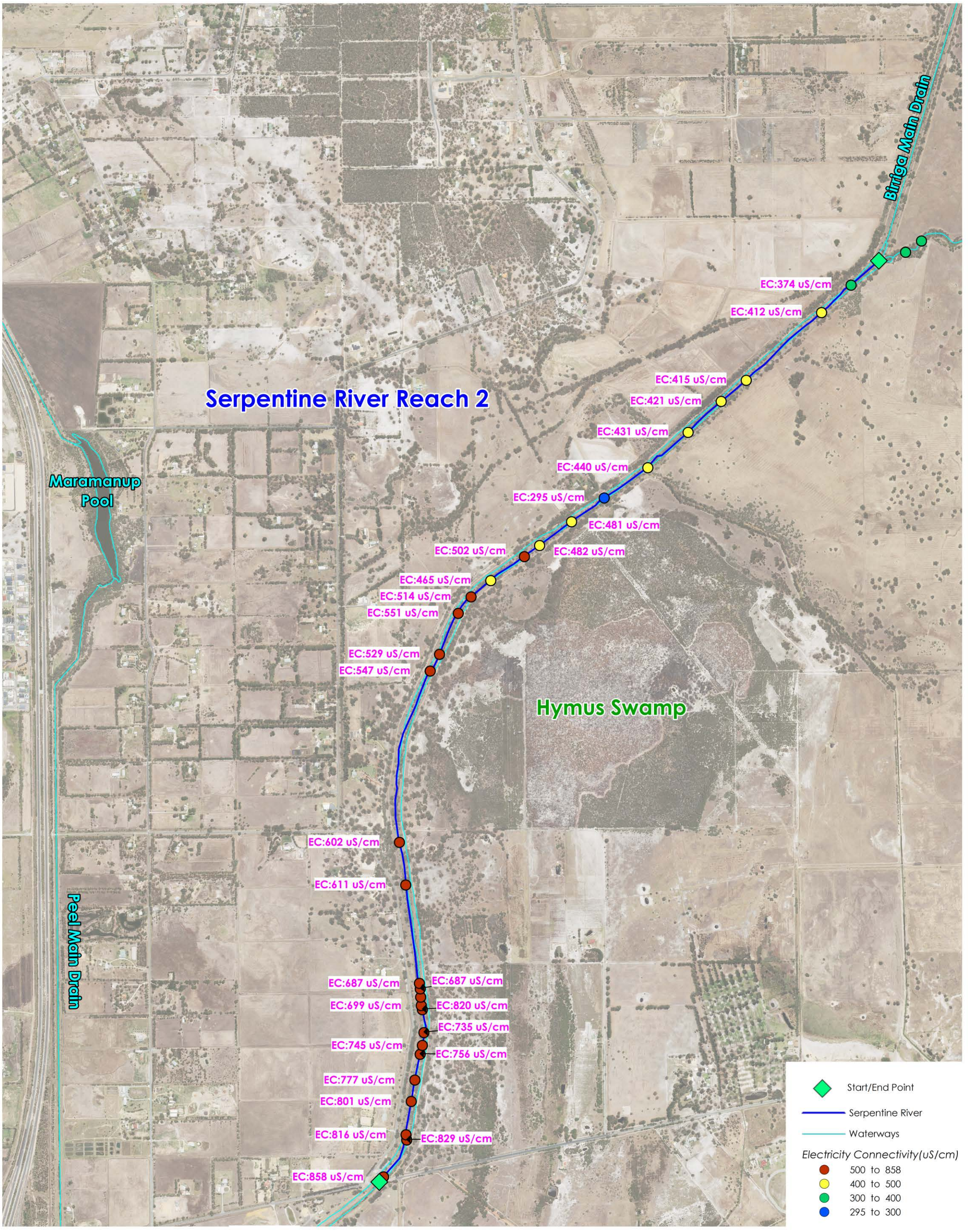
Figure 47 - Reach 2 Electrical Conductivity



Data source: DOP, DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

0 1,000
meters
Scale 1:15,000 @ A3

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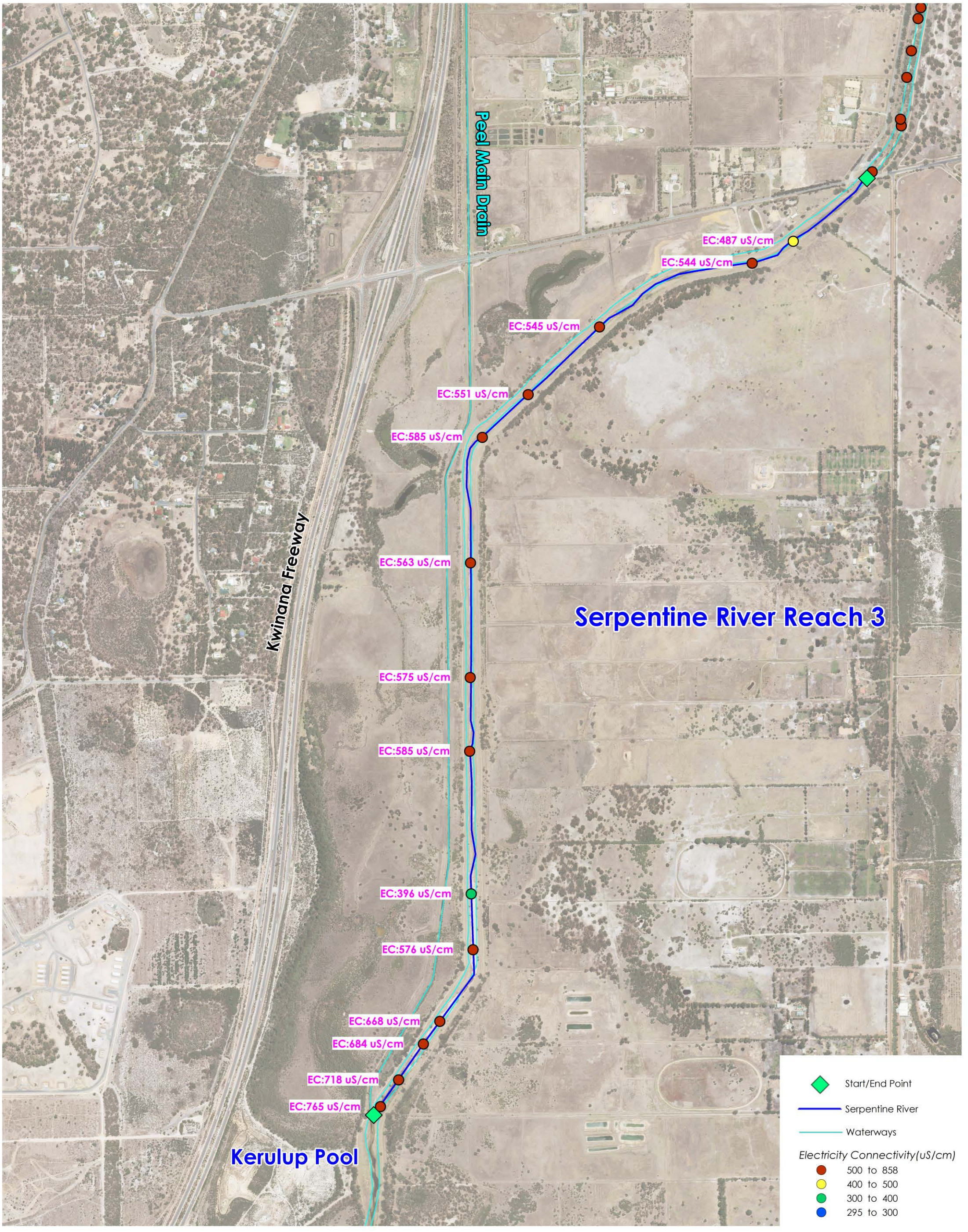
Figure 48 - Reach 3 Electrical Conductivity



Data source: DOP,DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:12,000 @ A3

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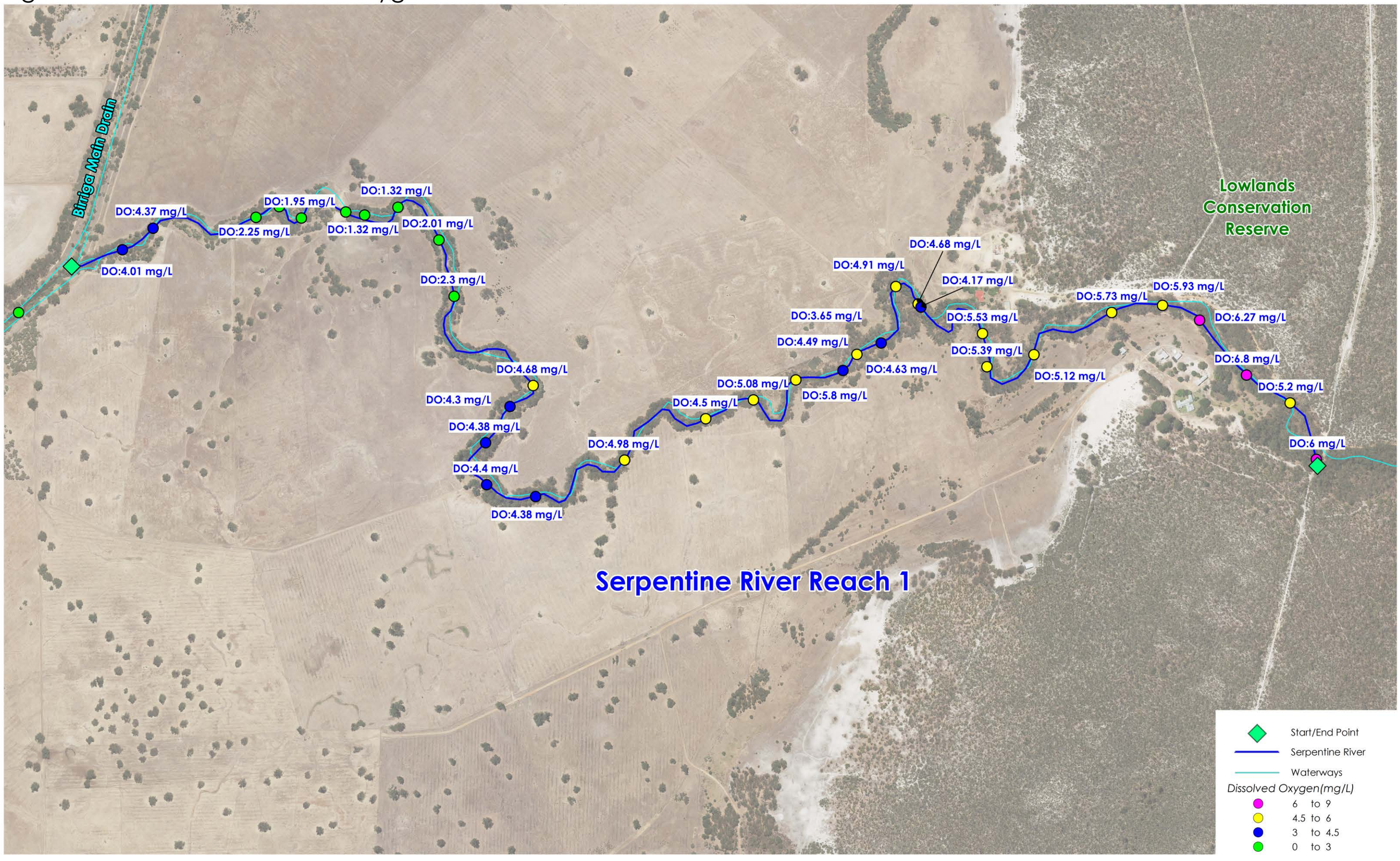
Figure 49 - Reach 1 Dissolved Oxygen



Data source: DOP,.DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

0 500
meters
Scale 1:8,000 @ A3

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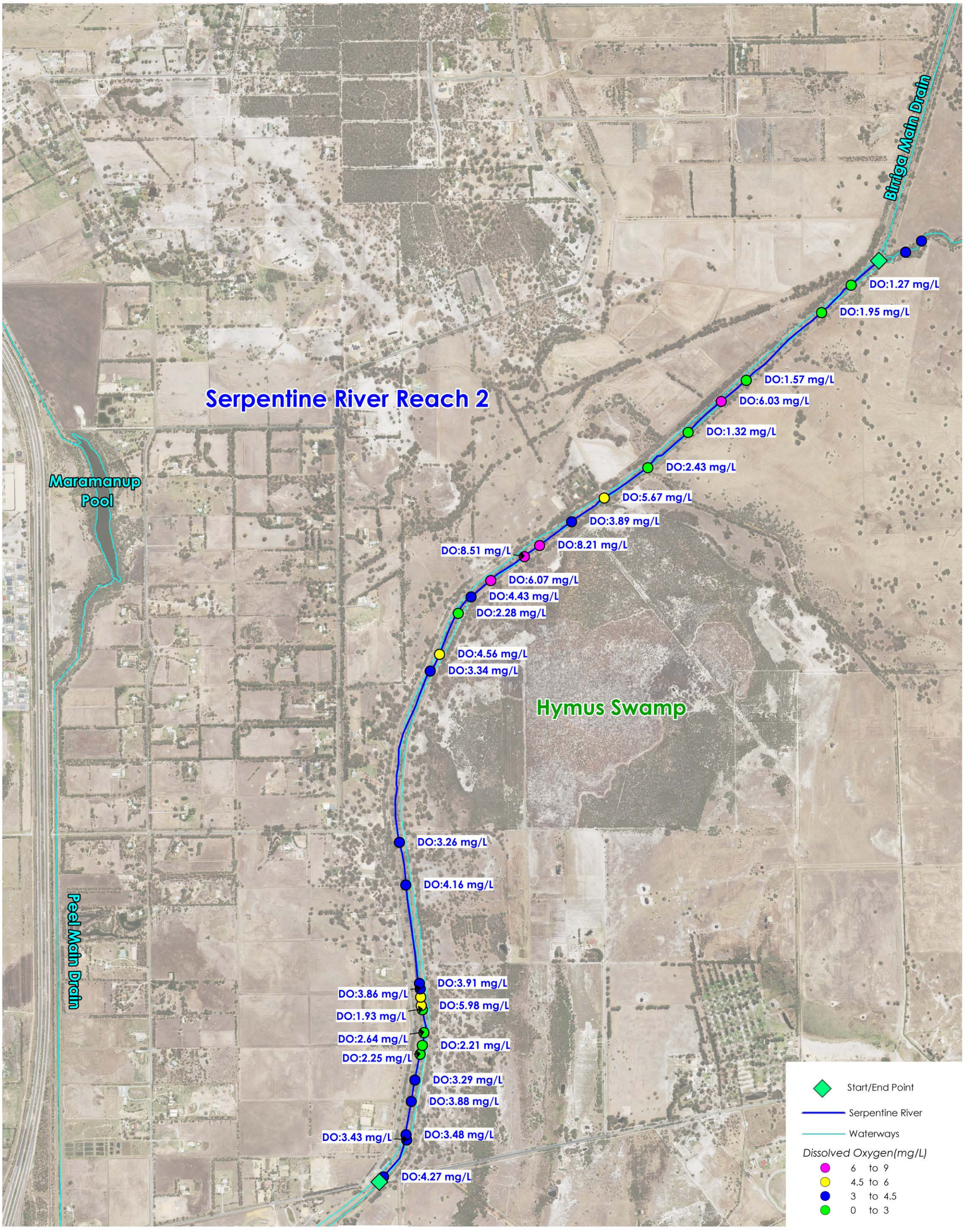
Figure 50 - Reach 2 Dissolved Oxygen



Data source: DOP, DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

0 1,000
meters
Scale 1:15,000 @ A3

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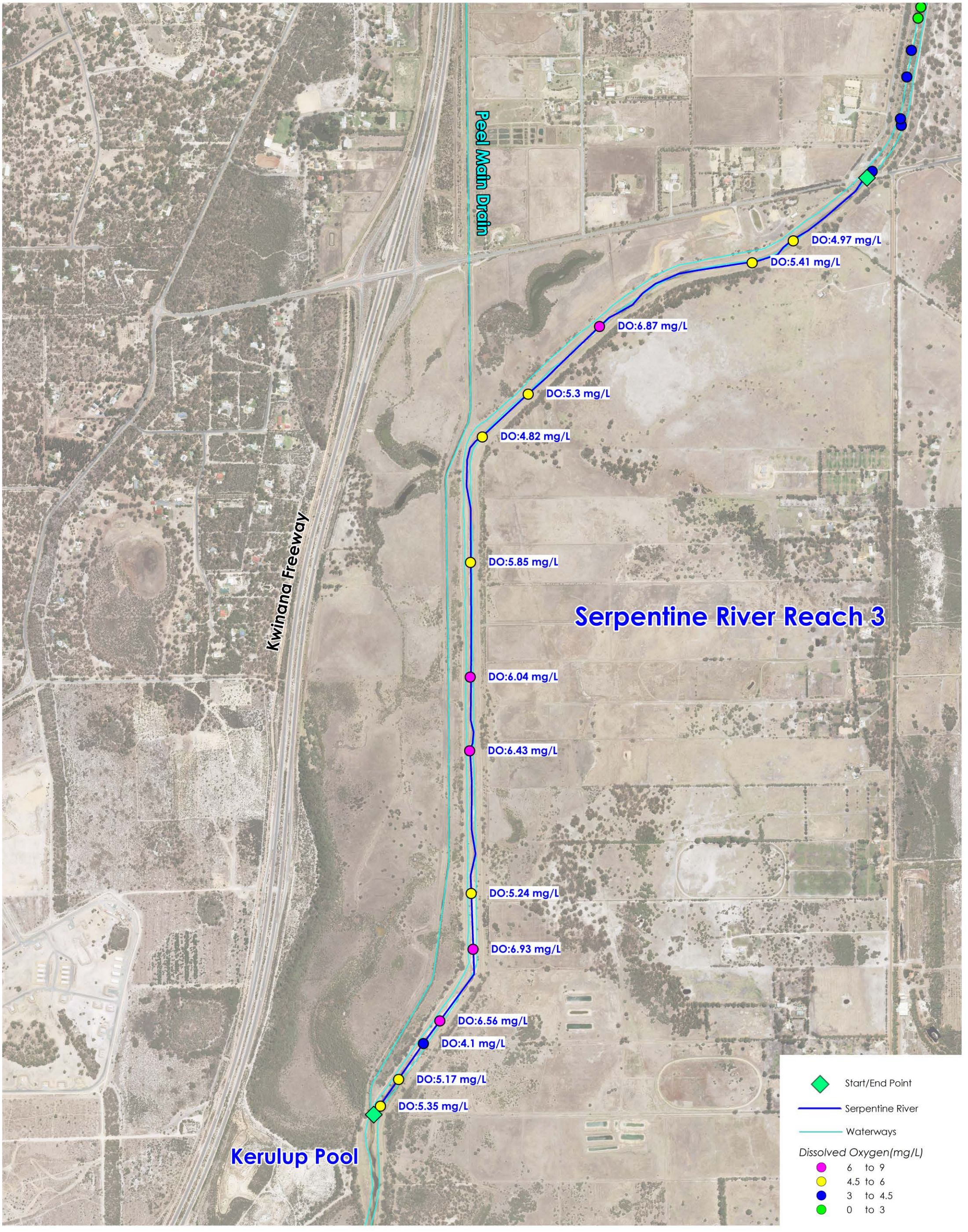
Peel Harvey Catchment Council - Serpentine River Action Plan
Figure 51 - Reach 3 Dissolved Oxygen



Data source: DOP,DBCA, PHCC, Created by: YY Projection: MGA: zone 50.

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meters
Scale 1:12,000 @ A3

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Client: Peel Harvey Catchment Council

Report	Version	Prepared by	Reviewed by	Submitted to Client	
				Copies	Date
Preliminary draft	V1	RP	HB	Electronic	Dec 2019
Draft for PHCC	V2	RP	HB	Electronic	Dec 2019
Revised Draft	V3	RP	HB	Electronic	Jan 2020
Final	V4	RP	HB	Electronic	May 2020

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