Groundwater Dependent Ecosystem Survey of the Barwon Downs region

Barwon Water

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DOCUMENT TRACKING

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Project Manager	Griffin Taylor-Dalton
Prepared by	Griffin Taylor-Dalton
Reviewed by	James Garden and Dr Richard Cresswell
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Abbreviations, initialisms and acronyms

Abbreviation	Description
Barwon Water	Barwon Region Water Corporation
BOM	Bureau of Meteorology
DELWP	Department of Environment, Land, Water and Planning
ELA	Eco Logical Australia Pty Ltd
EVC	Ecological Vegetation Class
GDE	Groundwater Dependent Ecosystem
LTA	Lower Tertiary Aquifer
mm	Millimetre

Executive Summary

Eco Logical Australia Pty Ltd was engaged by the Barwon Region Water Corporation to undertake an investigative study to identify Groundwater Dependent Ecosystems within the Barwon Downs region. This assessment arose as a result of a recommendation made within the most recent Barwon Downs vegetation monitoring report (ELA 2020).

Six patches of vegetation were identified as having the potential to rely upon, or at least utilise, available groundwater. These patches were identified as either Ecological Vegetation Class 23: Herb-rich Foothilll Forest or Ecological Vegetation Class 198: Sedgy Riparian Woodland. Both these vegetation communities have been known to utilise groundwater (Carr and Muir 1994).

Of the six patches identified, four were deemed as having a high likelihood of being able to utilise groundwater. These four patches shared the following characteristics:

- Modelled groundwater depth being no more than 10 m (often large sections of the vegetation were modelled at a 5 m depth to the water table)
- Modelled groundwater salinity commonly being between 0 – 500 mg / L
- Nearby watercourses having a moderate to high modelled probability of having a groundwater to surface water interaction
- Vegetation composition being that which has been previously identified as being able to utilise groundwater

One patch was mapped as having a moderate likelihood of being a Groundwater Dependent Ecosystem. This patch was assessed as having a moderate likelihood rather than a high likelihood due to a much higher modelled groundwater salinity (3,500 mg / L) in comparison to patches that were assigned a high likelihood of being a Groundwater Dependent Ecosystem. One patch (Boomerang Swamp) was determined as having a low likelihood of relying on available groundwater. This decision was a result of the landscape position of Boomerang Swamp. Boomerang Swamp is located near the top of a series of foothills. The swamp is nestled in a small plateau with the surrounding landscape steadily declining in elevation. Given this, it is likely that the swamp acts as a groundwater recharge zone.

There are several limitations of this assessment. These include:

- Only public land was assessed during the field survey. Future work should look to investigate suitable locations on private property as well. This would survey a wider area than this study and therefore potentially find addition patches of GDEs.
- All the potential GDEs that were identified as a part of this study are type III GDEs (i.e. those being ecosystems that are reliant on the sub-surface presence of groundwater within the rooting depth of the ecosystem; Eamus *et al*. 2016). Type II GDEs (those that rely on the surface expression of groundwater discharge) were not investigated and may be present in the area, particularly where surface water-groundwater interactions are modelled (DEWLP, 2018b) to be significant. Without drilling and obtaining core samples, identifying type III GDEs (Eamus *et al*. 2016) carries an inherent level of uncertainty as these GDEs could be being hydrated by available surface water. Future work should aim to also identify type II GDEs within the broader region,

as well as incorporate additional technical studies to confirm groundwater use by the mapped high likelihood type III GDEs identified in this study

- The presence/absence of a GDE does not account for different aquifer systems. Future works should aim to identify what aquifers systems patches of vegetation are likely drawing from

1. Introduction

1.1. Background

Eco Logical Australia Pty Ltd (ELA) was engaged by Barwon Region Water Corporation (Barwon Water) to undertake a study to identify Groundwater Dependent Ecosystems (GDE) across the Barwon Downs region and surrounding area. This was undertaken following recommendation from the most recent Barwon Downs vegetation monitoring report (ELA, 2020).

The primary aim of the previous assessment (ELA, 2020) was to better constrain the potential GDEs located within the surrounding investigation areas to inform further assessment of groundwater-pumping related impacts.

The significantly modified landscape and limited native vegetation cover near proposed bore locations, meant that suitable GDEs for monitoring were unable to be identified with confidence. In particular, the influence of surface water flows and other landscape processes (e.g. weed invasion, grazing, etc.) were thought likely to have a greater influence on the condition of vegetation and therefore would reduce the efficacy of monitoring for the purposes of assessing impacts associated with changes in ground-water levels.

It was recommended that a broader investigation of the Barwon Downs region be conducted to identify GDEs more suitable for monitoring, specifically targeting areas where Lower Tertiary Aquifer (LTA) outcrops are known to occur (as this is where groundwater pumping impacts are likely to have occurred). This report presents the findings of this investigation and identifies potential candidate sites for future monitoring.

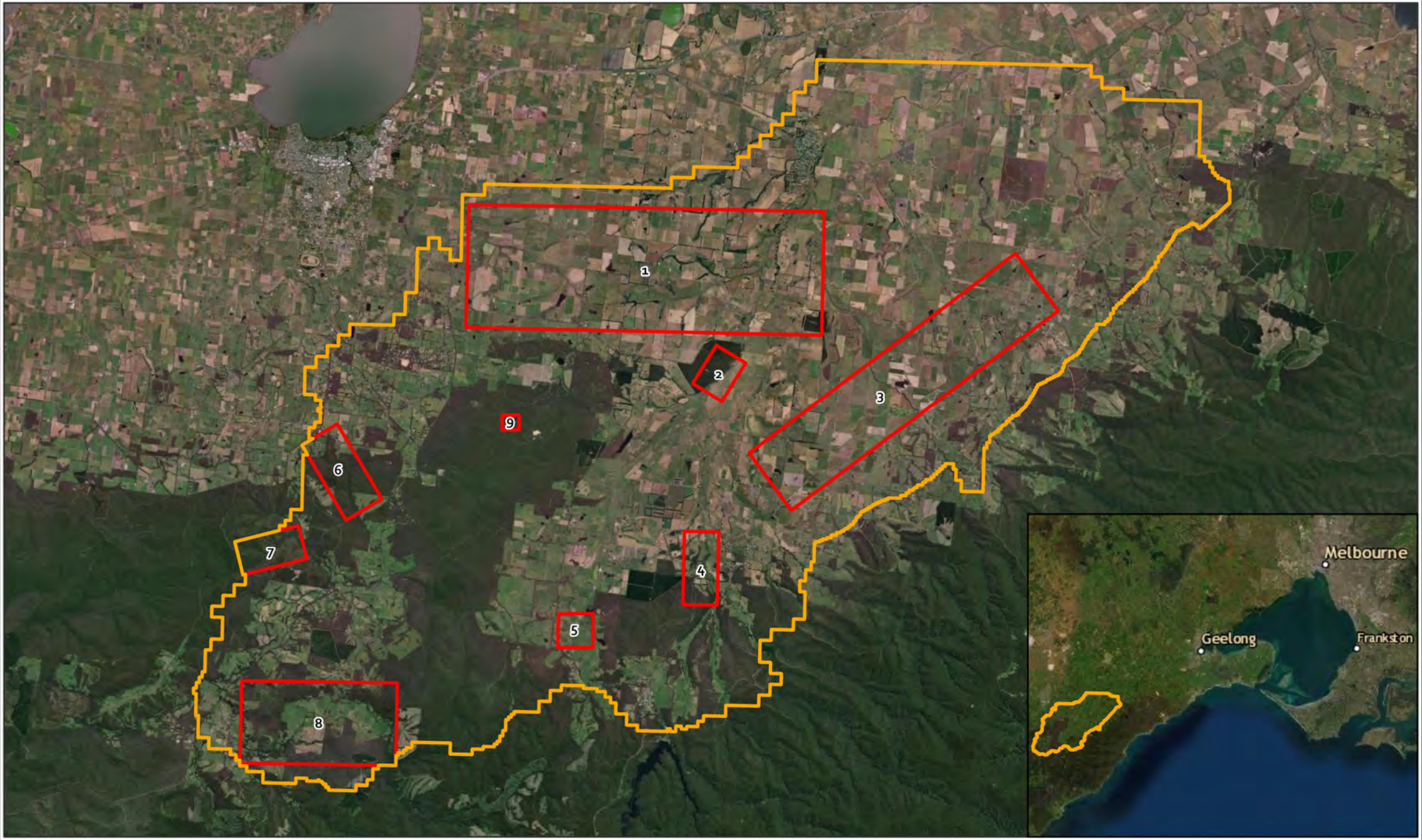
1.2. Aim

This study aims to improve the certainty of GDE identification within the Barwon Downs region. Field studies target LTA outcrop areas and additional data sets and models were reviewed, following from previous assessments (e.g. ELA, 2020). This study focuses on nine areas of investigation provided by Barwon Water (Figure 1). This includes Boomerang Swamp, which has been noted as an area of concern for the local community. Given the focus on understanding potential impacts to indigenous vegetation, patches of exotic vegetation and native plantations have been excluded.

1.3. Limitations and assumptions

The main limitation of this assessment is that no boring was undertaken to confirm that groundwater is residing beneath vegetation that has been mapped as potential GDEs. As such, certainty regarding whether a patch of vegetation is a GDE cannot be confirmed without further investigation.

Only public land was accessed as part of this investigation. Additionally, as the field validation was undertaken by a single ecologist, to maximise safety, only areas that were safe to traverse were investigated. This excluded steep slopes and areas inundated with water. Existing tracks were utilised where possible to survey the vegetation present.



Location map

Study area

Areas of investigation

N

0 1,500 3,000 6,000

Metres

Datum/Projection:
GDA 1994 VICGRID94

Project: 600-20MEL17547 Date: 20/07/2022

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2. Methodology

2.1. Desktop review

A desktop review was undertaken to inform the field survey on vegetation types that are likely to rely upon, or at least utilise, groundwater. The following sources were reviewed:

- Bureau of Meteorology (BOM) historic climate data (BOM 2022)
- Modelled extent of native vegetation (Department of Environment, Land, Water and Planning (DELWP) 2018a)
- Groundwater salinity modelling (DELWP 2019)
- Depth to water table modelling (DELWP 2019)
- Groundwater-surface water interaction (DELWP 2018b)
- Mapped watercourses (DELWP 2022)
- Previous studies including:
    - 17547 Barwon Downs Vegetation Monitoring report V4 (ELA 2020)
    - Inventory and Assessment of Floral and Faunal values of the Barwon Downs aquifer outcrop areas and associated streams, Otway Ranges, Victoria (Carr & Muir 1994)

2.2. Field survey

A field survey was undertaken from the 20 – 22 June 2022 to validate and map native vegetation communities that were within the nine areas of investigation (Figure 1). This process aimed to identify phreatophyte species (species that rely upon or can utilise groundwater) within each community. Species of particular interest included *Eucalyptus ovata* (Swamp Gum) and *E. viminalis* (Manna Gum) as they are likely to occur within the vegetation communities within the study area (DPI 2010). Additionally, each patch of vegetation was assigned to a best-fit Ecological Vegetation Class (EVC). Once mapped, each patch was categorised based on the likelihood that the vegetation had a groundwater interaction.

3. Results

Sections 3.1 and 3.2 detail the results of the desktop and field assessments. Investigation areas 1 and 2 (Figure 1) had no patches of GDE vegetation and therefore have been excluded from the relevant map series.

3.1. Desktop review

The desktop review detailed historic and modelled environmental data across the Barwon Downs region.

3.1.1. Past climate data

Annual rainfall data was gathered to provide insight into the potential availability of surface water within the study area. Data was gathered from the Colac Shire Office weather station and the Barwon Downs weather station (BOM 2022). These two stations were chosen as they represent the northern and southern extent of the study area and have relatively complete records, thus allow comparison across the study area. Additional climate-related data (temperate and windspeed) were investigated, however these data sets were either not collected beyond the 1980's or data were inconsistent and could not be used for accurate comparison.

Rainfall data was not available for the 2018 – 2022 period for the Barwon Downs weather station hence the 2008 to 2017 period (10 years) was chosen for comparison. Average annual rainfall at Barwon Downs is over 50% higher than at Colac. Interannual variability is comparable, however (Table 1).

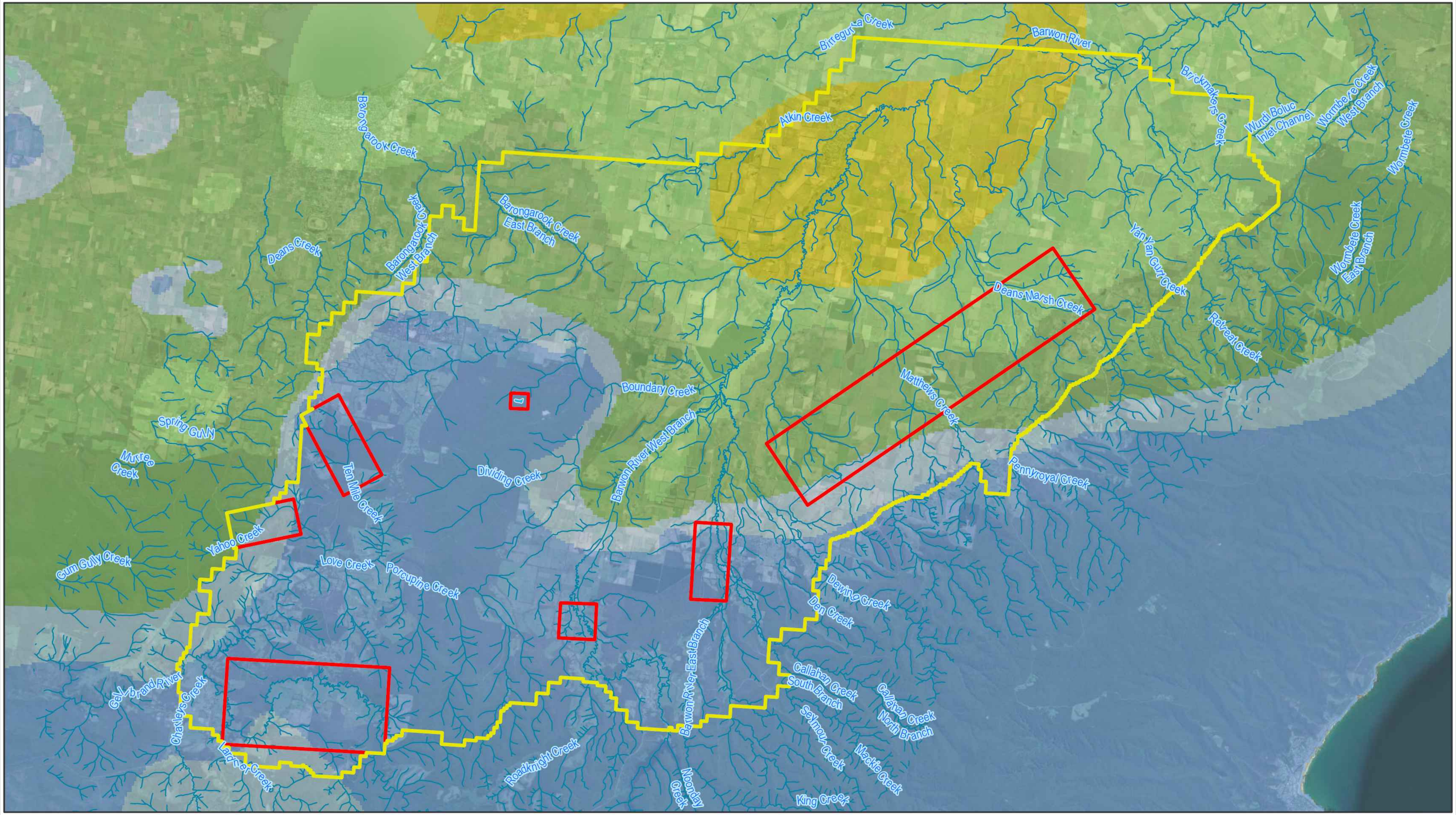
Table 1: Past rainfall data for within the study area (BOM 2022)

Weather Station	Average Rainfall (mm)	Standard deviation (mm)
Colac Shire Office	610.97	93.83
Barwon Downs	998.12	152.48

3.1.2. Groundwater salinity modelling

Groundwater salinity modelling was used to determine where groundwater salinity levels may be too high for flora communities. Salt is a common stressor for a lot of flora species, often resulting in a reducing in growth rates and a plants ability to take up water, among other metabolic changes (Munns 2002). The groundwater salinity modelling (DELWP 2019) detailed a wide spectrum of salinity levels across the study area, ranging from 0 mg/L to upwards of 13,000 mg / L (DELWP 2019) (Figure 2). For the of the areas of investigation, the upper limit of modelled salinity was 7,000 mg / L with most being below 1,000 mg / L. This level of salinity would be considered freshwater to mildly saline (Hillel 2000). Flora communities are unlikely to be able to utlise saline water

Investigation areas 4, 5, 6, 8, and 9 were either completely, or largely modelled as having a groundwater salinity of 0 – 500 mg/L. Investigation area 7 is modelled as having a spectrum of groundwater salinity levels, ranging from 0 – 3,500 mg / L. Finally, investigation area 3 had the highest modelled groundwater salinity level with groundwater salinity reaching up to 7,000 mg / L.



Groundwater salinity

Study area
Areas of investigation
Boomerang swamp
Watercourse

Groundwater salinity (mg/L) (DELWP 2019)

0 - 500
501 - 1,000
1,001 - 3,500
3,501 - 7,000
7,001 - 13,000

Datum/Projection:
GDA 1994 MGA Zone 54

Project: 17547 Date: 18/08/2022

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3.1.3. Depth to water table modelling

Depth to water table modelling (DELWP 2019) indicated that most mapped watercourses within the areas of investigation had an approximate depth to the water table of <5 m (Figure 3). For some areas, the depth to the water table increased to 10 m or 20 m.

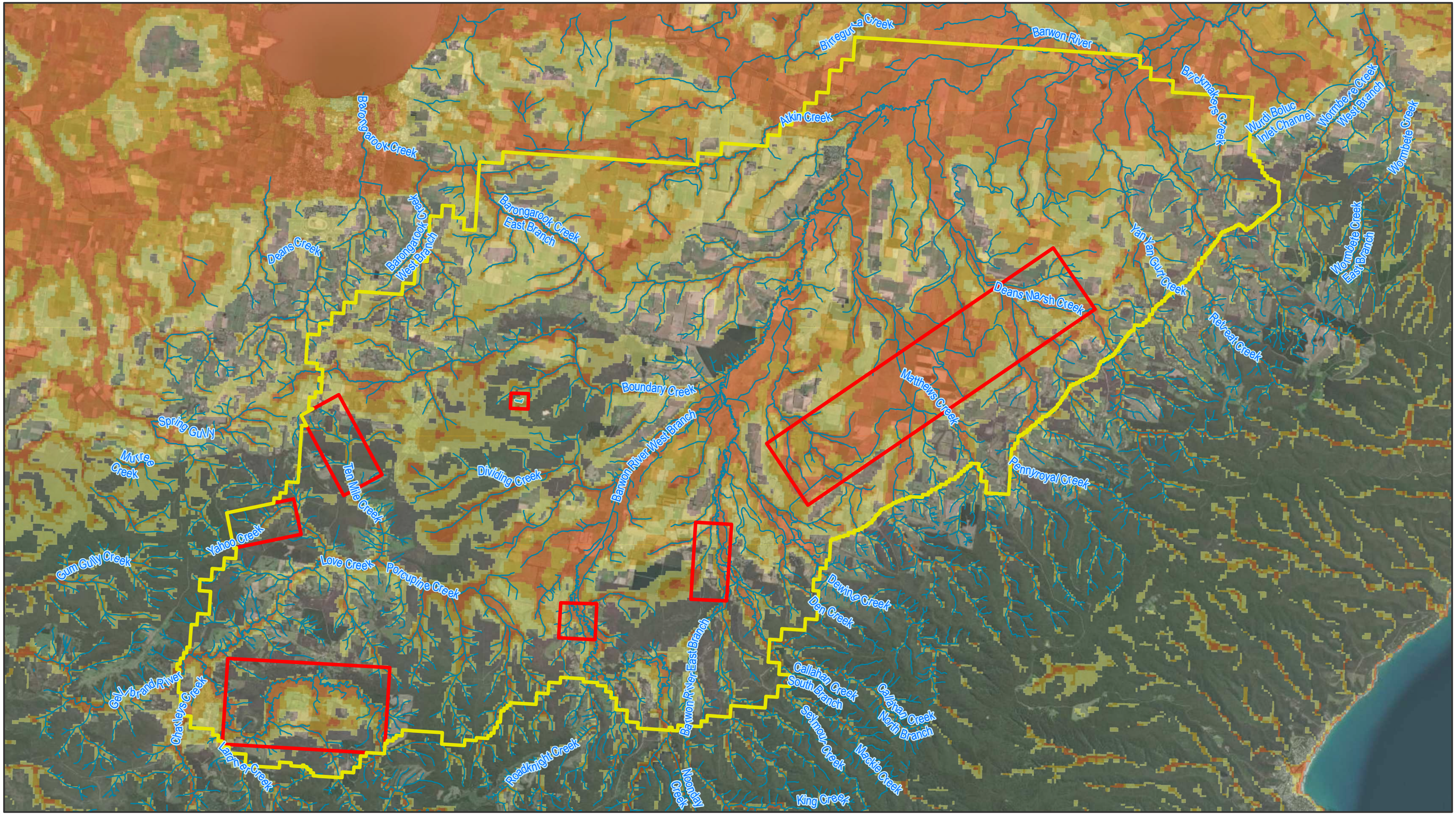
Watercourses within investigation areas 3, 4, 5, and 8 were modelled as having an average depth of 5 m to the water table. Investigation areas 6 and 7 have more variability ranging from 5 m to 20 m, depending on the topography of the water course and adjacent banks. Area 9 predominantly had a modelled depth of 10 m.

Given the context of this study, it is worth noting that different aquifer systems exist within the study area. For locations where the LTA outcrops, the alluvium may also act as an aquifer system.

3.1.4. Likelihood of groundwater – surface water interaction modelling

Likelihood of groundwater – surface water interaction modelling (DELWP 2018b) mapped all major water courses within the investigation areas (Figure 4 –Figure 9). Each watercourse has an assigned probability of groundwater interaction. For the areas of investigation this varied from moderate to high.

Major watercourses within investigation areas 3, 4, 5, and 8 had a high modelled probability of having an interaction with groundwater. Investigation areas 6 and 7 had a moderate modelled probability of having a groundwater interaction. Investigation area 9 has no modelled probability for this data.



Depth to water table (m) - Investigation area 3

Study area
Areas of investigation
Boomerang swamp
Watercourse

Depth to water table (m) (DELWP 2019)

5
10
20

N

0 2.5 5
Kilometres

Datum/Projection:
GDA 1994 MGA Zone 54

Project: 17547 Date: 18/08/2022

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3.2. Field survey

3.2.1. Vegetation validation

Seven patches of vegetation were validated across the investigation areas. One of these patches consisted of exotic vegetation and has not been included in this section as this assessment aims to only recommend patches of native vegetation to be considered for future monitoring programs. Additional, referenced, photographs (Figure 4 – Figure 9) follow the descriptive boxes in Table 2 -Table 8, which summarise the vegetation identified within each investigation area.

Table 2: Validated vegetation within investigation area 3

Area of investigation 3	
EVC 23: Herb-rich Foothill Forest	Bioregional conservation status: Vulnerable
The native vegetation mapped within investigation area 3 (Figure 4) conformed best to EVC 23. The vegetation resided along the steep banks of the creek line. This vegetation was identified as being in a poor condition, with significant disturbance from environmental weeds. Additionally, Gabion walls line the watercourse. The installation of this infrastructure has resulted in the removal of the understorey vegetation. This patch had a canopy dominated by *E. viminalis* and *Acacia melanoxylon* (Blackwood). Notably, most Eucalypts appeared to be young (<30 years old). The only other native species identified was *Olearia argophylla* (Musk Daisy Bush). Weeds were prominent within this patch. Most common exotic species identified included *Phalaris aquatica* (Bulbous canary-grass), *Vinca major* (Grater periwinkle) and *Genista monspessulana* (Montpellier broom).	

Table 3: Validated vegetation within investigation area 4

Area of investigation 4	
EVC 23: Herb-rich Foothill Forest	Bioregional conservation status: Vulnerable
The native vegetation within investigation area 4 (Figure 5) best conformed to EVC 23. This patch was situated alongside the Gellibrand River, extending approximately 10 – 20 m from the top of bank. Native species richness was high across all stratums with very few occurrences of exotic species. Dominant canopy species include *E. viminalis* and *E. obliqua* (Messmate). *A. melanoxylon* was commonly observed as an understorey tree. Common native species observed within the mid-storey include *Coprosma quadrifida* (Prickly Current-bush), *Olearia lirata* (Snowy Daisy-bush) and *Epacris impressa* (Common Heath). A large amount of diversity was observed amongst the groundcover species. These species included *Dichondra repens* (Kidney Weed), Pteridium esculentum (Bracken fern), *Hydrocotyle laxiflora* (Stinking Pennywort), *Poa labillardierei* (Common Tussock), *Tetrarrhena juncea* (Forest Wire-grass), *Dianella tasmanica*, *Viola hederacea* (Ivy-leaved Violet) and *Senecio glomeratus*.	

Table 4: Validated vegetation within investigation area 5

Area of investigation 5	
EVC: N/A	Bioregional conservation status: N/A
This patch of vegetation is located along the Barwon River West Branch. The watercourse was overgrown with exotic *Salix babylonica* (Weeping Willow) and *Rubus anglocandicans* (Blackberry). Minor occurrences of young unhealthy *A. melanoxylon* were also identified.	

Table 5: Validated vegetation within investigation area 6

Area of investigation 6	
EVC 23: Herb-rich Foothill Forest	Bioregional conservation status: Vulnerable
The vegetation within investigation area 6 runs parallel to Ten Mile creek (Figure 6). Vegetation within this area conformed best to EVC 23. This patch was observed as being of a high quality with large swathes of remnant vegetation. This vegetation was situated on moderately steep slopes located adjacent to the creek system. Canopy species within this patch included *E. viminalis, E. obliqua, Eucalyptus cypellocarpa* (Mountain Grey-gum) and *Eucalyptus radiata* subsp. *radiata* (Thin-leaved Peppermint) with *A. melanoxylon* occurring as an understorey tree. *O. lirata*, *Bursaria spinosa* (Blackthorn), *C. quadrifida*, *Leptospermum continentale* (Prickly Teatree), *Acacia mucronata* subsp. *longifolia, Notelaea ligustrina* (Privent Mock-olive), *O. argophylla, E. impressa* and Goodenia ovata (Hop Goodenia) were all observed within the mid-storey stratum. Groundcover species consisted of *Lomandra longifolia* (Spiny-head Mat-rush), *H. laxiflora*, *P. esculatum*, *D. repens*, *T. juncea* and *V. hederacea*.	

Table 6: Validated vegetation within investigation area 7

Area of investigation 7	
EVC 23: Herb-rich Foothill Forest	Bioregional conservation status: Vulnerable
The vegetation mapped within investigation area 7 has been identified as EVC 23. Similar to area 6, the vegetation within this patch was a of a high quality, albeit with some evidence of edge effects due to an access track running perpendicular to the mapped patch (Figure 7). *E. viminalis* was the main canopy species within the patch, however *Eucalyptus ovata* (Swamp Gum) was also high in abundance, though this species tended to occur as an understorey tree. *Acacia verticillata* (Prickly Moses), *C. quadrifida*, *Cassinia aculeata* subsp. *aculeata* (Common Cassinia), *Ozothamnus ferrugineus* (Tree Everlasting) and *Dicksonia antarctica* (Soft Tree-fern) occupied the mid-storey stratum with *P. esculatum*, *Clematis aristata* (Old-mans Beard), *L. longifolia, G. ovata*, *T. juncea* and *Solanum aviculare* (Kangaroo Apple) occupying the groundcovers. Exotic species that were frequently observed along the edge of the patch include *Phalaris aquatica* (Toowoomba Canary-grass), *Cenchrus clandestinus* (Kikuyu) and *Cirsium vulgare* (Spear Thistle).	

Table 7: Validated vegetation within investigation area 8

Area of investigation 8	
EVC 23: Herb-rich Foothill Forest	Bioregional conservation status: Vulnerable
Mapped vegetation within investigation area 8 was located within 20 – 50 m of the Gellibrand River, depending on the curvature of the watercourse (Figure 8). Vegetation within this area was mapped as EVC 23. Similar to areas 6 and 7, the condition of the vegetation was high. Edge effects were noticeable, as expected, given the patch of vegetation is located adjacent to a 4WD track. *E. viminalis* and *E. obliqua* occupied the canopy stratum. *A. melanoxylon* was the only understorey tree species within the patch. Mid-storey species were sparse though contained only native species. These species include *O. argophylla*, *O. ferrugineus, C. quadrifida* and *D. antarctica.* Groundcovers were diverse with many fern species occupying the ground stratum. Groundcovers observed within this patch include *P. esculatum, Lindsaea linearis* (Screw Fern), *Blechnum cartilagineum* (Gristle-fern), *C. aristata, Gonocarpus tetragynus* (Common Raspwort), *Sigesbeckia orientalis* (Indian Weed) and *Urtica incisa* (Scrub Nettle).	

Table 8: Validated vegetation within investigation area 9

Area of investigation 9	
EVC: 198 Sedgy Riparian Woodland	Bioregional conservation status: Depleted
This patch of vegetation is situated within the Otway Forest Park, surrounding Boomerang Swamp (Figure 9). Boomerang Swamp is situated on a north-east facing slope at an elevation of approximately 200 m nestled in a small plateau of the Otway Forest Park. The vegetation mapped during the assessment was determined as conforming to EVC 198. The overall condition of this vegetation was high however it was noted that some of the canopy trees were showing signs of a decrease in health (i.e. discoloured leaves, reduced foliage cover and dead or dying limbs). *E. obliqua* and *E. ovata* were the two canopy species present at this location. Typically, E. ovata was located closer to the water whereas *E. obliqua* was often situated further away from the swamp. Mid-storey species observed included *A.verticillata, A. melanoxylon* and *L. continentale.* Groundcovers consisted largely of grass and sedge species, these included *Gahnia radula* (Thatch Saw-sedge), *G. sieberiana* (Red-fruit Saw-sedge), *T. juncea*, *P. esculatum*, *D. tasmanica*, *Carex appressa* (Tall Sedge) and *Lepidosperma laterale* (Variable Sword-Sedge).	

3.3. Potential for groundwater dependent ecosystems

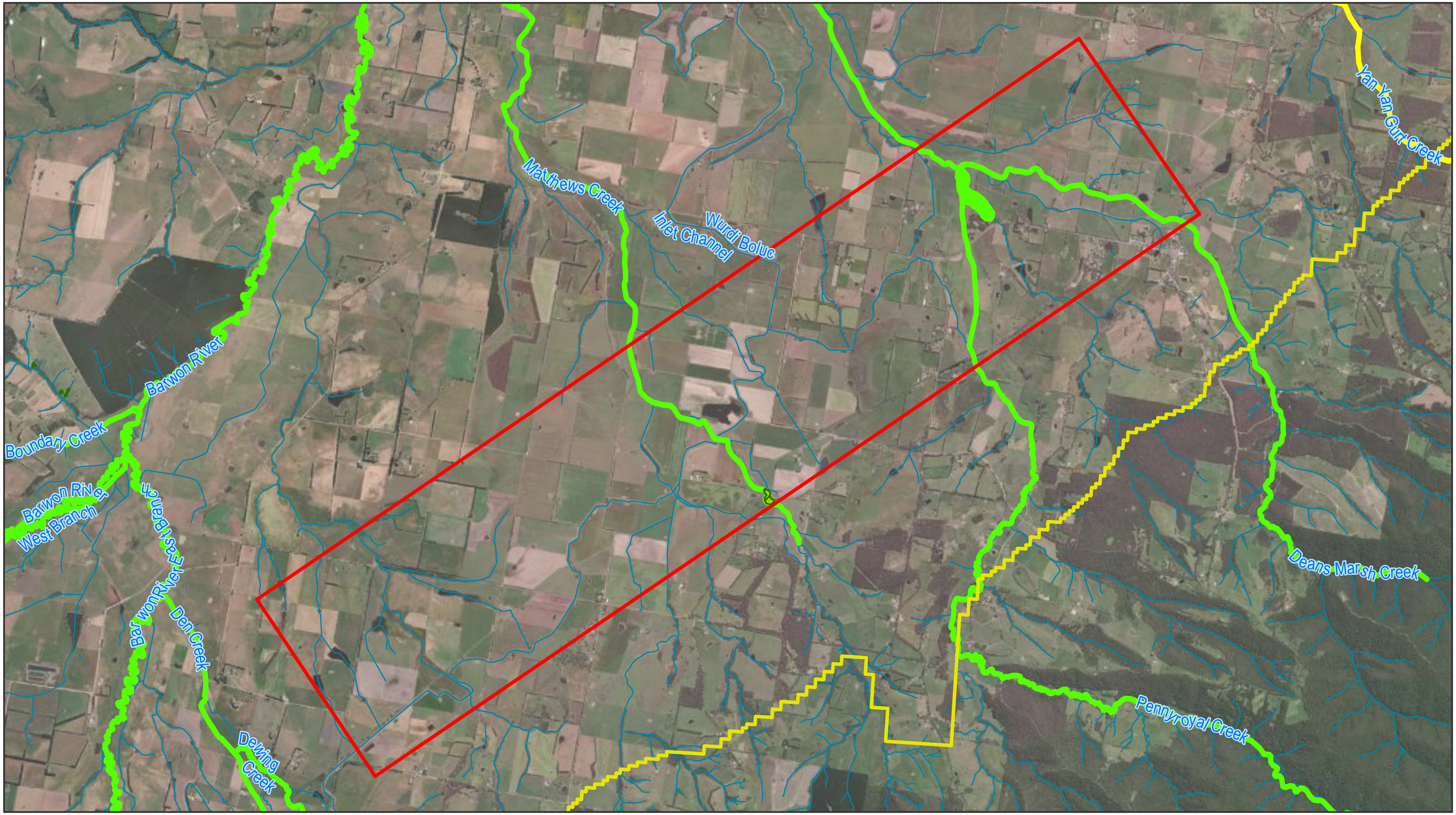
Vegetation validated as a part of this assessment was categorised based on the likelihood of the flora relying upon, or at the least being able to utilise, groundwater within the landscape (Figure 4 to Figure 9). The three subjective categories were assigned: high, moderate and low likelihood. Table 9 outlines the results of the assessment.

Areas that contained only exotic vegetation (i.e. investigation area 5) have not been included in this section as this assessment aims to only recommend patches of native vegetation to be considered for future monitoring programs.

Table 9: Likelihood of GDE vegetation within the investigation areas

Investigation area	Likelihood	Rationale
3	Moderate	• Modelled depth to water table is <5 m (DELWP 2019) • Modelled groundwater salinity is moderate (1,001 – 3,500 mg / L) • Matthews Creek, which is located in close proximity to the mapped patch of vegetation, is modelled as having a high likelihood of groundwater to surface water interaction (DELWP 2018b) • The vegetation community present has been recorded in previous studies as being hydrologically sensitive (Carr and Muir 1994), albeit in a poor condition.
4	High	• Modelled depth to water table is <5 m (DELWP 2019) • Modelled groundwater salinity is low (0 – 500 mg / L) (DELWP 2019) • The Barwon River East Branch, which is located within close proximity to the mapped patch of vegetation, is modelled as having a high likelihood of groundwater to surface water interaction (DELWP 2018b) • The vegetation community present has been recorded in previous studies as being hydrologically sensitive (Carr and Muir 1994)
6	High	• Modelled depth to water table varies from 5 m – 10 m (DELWP 2019) • Modelled groundwater salinity is low (0 – 500 mg / L) (DELWP 2019) • Ten Mile Creek, which is located within close proximity to the mapped patch of vegetation, is modelled as having a moderate likelihood of groundwater to surface water interaction (DELWP 2018b) • The vegetation community present has been recorded in previous studies as being hydrologically sensitive (Carr and Muir 1994)
7	High	• Modelled depth to water table is 5 m – 10 m (DELWP 2019) • Modelled groundwater salinity is low (0 – 1,000 mg / L) (DELWP 2019) • Yahoo Creek, which is located within close proximity to the mapped patch of vegetation, is modelled as having a moderate likelihood of groundwater to surface water interaction (DELWP 2018b) • The vegetation community present has been recorded in previous studies as being hydrologically sensitive (Carr and Muir 1994)
8	High	• Modelled depth to water table is 5 m – 10 m (DELWP 2019) • Modelled groundwater salinity is low (0 – 500 mg / L) (DELWP 2019) • The Gellibrand River, which is located within close proximity to the mapped patch of vegetation, is modelled as having a high likelihood of groundwater to surface water interaction (DELWP 2018b) • The vegetation community present has been recorded in previous studies as being hydrologically sensitive (Carr and Muir 1994)

Investigation area	Likelihood	Rationale
9	Low	• Modelled depth to water table between 10 – 20 m. The closer water table is to the surface, the more likely a wider range of species could utilise this resource. • The landscape position of Boomerang swamp suggests surface run-off likely recharges the swamp, as opposed to groundwater. • Some *E. ovata* individuals, which is a phreatophyte species, were observed as dead within the swamp. Given this species can utilise groundwater, the death of this species suggests that at some point the swamp may have dried up and there was no other water source for this species to utilise.



GDE vegetation - Investigation area 3

Study area
Areas of investigation
Watercourse

Validated vegetation
Native - remnant

GDE likelihood of Vegetation
Moderate

Likelihood of groundwater interaction (DELWP 2018b)
High
Moderate

N

0 400 800
Metres

Datum/Projection:
GDA 1994 MGA Zone 54

Project: 17547 Date: 19/08/2022

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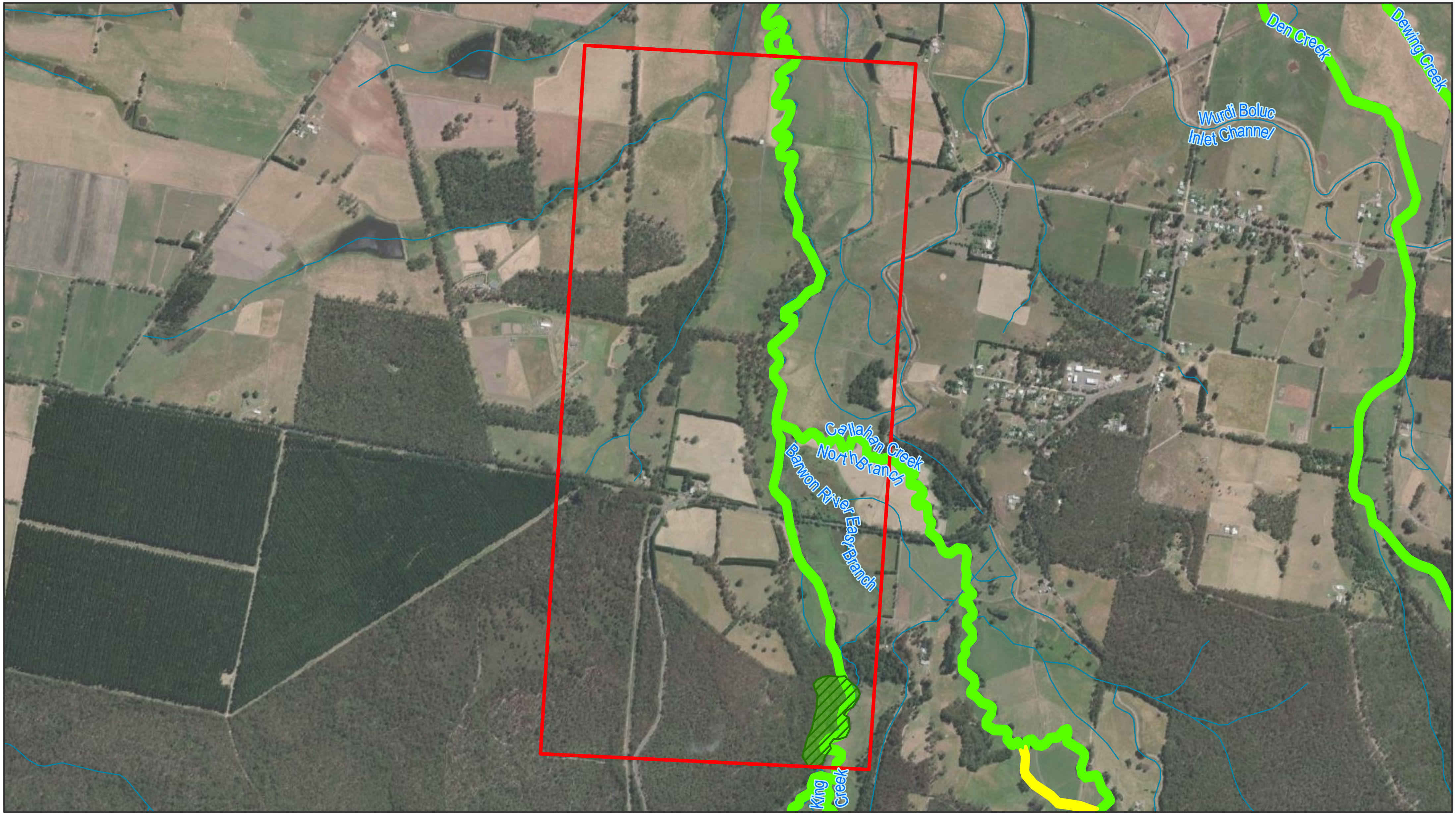

GDE vegetation - Investigation area 4

Study area
Areas of investigation
Watercourse

Validated vegetation
Native - remnant

GDE likelihood of Vegetation
High

Likelihood of groundwater interaction (DELWP 2018b)
High
Moderate

N

0 400 800
Metres

Datum/Projection:
GDA 1994 MGA Zone 54

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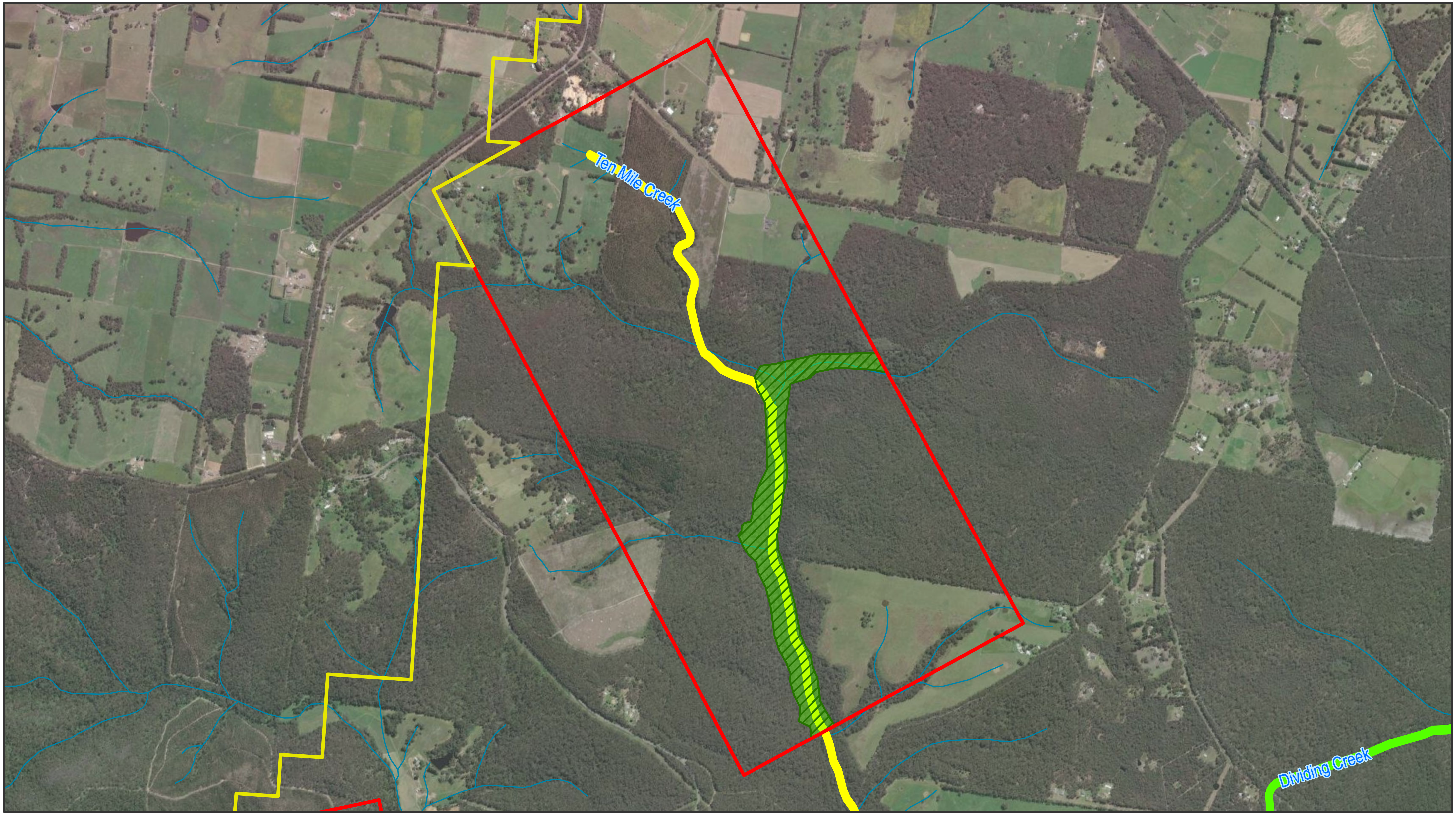

GDE vegetation - Investigation area 6

Study area
Areas of investigation
Watercourse

Validated vegetation
Native - remnant

GDE likelihood of Vegetation
High

Likelihood of groundwater interaction (DELWP 2018b)
High
Moderate

N

0 400 800
Metres

Datum/Projection:
GDA 1994 MGA Zone 54

Project: 17547 Date: 19/08/2022

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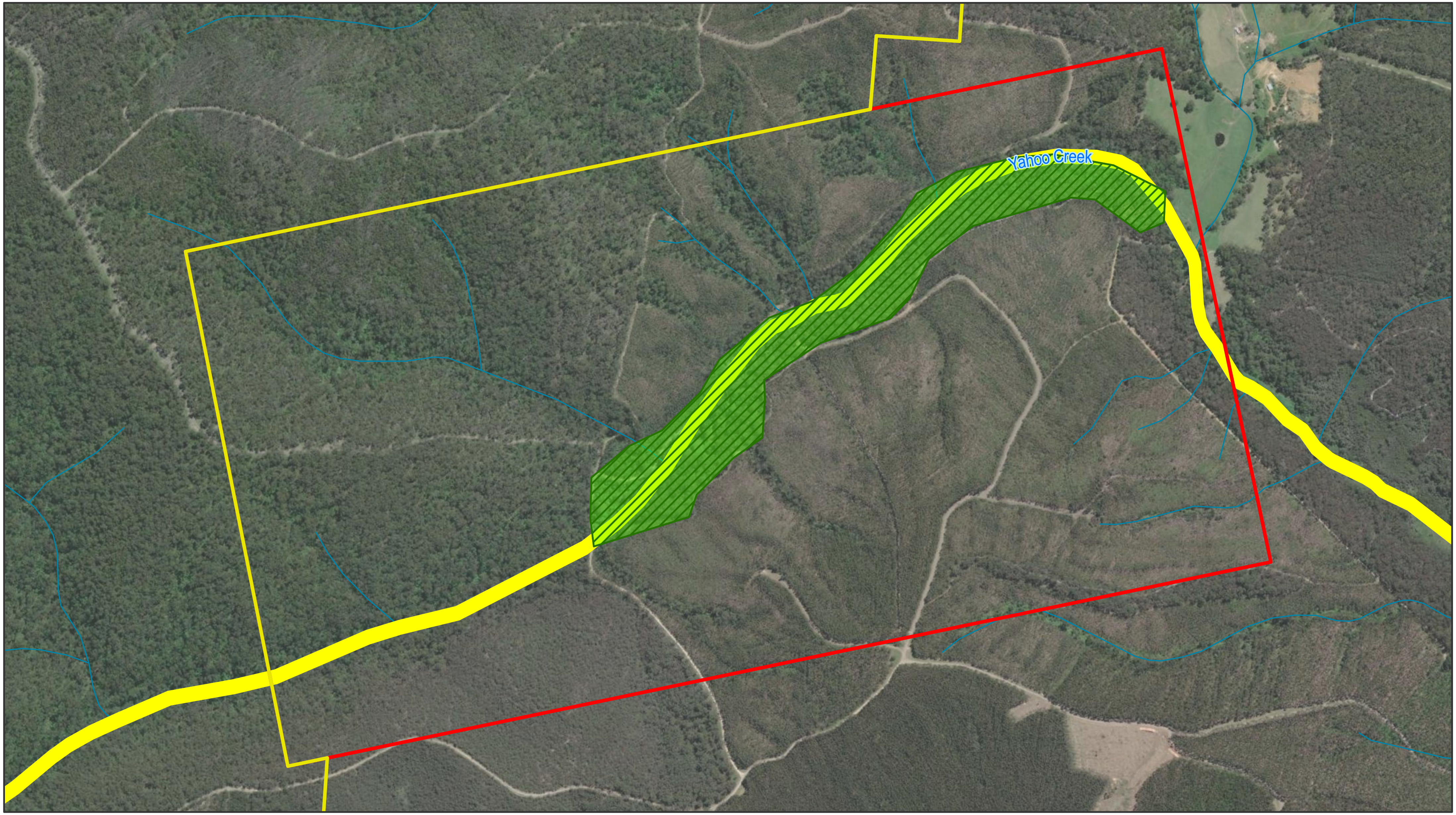

GDE vegetation - Investigation area 7

Study area
Areas of investigation
Watercourse

Validated vegetation
Native - remnant

GDE likelihood of Vegetation
High

Likelihood of groundwater interaction (DELWP 2018b)
Moderate

N

0 400 800
Metres

Datum/Projection:
GDA 1994 MGA Zone 54
Project: 17547 Date: 19/08/2022

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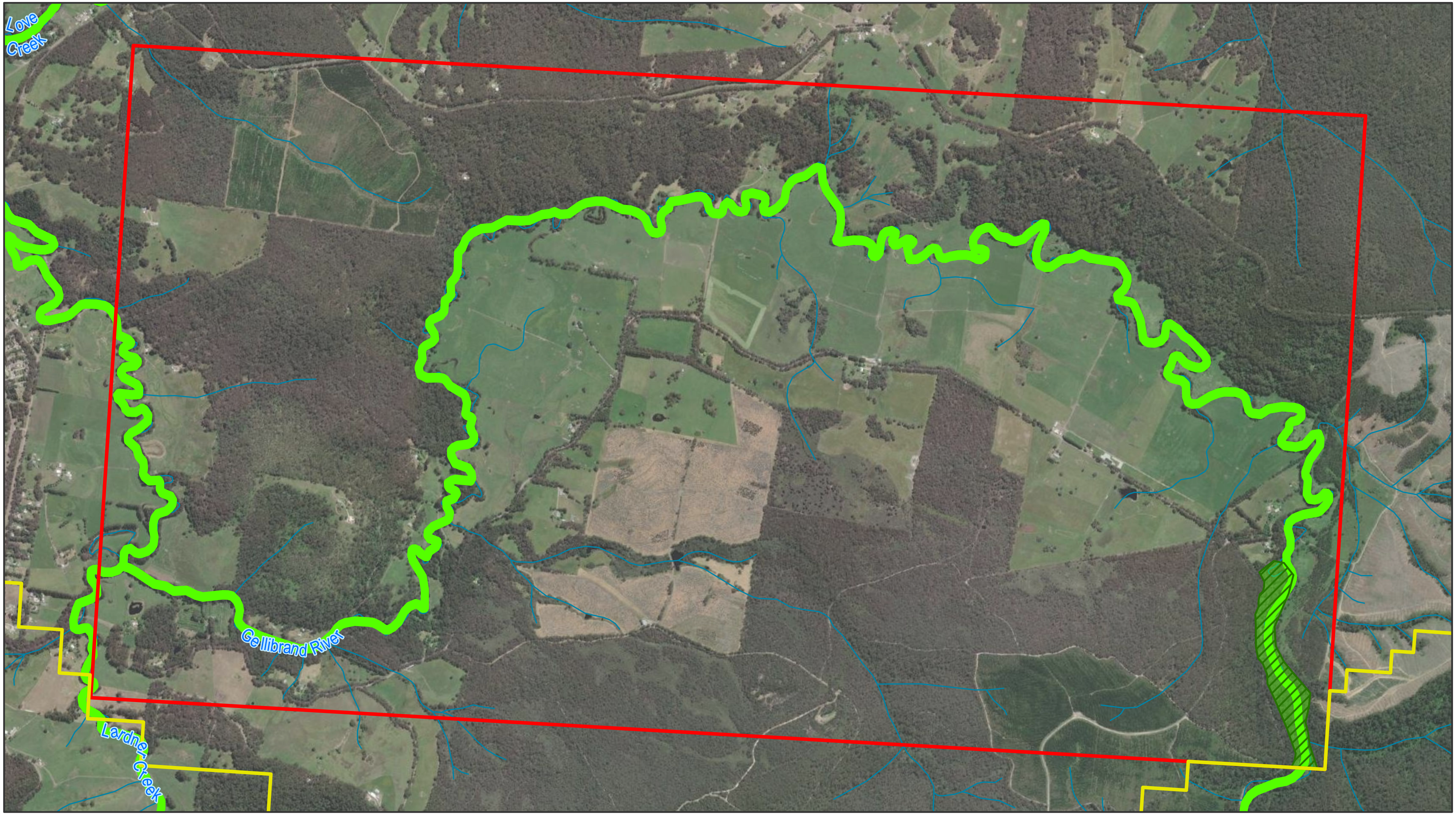

GDE vegetation - Investigation area 8

Study area
Areas of investigation
Watercourse

Validated vegetation
Native - remnant

GDE likelihood of Vegetation
High

Likelihood of groundwater interaction (DELWP 2018b)
High

N

0 400 800
Metres

Datum/Projection:
GDA 1994 MGA Zone 54

Project: 17547 Date: 19/08/2022

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GDE vegetation - Investigation area 9

4. Discussion

4.1. Assessment findings

4.1.1. High probability patches

Six patches of vegetation were mapped as having the potential to be GDEs. Four of these were deemed as having a high potential to be GDEs. These four patches all shared common trends:

- Modelled groundwater depth less than 10 m (often large sections of the vegetation are modelled at <5 m depth to the water table; DEWLP, 2019).
- Modelled groundwater salinity is generally between 0 – 500 mg / L (DEWLP, 2019).
- Nearby watercourses having a moderate to high modelled probability of having a groundwater to surface water interaction (DEWLP, 2018b).
- Vegetation composition has been previously identified as able to utilise groundwater (Carr & Muir, 1994).

The combination of these four factors at each site provides strong evidence that vegetation at these sites is likely to utilise groundwater for some (facultative) or all (obligate) of the time. Specifically:

1. Shallow modelled groundwater depth increases the likelihood that the root system of a flora species will be able to reach, and therefore utilise, the available groundwater. For eucalypt species, the depth to groundwater can be deeper than 5 m given that eucalypt root systems have been noted as reaching depths of 60 m (Stone & Kalisz 1991).
2. Salinity is modelled at between 0 -500 mg / L at all sites and this water would be considered fresh (Hillel 2000), therefore placing no constraint on the ability of flora species to utilise any available groundwater.
3. All patches are within close proximity to mapped waterways, many of which were modelled as having a moderate to high probability of groundwater-surface water interactions.
4. The floristics composition of the vegetation mapped fits that of communities that have previously been determined as relying upon, or at least have the ability to utilise, available groundwater.

The patches of vegetation that have been mapped as having a high likelihood of being GDE vegetation would be considered type III GDEs (Eamus *et al*. 2016) (i.e. ecosystems that are reliant on the sub-surface presence of groundwater within the rooting depth of the ecosystem).

4.1.2. Moderate probability patches

One patch of vegetation was determined as having a moderate probability of being a GDE. Similarities between this patch and the four patches mapped as being of a high probability were:

- Modelled groundwater depth was, on average, no more than 5 m
- The nearby watercourse was modelled as having a high likelihood of having a groundwater to surface interaction.

As such, this patch is likely to be able to utilise existing groundwater, if alternate surface water supplies are not available. Factors that reduce the likelihood of this patch from having a higher GDE likelihood were:

- Groundwater salinity levels were much higher than the other areas of investigation (up to 3,500 mg / L), therefore potentially limiting what species could utilise the resource
- Vegetation condition within the investigation area was poor, only containing canopy species that would typically be associated with the designated EVC.

4.1.3. Low probability patches

The vegetation surrounding, and within, Boomerang swamp was deemed as having a low probability of being a GDE. In favour of a GDE classification:

- Modelled groundwater salinity levels were low enough to support vegetation.
- The modelled depth to the water table did extend deeper than previous areas (as low as 20 m).

Despite these factors, mitigating conditions suggest this site is not groundwater dependent:

- Boomerang swamp is notably situated at an elevation of approximately 200 m, nestled in a small plateau, where the surrounding landscape is steadily descending away from the site. This landscape position lends well to the concept of Boomerang swamp being a consequence of representing a significant recharge zone, with ample surface water supply, as opposed to being a type II GDE (i.e. being reliant on the surface expression of groundwater) (Eamus *et al*. 2016).
- Several dead *E. ovata* were observed within and around the swamp. Given this species is a phreatophyte (DPI 2010) and it is unusual to see this species dead within and around a waterbody. While their deaths could also be as a result of another cause, such as disease or predation via insects, if groundwater were available, these species would have thrived.

4.2. Future works

Although comprehensive, this assessment has several limitations. Firstly, all areas surveyed were done so on public land. By accessing private land, future assessments could include a wider range of surveys areas and therefore have a potentially higher chance of finding GDEs. Based on the modelled data, for example, the parcels outlined in Table 10 could potentially contain additional GDEs.

Table 10: Parcels that may contain GDE vegetation

Nearest Town	Address	Standard Parcel identifier
Kawarren	1515 Colac-Lavers Hill Road, Kawarren, 3249	42A\PP2079
Kawarren	300 McDonalds Road, Kawarren, 3249	1\TP424536
Gellibrand	16 Rafferty's Road, Gellibrand, 3239 (Gellibrand River water frontage)	33J~A\PP3978

Secondly, only type III GDEs were identified during this assessment. Future works should attempt to identify additional types (I and II) of GDEs. This will likely need to be done in conjunction with access to private land, to survey a wider area and range of landscapes. To increase certainty regarding whether these potential GDEs are actually utilising groundwater, additional investigations could be undertaken, including collection of core samples taken at each location and assessed for soil moisture profiles and salinity and isotope assessments of groundwaters and vegetation. Pre-dawn surface moisture surveys can also illuminate areas where groundwater is close to, or discharging to, the land surface.

Finally, the identification of GDE vegetation does not provide any indication as to what aquifer system the vegetation is drawing groundwater from. Future works could look to identify these aquifer systems thus providing greater insight into how past groundwater pumping may have impacted the LTA.

5. Summary and Conclusions

ELA was engaged by Barwon Water to undertake a study to identify GDEs within the Barwon Downs region. This study was prepared following recommendations made as a part of the most recent Barwon Downs vegetation monitoring report (ELA 2020).

As a part of this study, six patches of vegetation were mapped as having a potential to rely upon, or utilise, available groundwater. Most of these patches of vegetation were identified as ecological vegetation community (EVC) 23: Herb-rich Foothill Forest. Vegetation surrounding Boomerang Swamp was identified as EVC 198: Sedgy Riparian Woodland. Both vegetation communities have been previously identified as being able to utilise groundwater (Carr and Muir 1994).

Of the six patches, four were determined as having a high likelihood of being GDEs. These patches all shared the following characteristics:

- Modelled groundwater depth being no more than 10 m (often large sections of the vegetation will be modelled at a 5 m depth to the water table)
- Modelled groundwater salinity commonly being between 0 – 500 mg / L
- Nearby watercourses having a moderate to high modelled probability of having a groundwater to surface water interaction
- Vegetation composition being that which has been previously identified as being able to utilise groundwater.

One additional patch was mapped as having a moderate likelihood of being a GDE. This patch was down-graded largely due to a modelled groundwater salinity (DEWLP, 2019) of 3,500 mg / L, which would limit the ability for flora species to utilise this water.

The vegetation surrounding and within Boomerang Swamp was determined to have a low probability of being a GDE, as it is likely that the swamp is a result of being a recharge zone as opposed to being fed via groundwater discharge.

There are several limitations of this assessment. These include:

- Only public land was assessed during the field survey. Future work should look to investigate suitable locations on private property. This would survey a wider area than this study and therefore potentially find addition patches of GDEs
- All the potential GDEs that were identified as a part of this study are type III GDEs (i.e. those being ecosystems that are reliant on the sub-surface presence of groundwater within the rooting depth of the ecosystem; Eamus *et al*. 2016). Type II GDEs (those that rely on the surface expression of groundwater discharge) were not investigated and may be present in the area, particularly where surface water-groundwater interactions are modelled (DEWLP, 2018b) to be significant Without drilling and obtaining core samples, identifying type III GDEs (Eamus *et al*. 2016) carries an inherent level of uncertainty as these GDEs could be being hydrated by available surface water. Future work should aim to also identify type II GDEs within the broader region, as well as incorporate additional technical studies to confirm groundwater use by the mapped high likelihood type III GDEs identified in this study

- The presence/absence of a GDE does not account for different aquifer systems. Future works should aim to identify what aquifers systems patches of vegetation are likely drawing from

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