Report: Part 1

Reedy Lake Flora Assessment – Environmental Water

Corangamite Catchment Management Authority

4 August 2023

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4 August 2023

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Via email: sharon.blum-caon@ccma.vic.gov.au

Dear Sharon

Reedy Lake Flora Assessment – Environmental Water

I am pleased to submit the final report for this important project.

Due to file size, the report is in two parts:

1. Background and methods
2. Results, discussion, and recommendations

This report is Part 1: Background and methods.

I have really enjoyed working with you on this project.

Yours sincerely

Leigh Smith
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WATER TECHNOLOGY PTY LTD

EXECUTIVE SUMMARY

At over 800Ha, Reedy Lake, located to the south east of Geelong, is the largest intermittently freshwater wetland in central Victoria. It is of outstanding botanical significance due to its diverse assemblage of freshwater to saline tolerant vegetation communities and the presence of rare plant species and associations. It is listed within the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site.

The original vegetation mapping report completed by Yugovic in 1983 (at the time of Ramsar listing) sets the benchmark for the wetlands ecological character and the Limits of Acceptable Change (LAC). Several subsequent studies mapped the extent of vegetation communities in 1995, 2004, 2006/7, 2010, 2012/13 and 2019, and additional information regarding the wetlands surface and groundwater hydrology and salinities, and overall ecology is available from studies completed between 2011 and 2020.

Because vegetation extents have been mapped at different times by different people using slightly different approaches and vegetation community classification, a consistent and consolidated time-series of the change in extent of vegetation types from 1983 to present is missing. This project set out to fill this important knowledge gap by mapping vegetation communities to a consistent classification and assessing the changes in the context of the wetland characteristics and environmental variables. Of particular interest was assessing vegetation extent changes against the prevailing hydrological regime.

The key vegetation communities investigated were *Phragmites australis* dominated reed beds, *Typha orientalis* dominated reed beds, *Bolboschoenus caldwellii* dominated beds of sedges/rushes and Lignum. Open water habitat is also an important component of the wetland ecology and is represented by areas inundated by water without a dominant cover of reeds or sedges/rushes. The open water habitat is typically shallow, with a fluctuating water level, and is characterised by clumps of the emergent rush *Schoenoplectus tabernaemontani*, isolated *Duma florulenta* bushes, and several floating and submergent species. Several areas of permanent deeper water exist.

Figure 1-1 – Reedy Lake

This study used several remote sensing and spatial analysis techniques[1] to:

- Map the changes in the extent and relative proportion of vegetation classes between 1983 and 2022
- Map wetland water extents and depths based on wetland surface elevations and water regime
- Investigate vegetation class surface elevation and water depth associations

Further techniques were used to:

- Investigate the changes in vegetation extent in the context of
  - the lifecycle and habitat preferences of the key vegetation communities
  - several environmental variables (rainfall, temperature, salinity)
- Assess the likely trajectory of future vegetation extent change based on the
  - continuation of current trends
  - influence of projected climate change
- Summarise, as best as possible, the efficacy of the watering regime in meeting Ramsar obligations and the agreed watering objective of the Lower Barwon Community Advisory Committee.

This study has demonstrated:

- the efficacy of using remote sensing methods to develop a consistent time series of change in vegetation community extent. The greater temporal resolution that is possible using these methods has shown that some vegetation communities can expand or contract significantly in extent over relatively short periods (~6-9 months) in response to changed conditions that are influenced by a combination of seasonal shifts in environmental variables and the impact of the watering regime.
- that the key vegetation communities at Reedy Lake respond, seasonally and inter-annually, to changes in water levels and presumably associated soil salinities. Different vegetation communities are favoured depending on the prevailing water regime. Periods of higher water levels favour freshwater vegetation communities and periods of drying favour saline tolerant vegetation communities, and those with root zones tapped in to fresh or saline shallow groundwater.
- Wetland surface elevations influence the
  - location and extent of key vegetation communities by creating preferable habitat conditions
  - response of vegetation communities to wetting by inundation and/or rainfall and drying

The project objectives were to increase CMA and community/stakeholder understanding of the following.

1. whether key vegetation communities at the wetlands have or have not changed in extent over time, and

    a. if so, to what degree have these extents changed, and

    b. how these extent changes have influenced the relative proportions of the key communities

This study has highlighted that these vegetation communities are highly dynamic and that although they have changed in extent and location over time their relative proportions have remained within the LAC.

For example, by 2018, the Landsat data showed that Tall Reed had increased in extent by 9.3% (30.6Ha) relative to 1988 whereas the extent of sedges/rushes had decreased by 44.8% (67Ha), and Lignum had decreased by 15.9% (3.51Ha). By 2022, the Sentinel-2 data has shown a 7% (4Ha) decrease in the extent of Tall Reed, a 7% (1Ha) increase in sedges/rushes, and Lignum extent has remained stable, relative to 2016.

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[1] Using the ArcGIS Geographical Information Software package by ESRI

2. whether changes in the extent of different vegetation community types can be related to:
    a. historical and prevailing climate (rainfall and temperature) patterns, and
    b. historical and prevailing hydrological (water level variation) conditions

This study has highlighted the control that wetland drawdown and rewetting exert on vegetation communities most likely through the inter-relationship with shallow groundwater and salinity. Temperature patterns will play a role in respect of the lifecycle of the representative species in each vegetation class, particularly during the spring – summer growth season. Rainfall per se is less of a direct influence overall, except through its influence on water levels in the Barwon River, however in some areas of the wetland, wetting of higher wetland elevations by extended periods of rainfall was observed to have influenced the balance between grassland (Distichlis distichophylla) and sedge (Bolboschoenus caldwellii) understorey. Drier periods favour Distichlis, whilst wetter periods favour Bolboschoenus.

3. whether any correlation in vegetation changes with climate/hydrology can inform potential future change
    a. based on continuation of the prevailing conditions
    b. based on a likely future climate scenario

Further monitoring of soil and groundwater salinities in conjunction with wetland drawdown and rewetting events would be required to provide greater resolution of data on the influence of prevailing water regime conditions on vegetation extents into the future. However, if current trends continue, with the ability to continue the draw down component of the watering regime, the wetland is likely to remain within the LAC.

Wetland areas ≤0.8mAHD appear to be showing the greatest response in maintaining or reducing the extent of Tall Reed. Increasing soil salinities under the wetland during post-drawdown dry phases are likely to be contributing to this effect. The southern perimeter is experiencing most of the increase in Tall Reed extent. Salinities around the western-northern-eastern perimeter are favouring coastal saltmarsh, sedges/rushes, and Lignum, with minor occurrences of Tall Reed.

The likely future climate scenario of reduced total rainfall, increased rainfall intensity and slightly increased seasonal temperatures would affect the length of the growing season and may be beneficial overall by creating slightly drier conditions within the wetland. However, the influence of future climate needs to be considered through the lens of the ENSO, IOD and SAM climate drivers, because as the past three years have shown, sustained La Nina and higher wetland water levels from flooding has limited the ability to drawdown the wetland.

Lastly, soil and groundwater salinities and levels in concert with the wetland watering regime need to be investigated under likely future climate change conditions to provide better insights into the likely influence of projected future climate on vegetation extents. Certainly, this study has highlighted the preferential shift towards Tall Reed accessing fresher groundwater around the southern perimeter of the wetland.

4. whether the watering objective to maintain the ecological character of the wetlands is being achieved

Yes, the ecological character of the wetlands is being maintained. The evidence shows the positive influence of the watering regime in the period 2016 to 2019 in reducing the relative extents of Tall Reed and increasing the relative extents of Sedges/Rushes. This assists with achieving a balance in cover of different vegetation types which have different habitat characteristics with benefits for birds, fish, frogs, and invertebrates. Habitat diversity and complexity assists in sustaining wetland ecological processes and this in turn supports the wetlands resilience to changes in environmental variables such as rainfall, water levels, temperatures, and salinity.

This is in accordance with the intent of the environmental watering objective, which is to:

> *"Maintain the ecological character of the wetlands". Ecological character is defined as the combination of ecosystem components, processes, benefits, and services that characterised the wetlands in 1983 when the wetlands were Ramsar listed.*

5. whether the Ramsar Limit of Acceptable Change is being met, based on relative changes in proportions:

> *"a habitat mosaic will be maintained at Reedy Lake that comprises open water, emergent native vegetation (sedges, rushes, and reeds), submerged vegetation and lignum shrubland with no habitat comprising more than 70 percent of the total wetland area for more than five successive years."*

Yes, the LAC for the wetlands is being met. Given the size of the wetland and the changes that are evident, it is likely that the LAC will continue to be met for the foreseeable future, if the wetland is able to be drawn down as per the watering regime.

6. how future changes in vegetation community extent can be monitored efficiently every two years.

It is recommended that the remote sensing method employed in this study is repeated into the future so that vegetation extents continue to be classified and mapped consistently to allow for comparison.

It is also recommended that additional analyses be performed to derive a retrospective time-series of Red-edge Normalised Difference Vegetation Index (NDVIre) to provide further insights into seasonal changes in vegetation community health/stress since 2015/16 that can be related to environmental variables.

CONTENTS

1 INTRODUCTION

Corangamite CMA engaged Water Technology to complete a remote sensing based, flora assessment of Reedy Lake to investigate the efficacy of the environmental watering regime that has been in place since 2016, and to provide a more complete record of vegetation change since the site was Ramsar listed in 1983.

Project objectives

The overarching purpose of this project was to develop a time-series of change in the extent of key vegetation types at Reedy Lake, that can be used to inform whether the ecological character of the wetlands is being maintained within the Limits of Acceptable Change (LAC) by the recommended watering regime.

> ***Limit of Acceptable Change****: a habitat mosaic will be maintained at Reedy Lake that comprises open water, emergent native vegetation (sedges, rushes, and reeds), submerged vegetation and lignum shrubland with no habitat comprising more than 70 percent of the total wetland area for more than five successive years.*

This project has been initiated to increase CMA and community/stakeholder understanding of:

1. whether key vegetation communities at the wetlands have or have not changed in extent over time, and
    a. if so, to what degree have these extents changed, and
    b. how these extent changes have influenced the relative proportions of the key communities
2. whether changes in the extent of different vegetation community types can be related to:
    c. historical and prevailing climate (rainfall and temperature) patterns, and
    d. historical and prevailing hydrological (water level variation) conditions
3. whether any correlation in vegetation changes with climate/hydrology can inform potential future change
    e. based on continuation of the prevailing conditions
    f. based on a likely future climate scenario
4. whether the watering objective to maintain/improve the ecological character of the wetlands is being met.
5. whether the Ramsar Limit of Acceptable Change (above) is met, based on relative changes in proportions.
6. how future changes in vegetation community extent can be monitored efficiently every two years.

2 BACKGROUND

2.1 Site description and catchment setting

Reedy Lake is a shallow freshwater to brackish wetland situated in a roughly circular sedimentary basin on the left bank floodplain of the Barwon River, approximately 6 to 10km downstream of Geelong (Figure 2-1).

Figure 2-1 – study location

2.2 Site geomorphology, geology, topography, and hydrogeology

The sedimentary basin of Reedy Lake is formed in recent (Quaternary, Holocene) beach sands and estuarine sand, silt, clay, and recent shells identified as unit R3 in the 1:63,360 Geelong Geology Map Sheet (Geological Survey of Victoria, 1963; No.857, Zone 7), an excerpt of which is shown in Figure 2-2 (Reedy Lake outlined in red). It is bounded to the west, north and east by older (Quaternary, Pleistocene) high level alluvium deposits, outwash sand gravel and clay identified as unit Q3, and to the south by the Barwon River.

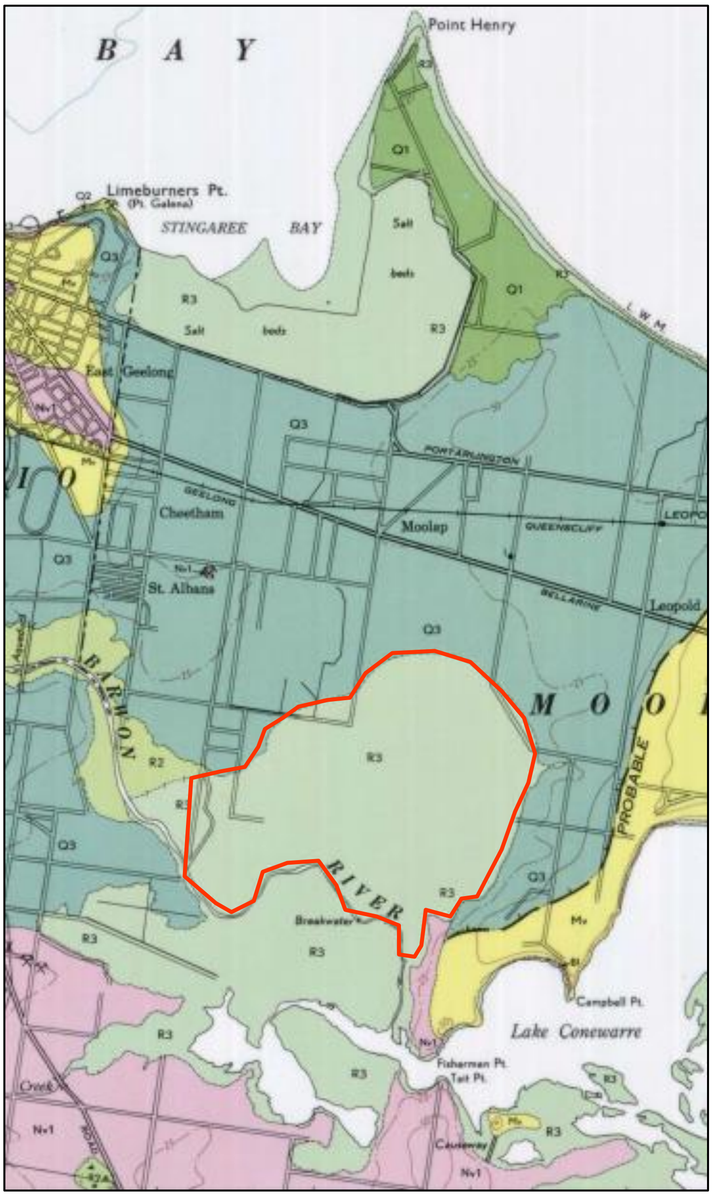

Figure 2-2 – regional geology of Reedy Lake (outlined in red) (source: Geological Survey of Victoria, 1963)

The wetland is a relatively shallow feature (Figure 2-3). The lowest point is -0.1mAHD in the 'Big Hole' whilst much of the wetland bed is between 0.3-0.6mAHD. The western-northern-eastern perimeter is typically between 0.6mAHD and 1.5mAHD There is a natural levee that runs along the left bank of the Barwon River forming the southern permitter of the wetland that is typically between 1.5mAHD and 2mAHD. Large areas of the southern perimeter range between 1.5 and 4.4mAHD.

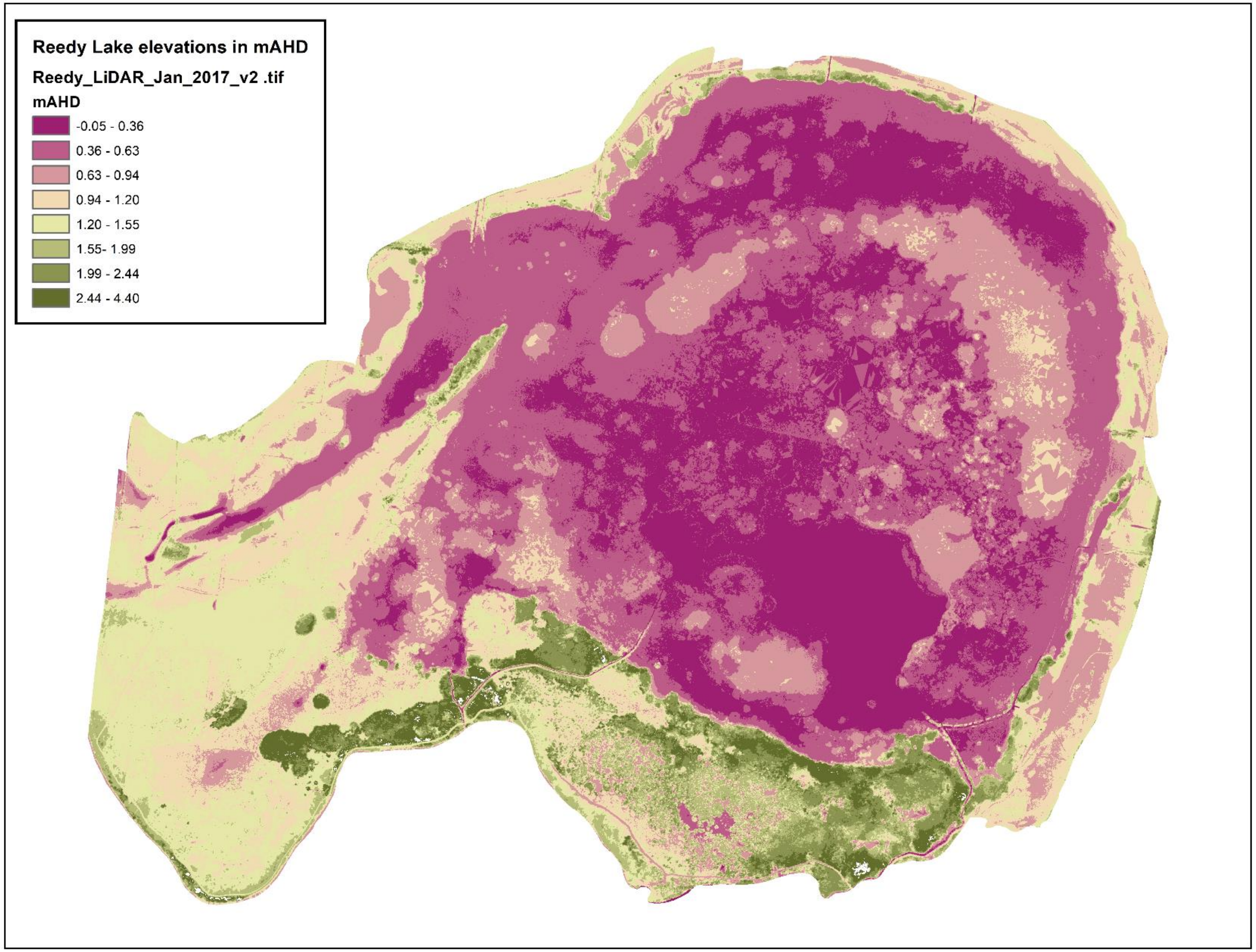

Figure 2-3 - Reedy Lake elevations derived from the 1m Digital Elevation Model (date source: CCMA, January 2017)

The lakebed comprises a veneer of silt (Quaternary paludal sediments) 0.1 to 0.2 m thick. This is underlain by a bed of sands and shells (coastal lagoon deposits) generally 1 to 2 m thick. Siltier sediments lie below these sands to a depth of 4 to 6 m. Below this lies a layer of highly plastic clay (Fyansford formation) more than 4 m thick, whose surface is at -0.2mAHD. The sands and shells are very porous. Together with the underlying silts, they form an aquifer, perched above the clay that is restricted in extent to the wetland basin.

The surface silts are not expected to significantly impede the hydraulic connection between the lake water and the aquifer. However, the underlying clays are likely to prevent any significant exchange with deeper regional aquifers below the lakebed. (Miner, 2006 in Ecological Associates, 2007). This perched aquifer receives recharge water from three sources: the regional aquifer that discharges at the base of the scarp that runs around the western-northern-eastern perimeter of the wetland, and from the Barwon River and from Lake Connewarre to the south. The shallow groundwater system flows in a southerly direction towards Lake Connewarre and is rapidly recharged by wetland filling events.

2.3 Site hydrology and modifications

2.3.1 Water level monitoring

Reedy Lake has a small local catchment of 27km^2 but is flooded almost entirely by water from the Barwon River (Ecological Associates, 2007). Water levels (to mAHD) from the Barwon River at the lower barrage (gauge 233269; introduced in 2012) are shown in Figure 2-8 for the period 2016 to 2022. Water level monitoring was introduced in 2016 in the 'Big Hole' in Reedy Lake at gauge (233603) which also records water levels to mAHD. The period 2016 to 2022 is shown in Figure 2-9. The records illustrate the seasonality in flows of the Barwon River and the effect of the environmental watering regime in Reedy Lake from 2016 to 2019. Both sets of records also show the period of wetter years from 2020 to 2022, courtesy of La Nina.

2.3.2 Water level history

Previous reports state that a constant water level of approximately 0.8 m AHD was maintained from around 1970 to 2006 except for two periods when the wetland was purposefully drained in 1995/96 and 2005/06.

2.3.3 Modifications including inlet and outlet channels and water level controls

Wetland inflows

Water enters the wetland in three ways:

- when water levels in the Barwon River exceed 1.7m AHD (Water Technology, 2011) sufficient to overflow the low points in the natural levee that runs between the river and Reedy Lake along its southern margins, upstream of the barrage. This typically occurs during winter and spring high flows. The lower Barwon River barrage/weir (originally constructed in the 1860s, modified in the 1920s and 1960s, completely rebuilt in 2021) has raised upstream water levels in the river which increases the frequency with which high flows from the river can enter the wetland. Water level monitoring shows the wetland is quickly filled by overbank flow events from the Barwon River, with the median number of such events each year being three, and typically occurring between July and October;
- when the height of the penstock flow regulator on the 1200mm box culvert on the inlet channel (originally constructed in 1953 and modified in the 1960s and 70s and again in 1997) situated upstream of the Barwon River weir (Figure 2-4) is adjusted to allow water into the wetland from the Barwon River weir pool, which sits at a level of 0.87mAHD. The inlet channel has an invert of approximately 0.1mAHD. The environmental entitlement for the lower Barwon River wetlands (refer 2.3.4) allows water to be diverted from the Barwon River into Reedy Lake when river levels are above 0.7 m AHD (Water Technology, 2022).

- Tidal influence is achievable when the wetland is fully drawn down and the outlet channel is open to Lake Connewarre

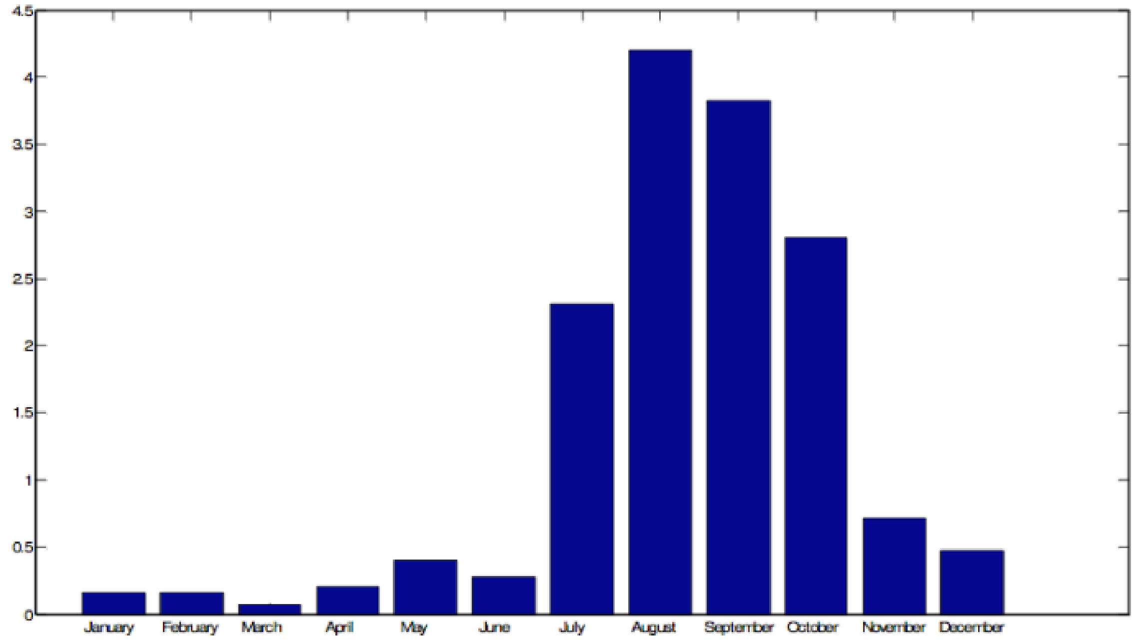

Figure 2-4 – mean number of overbank flow days per year (1955 to 2010) highlighting the period where high-flow inflow events to the wetland from the Barwon River are most likely to occur (Water Technology, 2011).

Figure 2-5 – inlet channel and penstock regulator (water level at time of image (21/04/23) was 1.0mAHD)

Wetland outflows

Since 1967-78, saline water from high tides in Lake Connewarre has not been able to naturally enter the wetland from downstream due to the construction of an earthen embankment across the natural outlet sill (with an original surface level of approximately 0.5mAHD) designed to retain water within the wetland.

Water leaves the wetland in two ways:

- Via an outlet channel (constructed in 1996) with an invert of approximately 0.1mAHD that allows the wetland to be drained when water levels in the Barwon River and downstream Lake Connewarre are low. The outlet channel is also regulated so that water can be held in the wetland to 0.8mAHD as part of the environmental watering regime.
- Reedy Lake can fill to levels up to ~1.1mAHD and eventually spill over the earthen embankment across the outlet sill (located downstream of the barrage) to the Barwon River and Lake Connewarre

Tidal influence is achievable when the wetland is fully drawn down and the outlet channel is open to Lake Connewarre.

2.3.4 Environmental entitlement

The environmental entitlement for the lower Barwon wetlands does not provide access to water held in storage. Instead, it allows water to be diverted from the Barwon River into Reedy Lake and Hospital Swamps when river levels are above 0.7 m AHD (Australian Height Datum). High water levels in the Barwon River can also result in the natural wetting of the wetlands (VEWH, 2022[2]).

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[2] https://www.vewh.vic.gov.au/rivers-and-wetlands/central-region/lower-barwon-wetlands

Figure 2-6 – outlet channel and regulator (21/04/23)

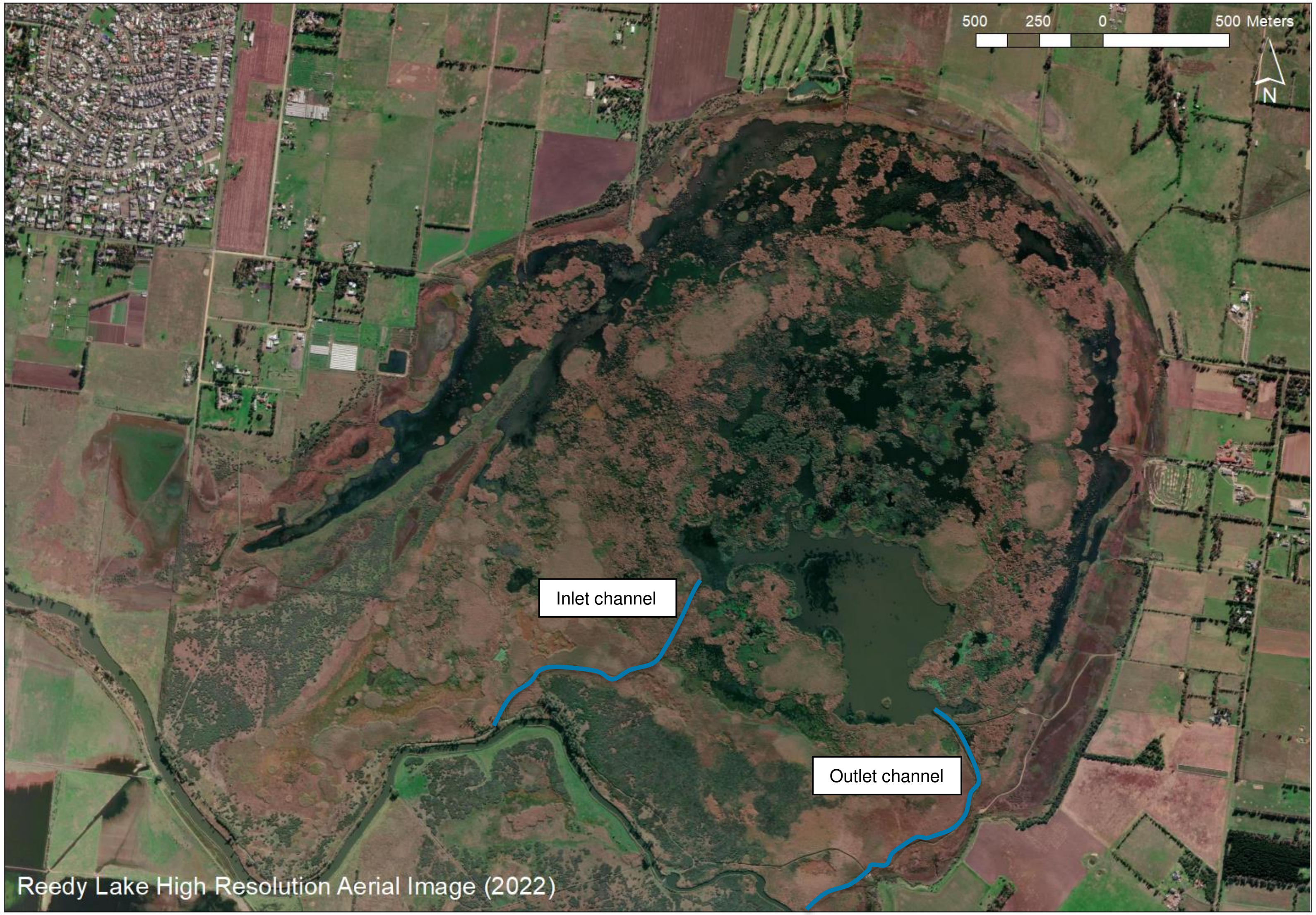

Figure 2-7 – inlet and outlet configuration for Reedy Lake

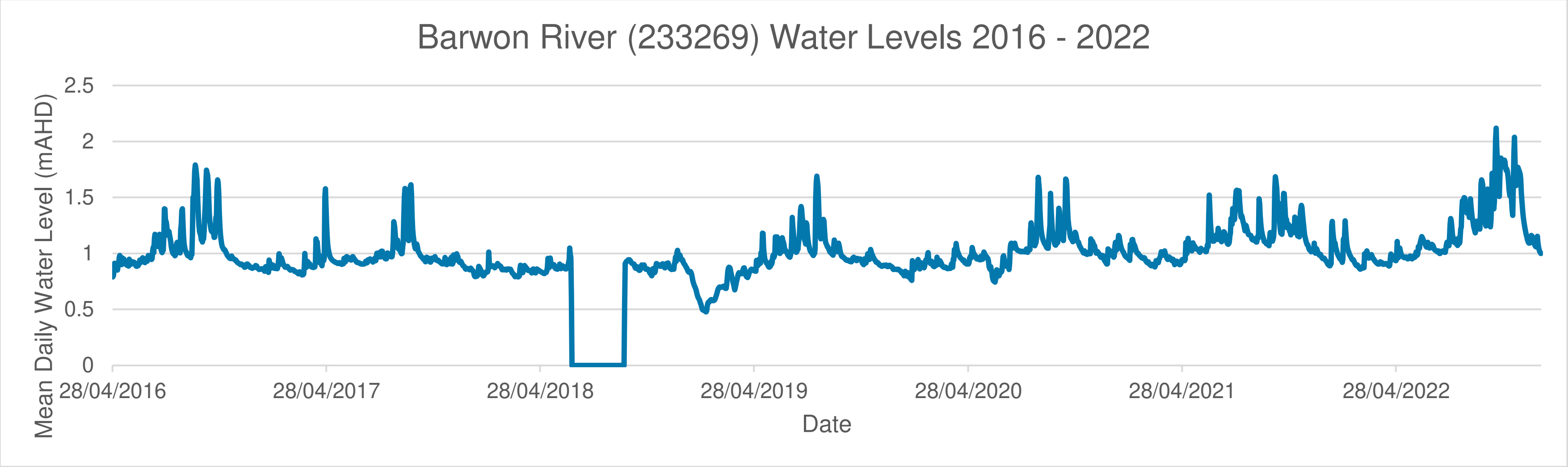

Figure 2-8 – Barwon River (233269) water levels to mAHD (2016-2022)

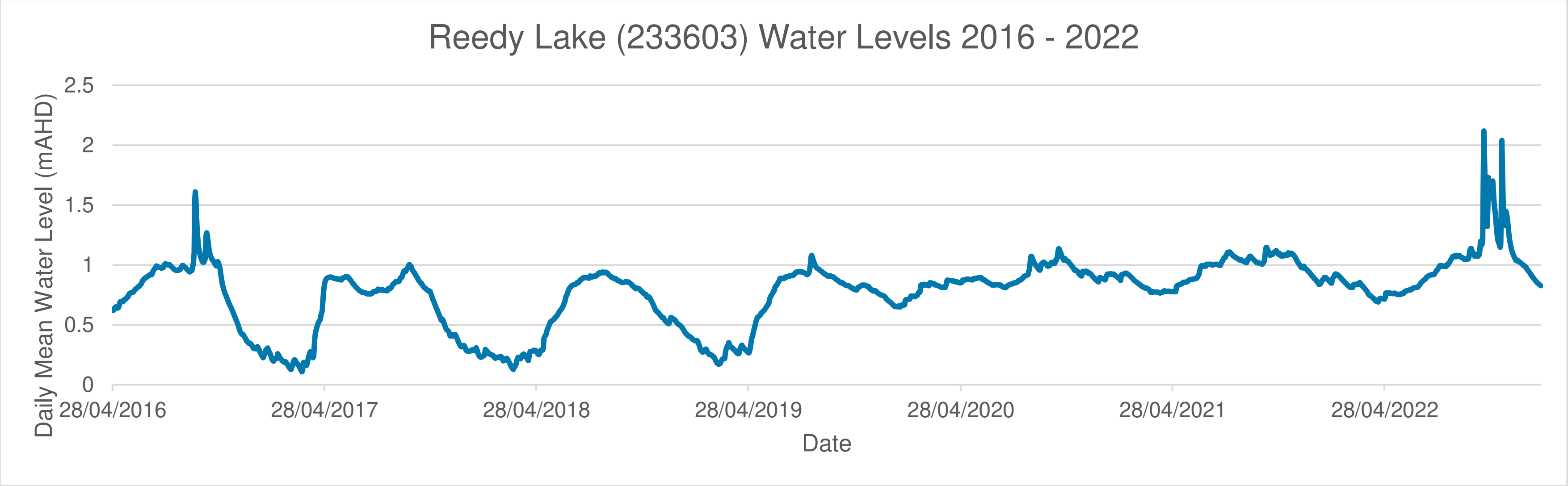

Figure 2-9 – Reedy Lake (233603) water levels to mAHD (2016-2022)

2.3.5 Water extents

According to Ecological Associates (2007) when the water level reaches 0.4mAHD, approximately 356Ha (or 63%) of the wetland area is inundated. The outlet structure allows water to be retained to 0.8mAHD, when the wetland is flooded to an area of 565Ha[3]. The earthen embankment across the outlet sill allows water to be retained to 1.1-1.2mAHD.

For illustration purposes, the water extent for 0.8mAHD is shown in Figure 2-10.

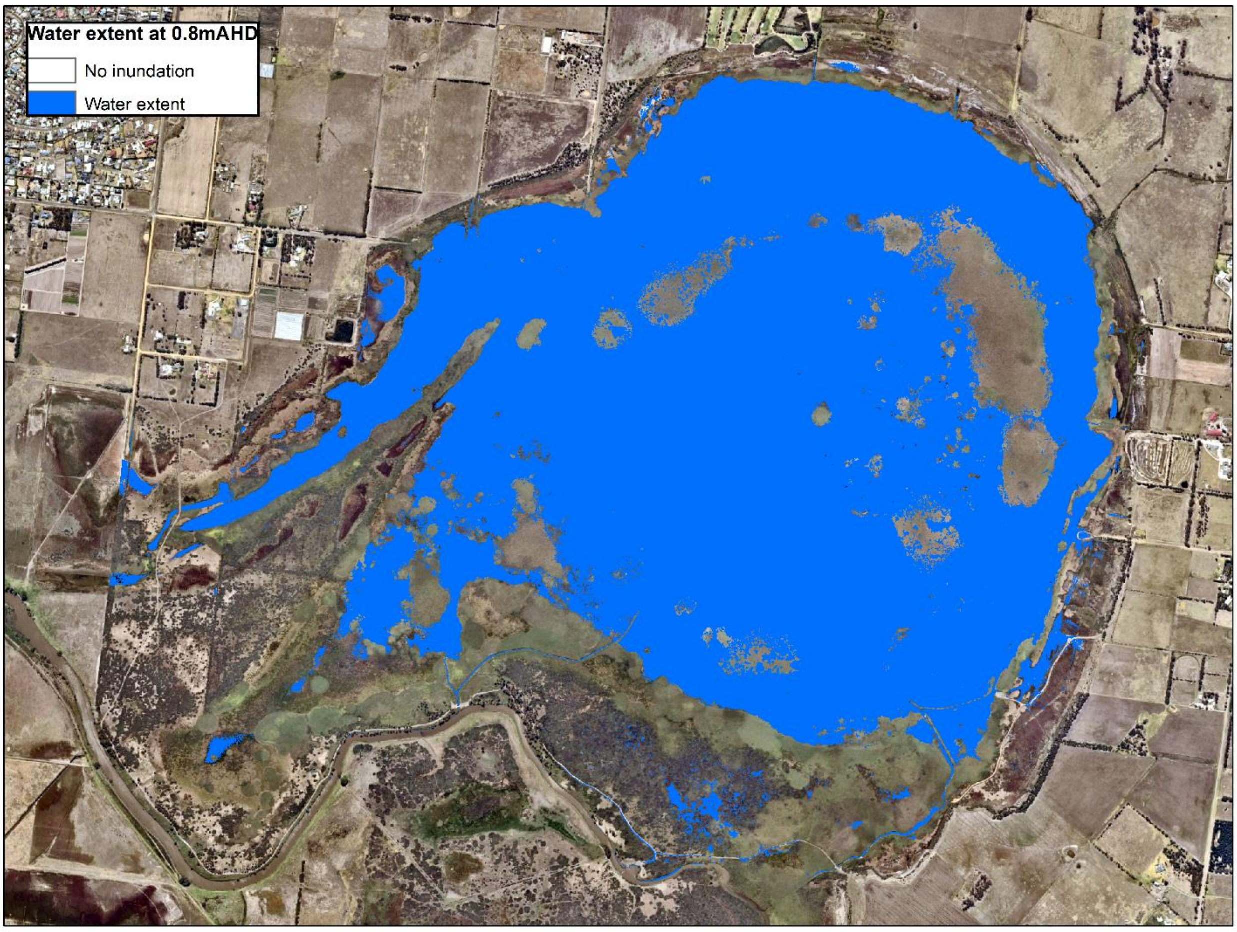

Figure 2-10 – Reedy Lake water extents to mAHD derived from the 2017 1m Digital Elevation Model overlaid onto 2021 high resolution aerial photography (source: Nearmap)

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[3] Note. The wetted area (565Ha) of the wetland at 0.8mAHD is often quoted as the area of the wetland, however there are significant areas of vegetation at Reedy Lake at elevations above 0.8mAHD. This area is therefore different to the total area of the wetland at approximately 876Ha (Figure 2-17). This larger area was adopted in this study, because it was used for previous vegetation mapping, and includes all vegetation communities of interest.

2.4 Key environmental variables influencing vegetation

Previous reports and research have highlighted the importance of wetland water levels, rainfall, temperature, and salinity at Reedy Lake and other wetlands as being key influences on the location of different vegetation classes within wetlands, and potentially exerting controls on their extent based on the habitat preferences and tolerances of the key plant species comprising the vegetation classes of interest.

2.4.1 Water levels

Water levels control the extent and depth of inundation across Reedy Lake. Inundation depth and frequency are key determinants of plant health.

2.4.2 Rainfall

Local rainfall is important for wetting soil profiles and maintaining vegetation in and around the wetland, especially around the permitter at elevations above 0.8mAHD where inundation from high water levels infrequently reaches. Rainfall patterns may affect antecedent soil conditions prior to inundation events within the wetland, however the wetting effect of rainfall is typically exceeded by evapotranspiration rates.

2.4.3 Temperature

Soil and water temperatures are important in relation to the lifecycles of wetland vegetation, particularly temperatures at the start of the growing season in Spring, which typically need to be >20°C; and sustained throughout the growing season, which for many vegetation types extends through summer into early Autumn at Reedy Lake. Although above ground biomass dies off for many vegetation types at Reedy Lake during winter, there is still important growth occurring below ground in the rhizomes of these plants.

2.4.4 Soil salinity and groundwater

The basin of Reedy Lake forms a topographic low in the regional landscape that acts as a groundwater discharge zone, with flow from several groundwater systems converging and terminating at or around the wetlands (Ecological Associates, 2014). According to Ecological Associates (2007) an initial assessment of the role of surface and groundwater in the wetland ecosystem (Lloyd Environmental 2005) suggested that groundwater salinity is important in determining the distribution of reeds.

The north western, northern and eastern perimeter of the wetland is subject to shallow saline groundwater that promotes the growth of plants tolerant of high salinities and waterlogging, such as coastal saltmarsh (Ecological Associates, 2007). Less saline conditions persist along the southern perimeter of the wetland with shallow fresh groundwater present as evidenced by the large stands of sedgeland (dominated by *Bolboschoenus caldwellii*), and Phragmites and Typha on the natural levee between the wetland and the Barwon River.

When groundwater electrical conductivity (EC) in the Reedy Lake boreholes was measured in 2007, the water table was at -0.6mAHD under the ‘Big Hole’ with EC around 20,000, increasing to over 70,000 EC[4] towards Lake Connewarre at the same depth. EC was much less (<4,000) near the inlet channel and the water table was at the same level as the invert of the inlet channel at -0.1mAHD. As evidenced by the monitoring completed in 2007, ground water table levels increase as the wetland refills, with resulting water table heights in bores being equivalent to wetland water levels.

According to Ecological Associates (2007) groundwater salinity appears, in general, to be close to the limit tolerated by both Typha and Phragmites under normal growing conditions. Both species prefer salinities of

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[4] Note. The salinity of seawater is typically ~50,000EC

less than 5000EC but tolerate salinities of up to 20,000 EC (Lissner and Schierup 1999), a conductivity like that reported under the ‘Big Hole’. Rooting depths for both species were observed by Ecological Associates (2007) to be between 0.3m and 1.0m below surface depending on location, so they can access shallow groundwater. It is likely that shallower rooting occurs over more saline groundwater and deeper rooting over fresher water. Rooting depth may also influence the permanence (resilience) of the stands of reed.

Higher groundwater salinities will likely prevent reeds spreading to higher elevations and the observed 2007 extent of reeds in many areas around the north western, northern and eastern permitter appeared limited to 0.3-0.5mAHD, which is assumed to be due to the influence of saline groundwater discharge from the regional aquifer to the north, limiting the suitability of conditions for reeds that would otherwise be favourable up to 0.8mAHD in the absence of this influence (Ecological Associates, 2007).

Around the south eastern permitter of the wetland, the upper elevation limit is equivalent to the highest wetland water levels (i.e., at around 0.8mAHD). 0.8mAHD is an important threshold because it represents a limit to the extent of wetland over which freshening of shallow saline ground water can regularly occur during filling events. At surface elevations above 0.8mAHD, groundwater can become hypersaline due to the action of processes that increase salt concentrations in the soil that then get flushed back into groundwater[5]. Intrusion of saline water from Lake Connewarre appears to have a strong influence on groundwater salinities underneath and in the south eastern part of the wetland.

In contrast, reeds have colonised significant areas above 0.8mAHD to the west and south-west of the wetland, displacing some areas originally vegetated by Lignum overstorey with grassland understorey. The groundwater salinity is much lower in this area, with a reported conductivity of 3680 EC. This is likely to reflect the freshening effects of the Barwon River above the lower breakwater on the Reedy Lake aquifer. The breakwater maintains the river level at or above the normal level of Reedy Lake, creating a hydraulic gradient away from the river. Fresh river water recharging the banks will displace saline groundwater and will create a flushed zone (Ecological Associates, 2007). This shallow, fresh groundwater is likely to have supported the spread of reeds in this area, even though it is not subject to frequent inundation. Reeds have also colonised areas adjacent to the outlet channel because of the freshening effects of water flows through the outlet.

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[5] In shallow groundwater conditions, water and dissolved salts move by capillary action to the soil surface. When the water evaporates from the surface, the salts are left behind. The excess salts prevent plant roots from making use of water in the soil.

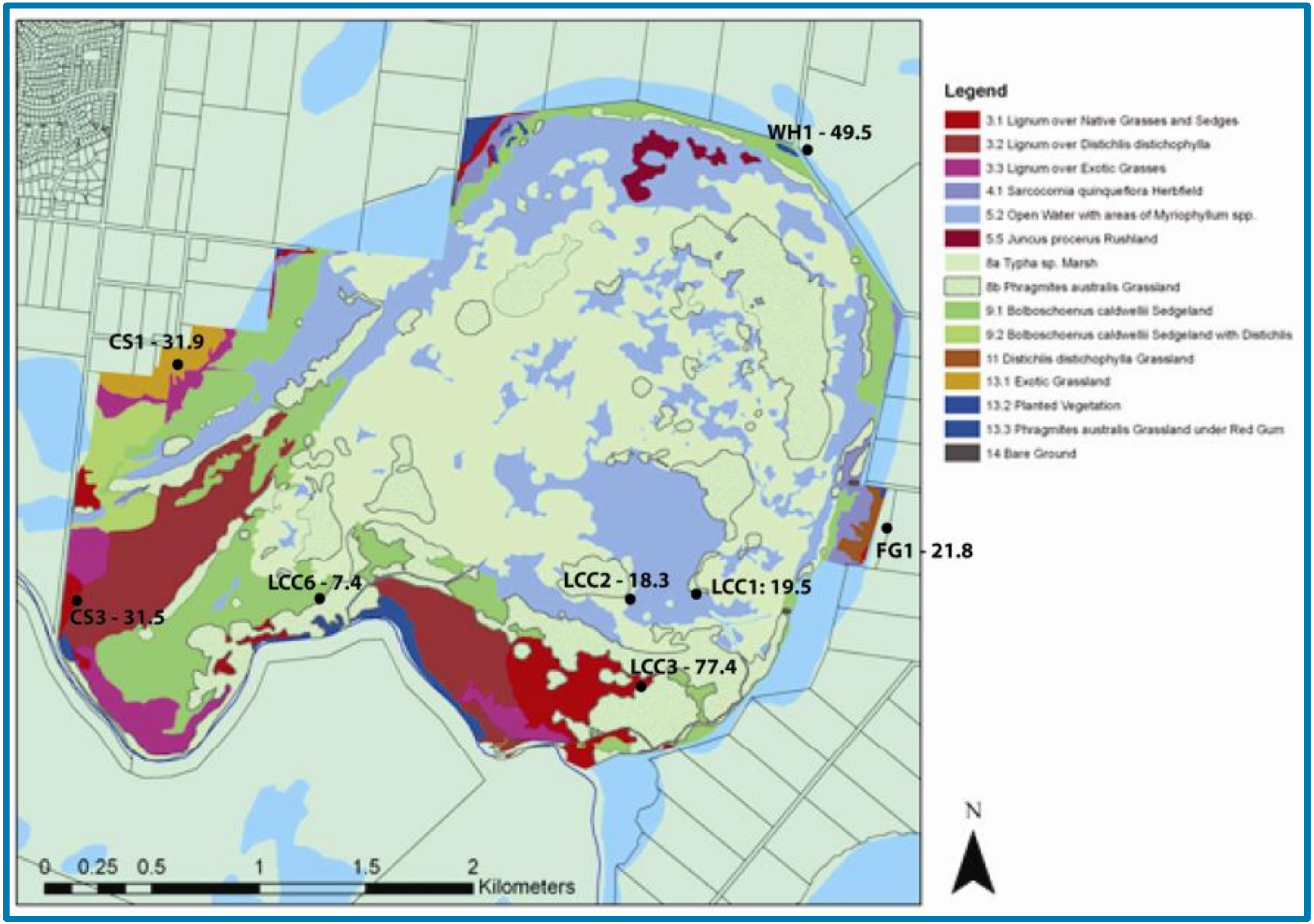

Figure 2-11 – location of groundwater bores where salinity was measured (source: Figure 15, Ecological Associates, 2014)

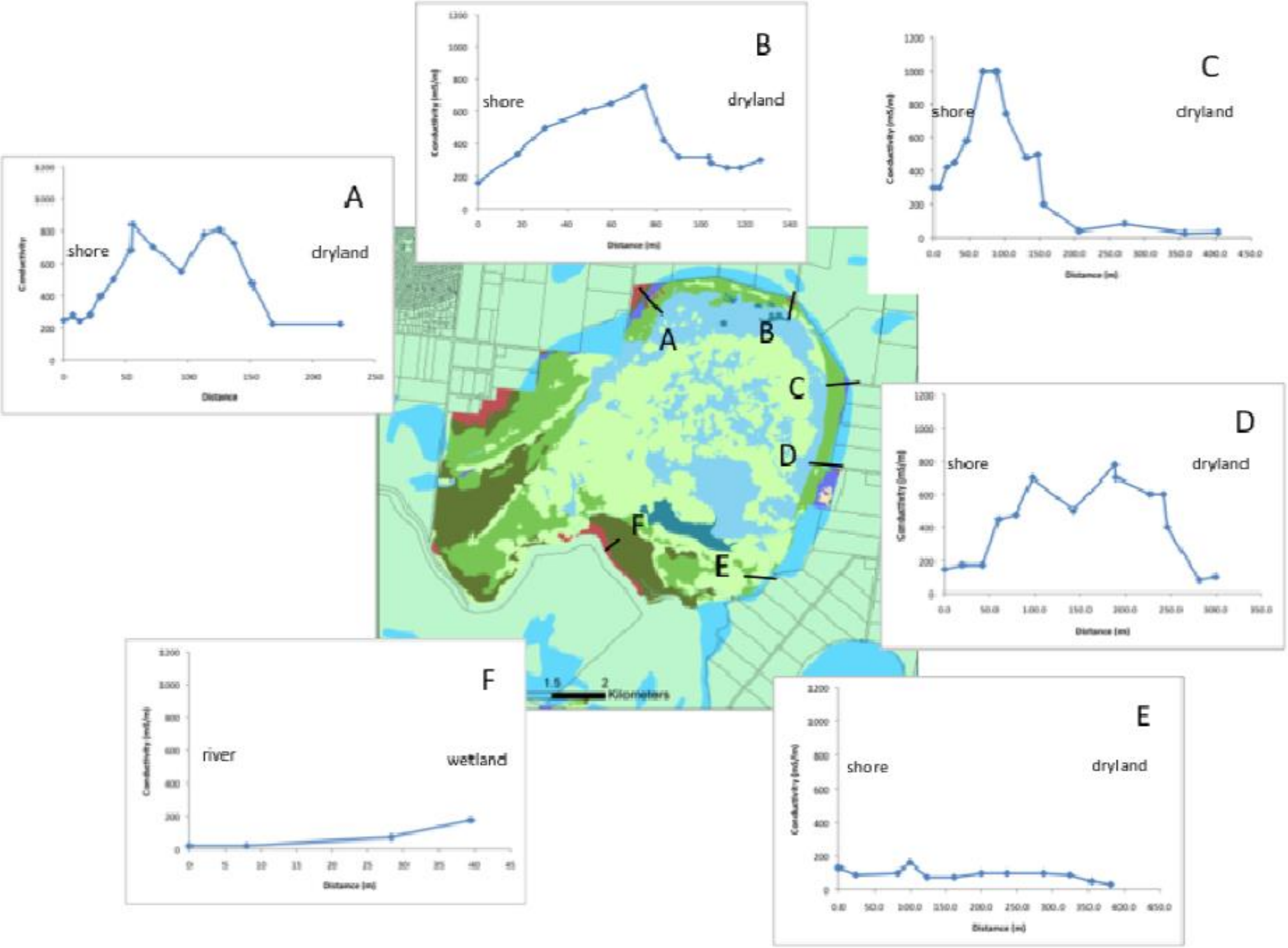

Figure 2-12 – Soil conductivity transects at the lake perimeter (Ecological Associates, 2014; Figure 9, p17). A. Moolap Station Road. B. Whitehorse Road. C. O'Halloran Road. D. Fitzgerald Road. E. Outlet Track. F. Riverbank near inlet. C. O'Halloran Road. D. Fitzgerald Road. E. Outlet.

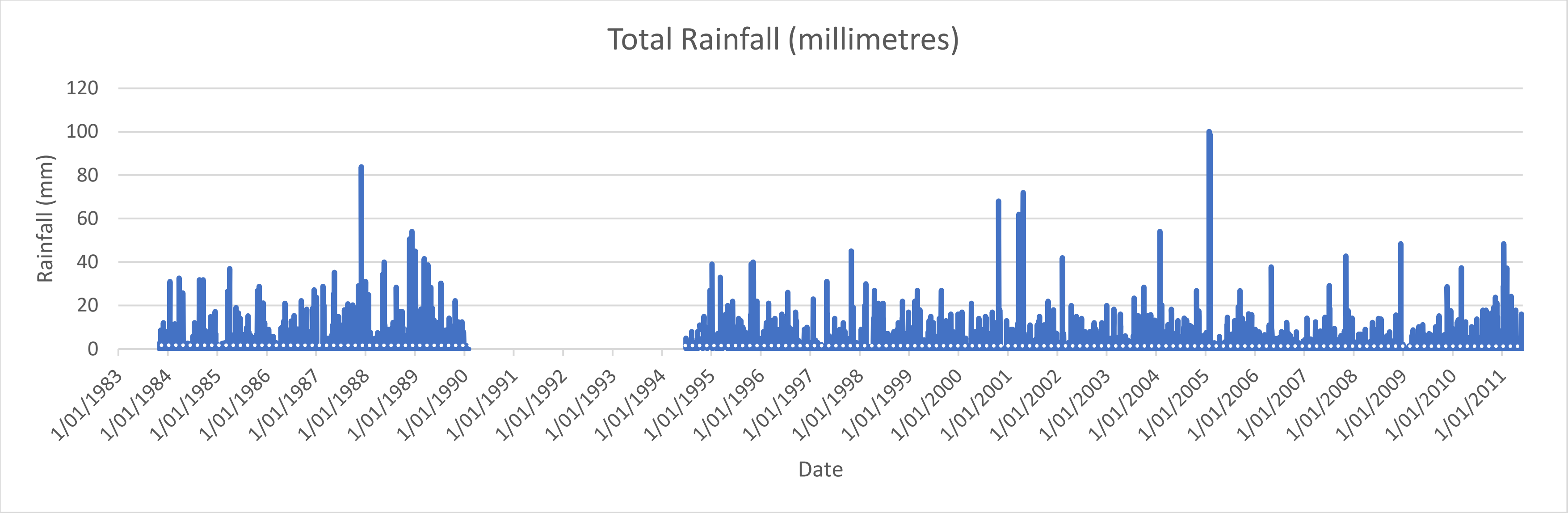

Figure 2-13 – rainfall records (1983 to 2011) from the Grovedale gauge

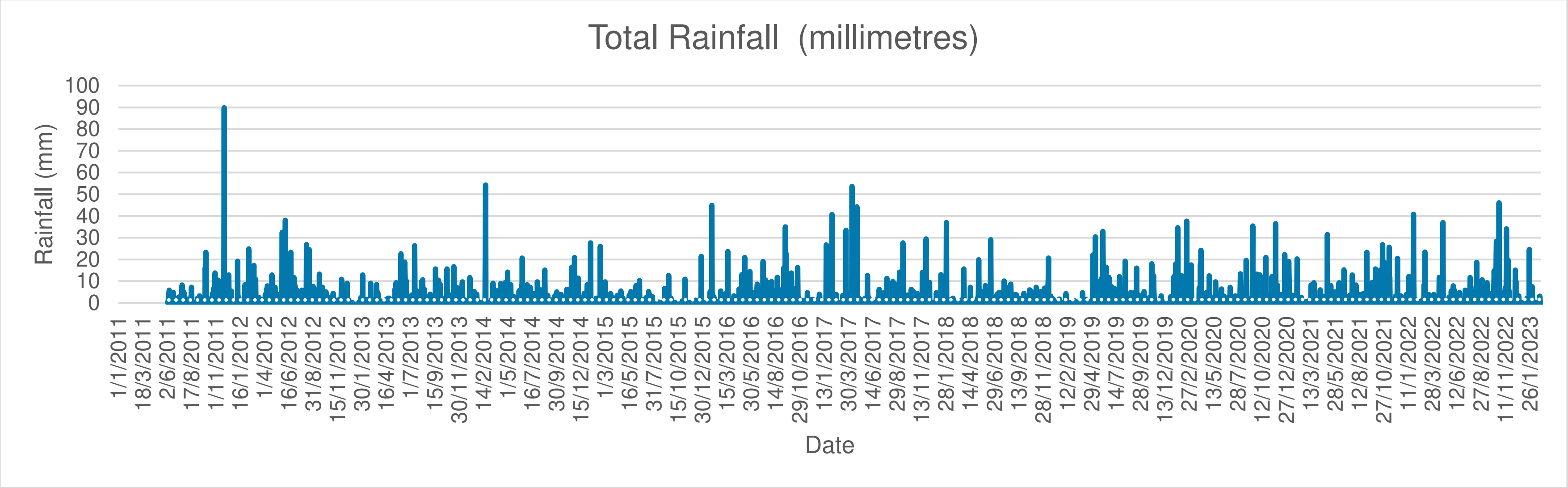

Figure 2-14 – rainfall records (2011 to 2023) from the Geelong Racecourse gauge

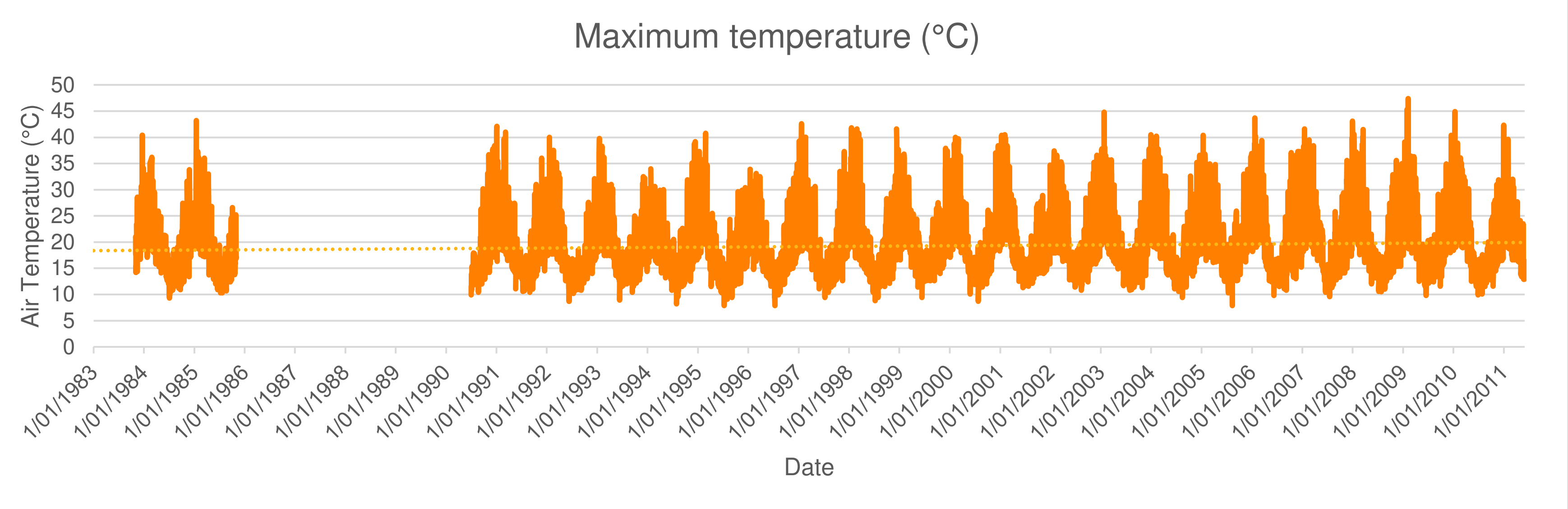

Figure 2-15 – temperature records (1983 to 2011) from the Grovedale gauge indicating a trend towards increasing maximum temperatures

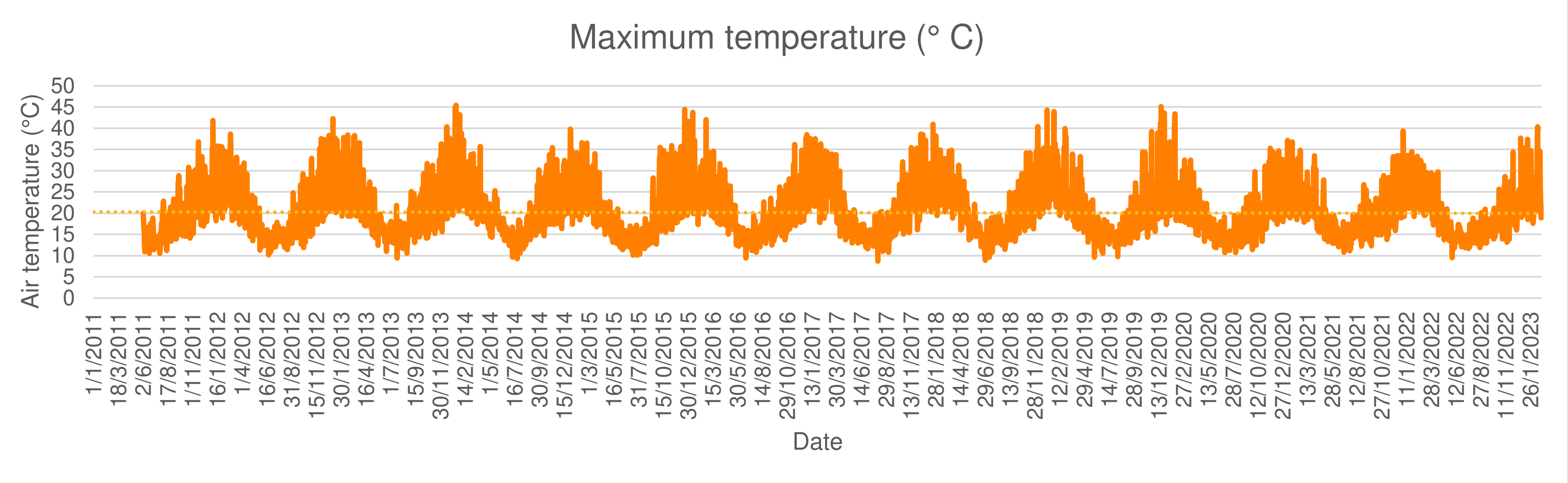

Figure 2-16 – temperature records (2011 to 2023) from the Geelong Racecourse gauge indicating no significant trend in maximum temperatures

2.5 Previous vegetation extent mapping

Reedy Lake has been the subject of five previous vegetation mapping exercises, as shown in **Error! Reference source not found.**.

Table 2-1 – previous vegetation mapping reports

Report Date	Report Title	Primary Author(s)
1985[6]	The vegetation at Lake Connewarre State Game Reserve	J. Z. Yugovic (Arthur Rylah Insititute)
2007	Reedy Lake groundwater and ecology investigation	Ecological Associates
2010	Vegetation mapping of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site	S. J. Sinclair (Arthur Rylah Insititute)
2014	Reedy Lake vegetation monitoring	Ecological Associates
2021	Wetland monitoring and assessment program for environmental water: stage 3 final report	P. Papas (Arthur Rylah Insititute)

All of these vegetation mapping exercises worked off a total wetland area of 876Ha as shown in Figure 2-17.

The series of figures below are taken from these respective reports and serve to illustrate two things:

1. The differences in vegetation mapping approach used. Some studies focus on Tall Reed or Tall Marsh only. Other studies focused on mapping the suite of Yugovic equivalent vegetation classes and others on the suite of wetland Ecological Vegetation Classes. It can be difficult to reliably compare changing extents given the different mapping methods and focus of these different studies. A key example is the vegetation class termed ‘Typha association’ which includes other species (not just Typha) and open water and thus does not represent absolute cover of Typha in the same way that the absolute cover of the dense Phragmites stands is represented in the same mapping. Also, some studies combine Phragmites and Typha into one class and others distinguish between the two species.
2. There have been changes in the extent of different vegetation classes according to the mapping, but these changes may be as much an artefact of the classification and mapping approach used as much as an actual change.

Because of these constraints, the areas (in Ha) of the key vegetation classes reported from these different reports should therefore be treated with caution. It is fair to use these reported areas as being indicative of the extent at the time of mapping, but they are not suitable for reliably assessing extent changes over time.

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[6] Note, the fieldwork and aerial photo capture used for interpretation was conducted in 1983.

Figure 2-17 – total area of Reedy Lake for wetland vegetation mapping purposes (consistent across all previous reports and this study)

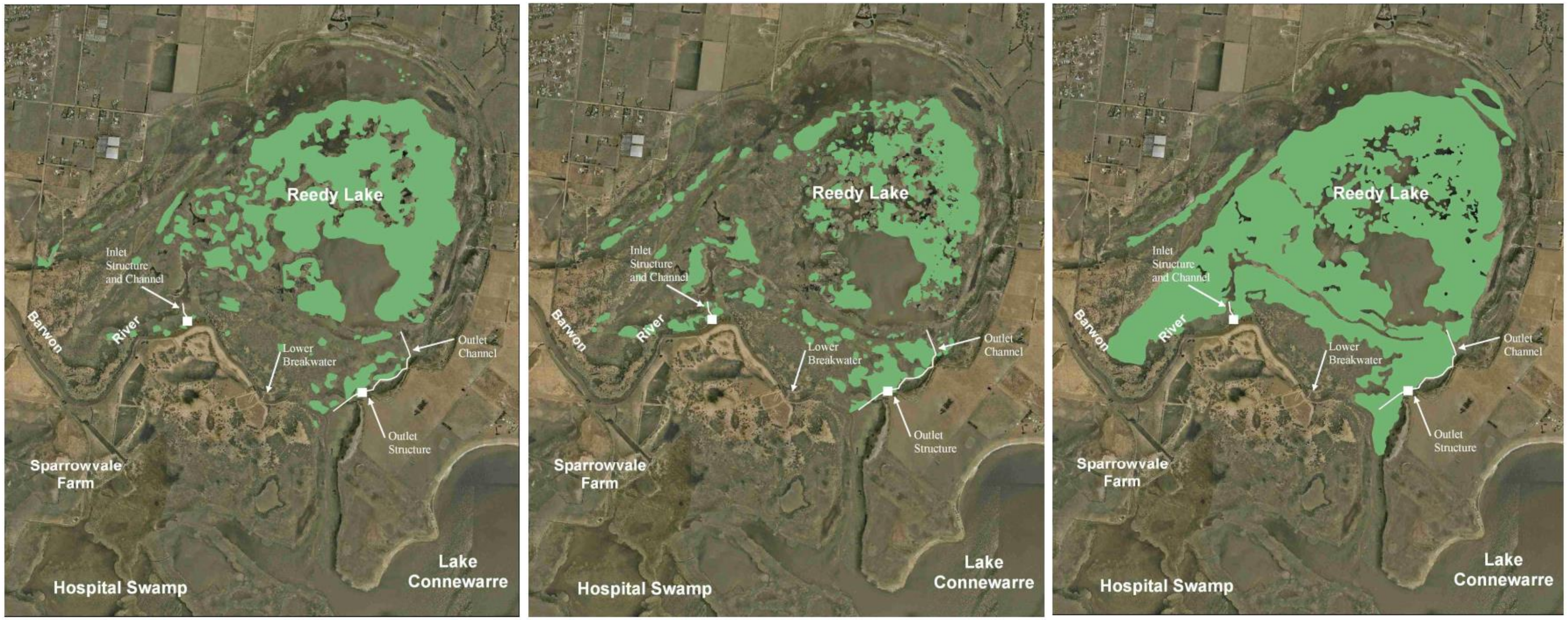

Figure 4. The extent of reeds (*Phragmites* and *Typha*) in 1984 overlayed on 2004 photography.

Figure 5. The extent of reeds (*Phragmites* and *Typha*) in 1995 overlayed on 2004 photography.

Figure 6. The extent of reeds (*Phragmites* and *Typha*) in 2004 overlayed on 2004 photography.

Figure 2-18– Extent of Tall Reed (Phragmites and Typha) from Yugovic (1983), and as mapped from 1995 and 2004 aerial imagery, all imposed over 2004 aerial imagery (by Ecological Associates, 2007). This mapping was completed by Ecological Associates as part of their work in 2007 and served to illustrate the change in Tall Reed only at these three timesteps.

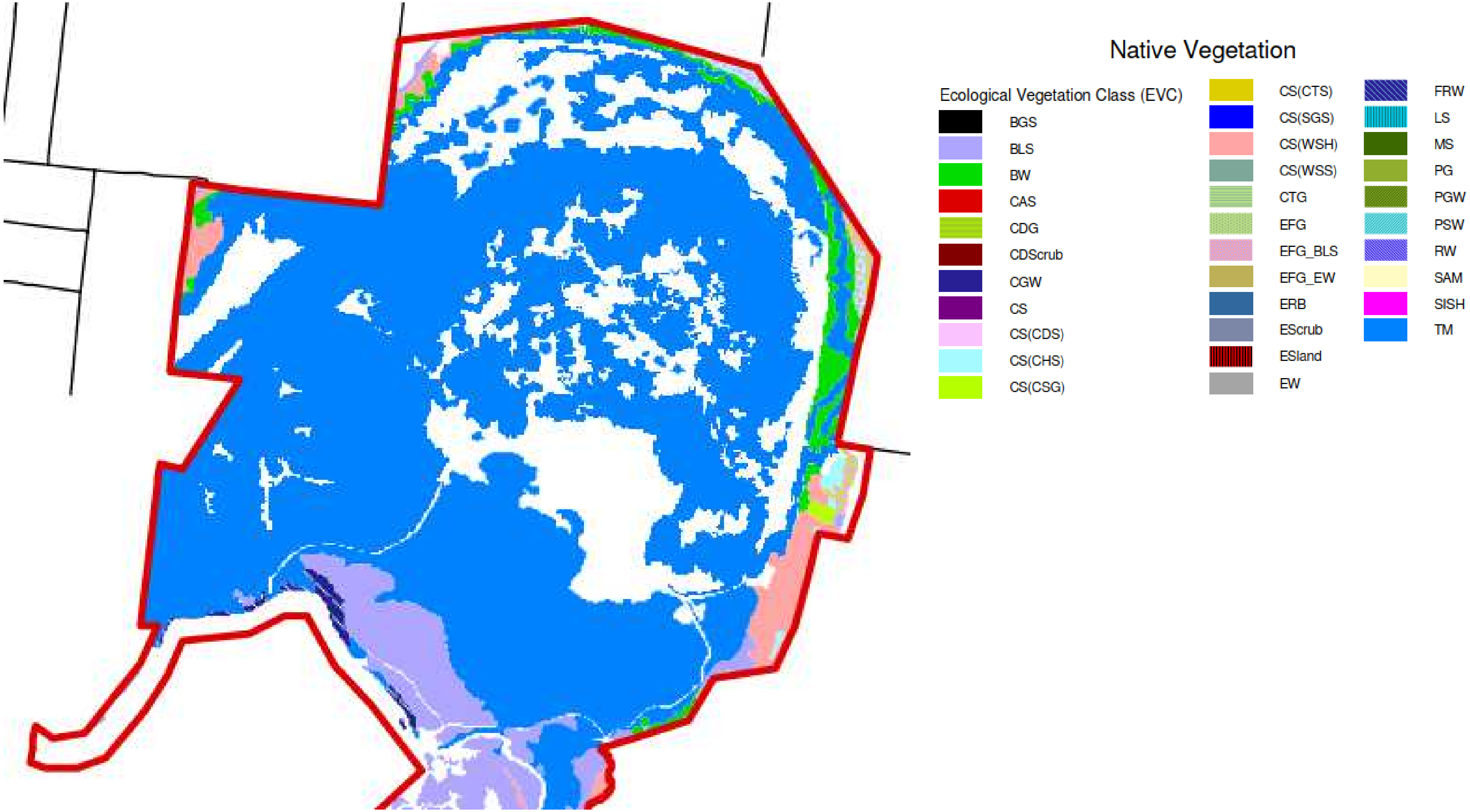

Figure 2-19 – extent of Tall Marsh (Phragmites and Typha) and fringing vegetation (by ARI, 2010). Note: Phragmites and Typha were mapped as a single unit due to the limitations of image quality (Ecological Associates, 2014). This mapping shows Tall Reed as one single unit but also identifies other Ecological Vegetation Classes (EVC) around the wetland perimeter.

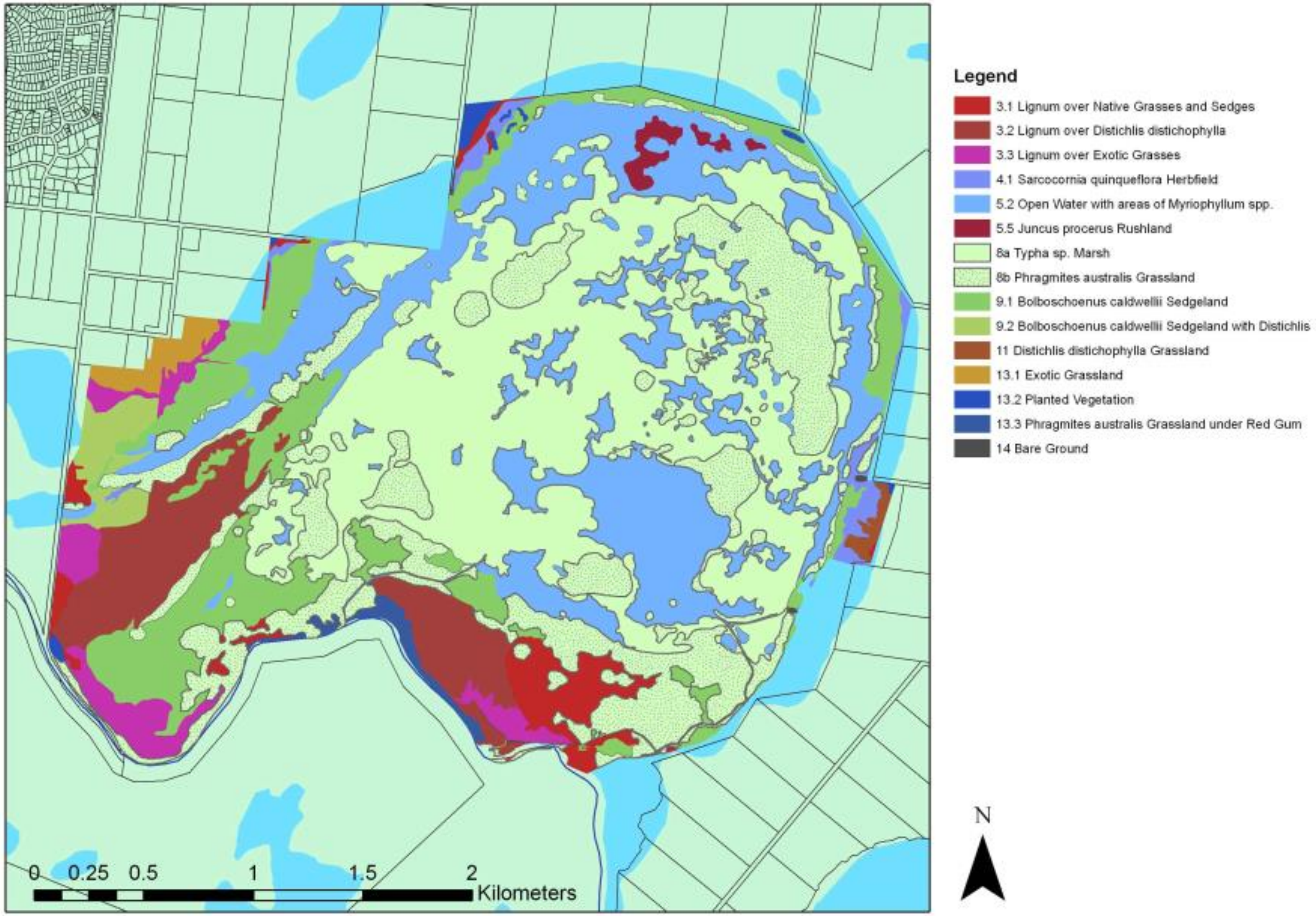

Figure 2-20 – Ecological Associates (2014) mapping of vegetation extents in 2012. This mapping split Tall Reed into Phragmites and Typha and identified other vegetation classes of interest to the Limit of Acceptable Change.

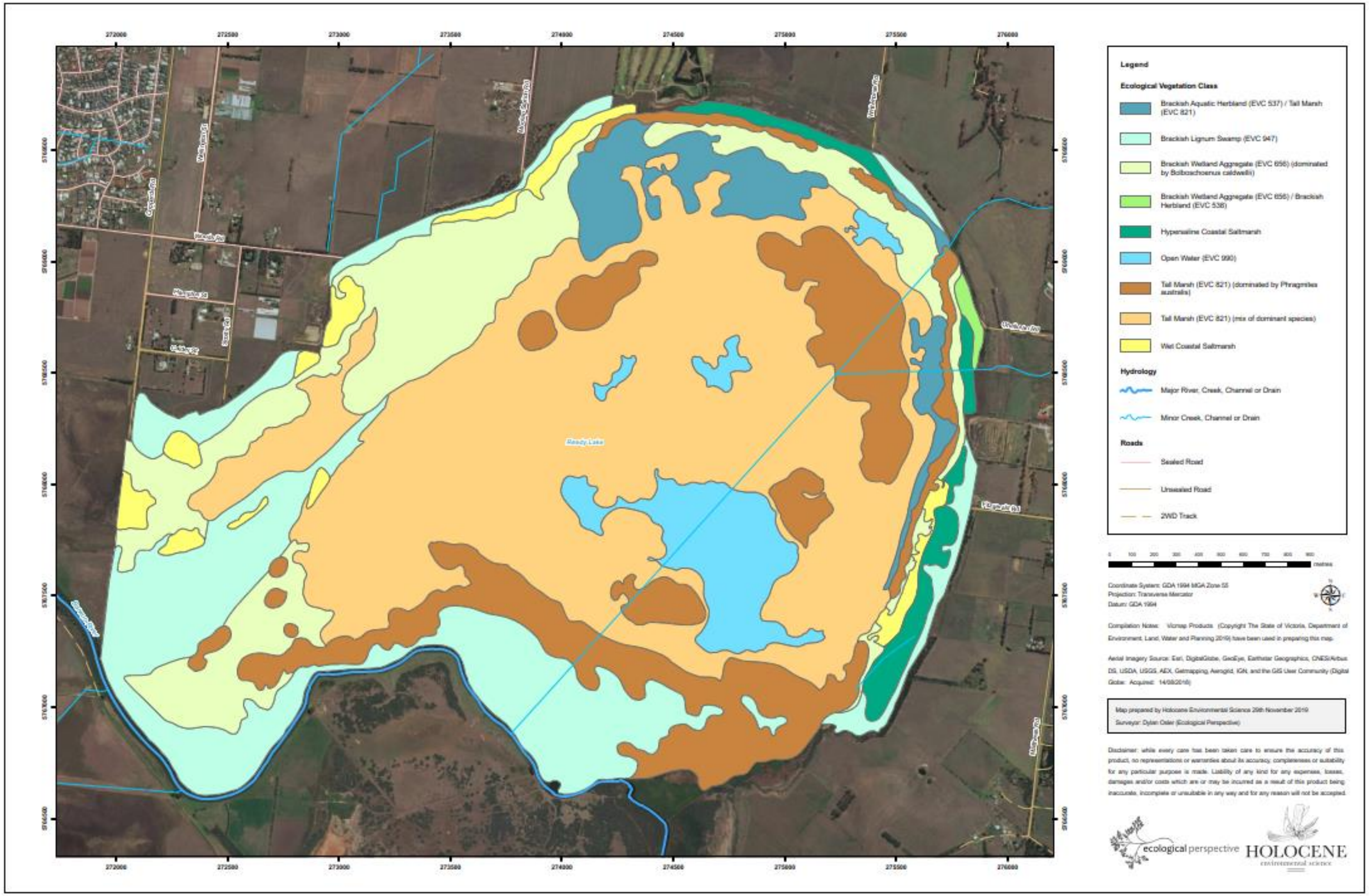

Figure 1 Ecological Vegetation Classes, Reedy Lake, Moolap, November 2019

Figure 2-21 –Ecological Perspectives mapping (2019). This mapping identified vegetation classes of interest to the Limit of Acceptable Change

2.6 Lifecycle character and habitat preference of the vegetation types in this study

A focus of the previous studies has been on tall reeds due to concerns that they have been expanding in extent at the expense of more diverse freshwater vegetation communities that require areas of open water to flourish. The changing extent of reeds since 1983 has not been constant and gradual but has involved significant variation. Some of this variation has been attributed to carp infestation and grazing practices no longer influencing the wetland and some has been attributed to variation in the lake water regime and the resulting balance of fresh and saline water because of works to permit artificial adjustment of water levels. Reeds are an important component of the lake ecosystem. Reed beds provide habitat for cryptic waterbirds, such as Australasian bittern, and provide sheltering and feeding habitat for frogs. Swamp harrier nest in the reeds. The stems and leaves provide nesting materials for waterbirds such as straw-necked ibis (Ecological Associates, 2014). The issue is not the presence of reeds, but their potential to dominate the wetland cover.

2.6.1 Tall Reed: Phragmites australis

The largest beds of Phragmites form a fragmented semi-circle in the north of the wetland. This feature has been present since before 1983 (Figure 2-22). Phragmites stands are typically dense and continuous. Other stands occur in the south of the wetland and on the natural levee along the Barwon River.

According to Ecological Associates (2014):

- Phragmites plants near the inlet grew very tall and at low densities but with large leaves. These plants are growing above the full supply level of the lake but have access to relatively fresh groundwater (sampled at bore LCC6 with 7.6 mS/cm within 0.5 m of the surface: Figure 2-11).
- Plants on the northern and eastern edge of the lake tended to be shorter and grow at high densities with small leaves. The groundwater in these areas is generally more saline
- Plants growing in flooded areas of the lake bed, along the inlet channel and at the outlet were fairly similar in morphology.

Phragmites has a seasonal cycle of shoot production and senescence. New shoots are produced each year from starchy underground rhizomes in spring (September and October) reaching a maximum number of stems by November (Ecological Associates, 2014). Growth continues throughout summer with a peak by late summer or early autumn (Rogers and Ralph, 2010). Shoots develop leaves through spring and early summer then flower in late summer (January/February) and into autumn. In autumn and winter above ground shoots and stems die-off and carbon and other nutrients are relocated to underground storage tissues (roots and rhizomes). These growth stages are influenced by environmental conditions. The quantity of growth and the timing of growth phases can be affected by drought stress, flooding stress and salt stress (Ecological Associates, 2014).

The most favourable conditions for Phragmites appear to be fresh soils with shallow flooding and persistent waterlogging (Ecological Associates, 2014; Rogers and Ralph, 2010). Under these circumstances stems will grow at low densities with large leaves and tall stem heights. Stem length will increase through summer and into autumn and leaf length will peak in January. Under more stressful conditions stems will be shorter and grow at higher densities. Leaves will be shorter and reach their maximum length in late spring or early summer. It is expected that in the longer term these growth patterns will relate to a decline in the extent of Phragmites beds (Ecological Associates, 2014).

It is only in areas within or adjacent to the lake or river that the reed beds dominate; as in these areas the groundwater is fresher (intermediate between lake water and the regional groundwater) and vegetation has permanent or intermittent access to fresh surface water (Ecological Associates, 2014).

Figure 2-22 – historic panchromatic aerial photo of Reedy Lake (from 1984) showing the persistent semi-circle of Phragmites (green line)

2.6.2 Tall Reed: Typha orientalis

Yugovic (1985) observed that forming a mosaic with Phragmites across the lakebed is a structurally open, species rich association dominated by Typha and characterised by the succulent herb *Crassula helmsii* together with floating species such as *Azolla filiculoides*, *Lemma minor* and *Wolffia Australiana* and clumps of *Schoenoplectus Validus* (later reclassified as *Bolboschoenus caldwellii*).

Typha itself typically occurs at lakebed elevations below 0.5mAHD and is absent in the 'Big Hole'.

Growth forms are less easily distinguished in Typha. Ramet[7] density appeared to indicate plant vigour most reliably with high densities providing a large photosynthetic surface and growth potential. Typha stands grow in strongly cyclic phases of vigorous growth for several years followed by senescence and low ramet densities. These cycles create variation in local patches within the lake but have little bearing on the overall spread of Typha in the lake. This growth pattern can result in rings of Typha forming over time. Rapid above ground growth typically occurs in spring and early summer, while below ground growth increases after mid-summer. New shoots emerge in autumn and winter (Roberts and Marston, 2000; in Rogers and Ralph, 2010). The rhizomes and roots of Typha are buried in anaerobic sediments but they can transport oxygen from shoots to roots for growth and respiration (Brix et al. 1992; in Rogers and Ralph, 2010).

At the scale that Typha was monitored by Ecological Associates in 2014, it is possible that sites will report variation in performance that is related to the growth stage of the stand and not overall environmental conditions. Environmental stress may be better indicated by poor performance at several sites at once or by a change in overall extent, as measured by vegetation mapping.

Typha is more physiologically suited to stable, rather than fluctuating, water levels (Deegan et al. 2007; Matsui and Tsuchiya, 2006; White et al 2007; in Rogers and Ralph, 2010) and prefers water regimes from permanently wet to seasonally or periodically dry for three to four months, however extended dry periods increase the exposure to the desiccating effects of salinity resulting in above ground plant die-off (Roberts and Marston, 2000; in Rogers and Ralph, 2010). Ramets may survive dry conditions for three to four months following rapid growth in summer and rhizomes may remain viable for a few years when protected from desiccation (Roberts and Marston, 2000; in Rogers and Ralph, 2010).

Typha exhibits optimal growth in water temperatures of 25-28°C (Cary and Weerts, 1984; in Rogers and Ralph, 2010) which coincides with summer. Roberts and Marston (2000; in Rogers and Ralph, 2010) reported from field observations that inundation in spring and summer is favoured as it correlates with the growing season.

Typha is moderately salt tolerant however growth is reduced at 5000 EC and individual plants are damaged at 10000EC (Hocking, 1981; in Rogers and Ralph, 2010).

2.6.2.1 Submergent aquatic macrophytes in open water areas associated with Typha

Open water areas support semi-emergent and floating aquatic macrophytes including *Myriophyllum spp.*, *Potamogeton spp.* and *Villarsia reniformis*. These soft-leaved plants provide physical habitat and food sources for macroinvertebrates, small fish, and dabbling waterfowl. Open water habitat contributes to the species diversity of the wetland by supporting large wading and piscivorous waterbirds.

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[7] A ramet is a single physiological individual produced by clonal propagation.

> *Due to the difference in the structure of Phragmites stands and the Typha dominated vegetation association it is important to map them separately, as it is misleading to co-classify the Typha association as a Tall Reed stand where it is not dense and continuous and includes open water and other plant species.*

2.6.3 Sedges and rushes: Bolboschoenus caldwellii

Yugovic (1985) observed 80-250m wide bands of sedgeland growing in brackish water along the western, northern, and eastern shoreline of Reedy Lake. Yugovic further notes that a dynamic equilibrium operates between the sedgeland and saltmarsh (see 2.6.4) in response to the depth and periodicity of lake water levels. A broad zone of sedgeland also occurs in the southern part of the wetland.

Bolboschoenus caldwellii beds are present mainly at the upper limit of flooding. It tolerates salinity and prefers damp to wet soils in permanent to semi-permanent water around the edges of wetlands, saltmarshes, and wet depressions to a water depth of ~0.25m. This semi-aquatic perennial species typically has a short growing cycle. It emerges from bulbs in early Spring and grows rapidly to 1.2m high by 1m wide, flowering between October and April. When the weather cools, it dies back to the bulb and remains dormant over winter. Most biomass recruitment above ground is mainly from vegetative expansion (rhizomes), as this is unaffected by salinities up to 12g/L (22,000 EC) however, it has very viable seeds that can float for up to three months and thus disperse over wide areas. Seeds germinate in late spring and summer if temperatures are 20-25°C and salinities on the damp wetland surface are less than 2-4g/L (3600-7200 EC). Hatton (2009) reports that 'clonal growth is critical to population maintenance and dynamics in saline wetlands', which increase the likelihood of future vegetative offspring but is not good for genetic diversity. It allocates greater biomass to rhizomes under increasing salinity, so that when it grows under saline conditions it can achieve large population sizes and densities that are tolerant of the year-to-year changes in wetting and drying conditions.

Juncus procerus and other sedges and rushes are also present within the wetland, but less dominant.

> *Sedges/Rushes in this study is a broad class encompassing Bolboschoenus, Eleocharis, Juncus, Schoenoplectus, and other sedge and rush species present in Reedy Lake.*

2.6.4 Coastal Saltmarsh

The north western, northern and eastern shoreline of Reedy Lake is dominated by halophytes (Samphire: *Sarcocornia quinqueflora* herbfield). Salinity measurements (Figure 2-12) conducted by Ecological Associates in 2014 along transects A to D found electrical conductivity at the water's edge is relatively low, 150 to 300 mS/m ECa[8], then increases to over 600 mS/m ECa within 20 to 50 m from the lake. The zone of high conductivity extends over a further 60 to 200 m. At further distances conductivities gradually decline. Conductivities of less than 100 mS/m ECa were recorded at the end of the transects. These salinities confirm the habitat is preferable for saltmarsh around the perimeter.

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[8] ECa = Apparent Electrical Conductivity

> *Temperature Coastal Saltmarsh is listed as a vulnerable vegetation community under the EPBC Act (1999)[9].*

2.6.5 Tangled Lignum: Duma florulenta

Yugovic (1985) observed remnants of Lignum (*Duma florulenta*) shrubland over *Distichlis* grassland on elevated sites around the perimeter of the wetland. There are two large and distinct occurrences of Lignum around the southern perimeter and elsewhere around the western-northern-eastern perimeter, Lignum appears in discontinuous, narrow bands.

Lignum has a very deep rhizomatous root system, penetrating to at least 3m, and is highly tolerant of drought and salinity (State of Victoria, 2023[10]) because of its ability to access reserves of shallow groundwater. It can remain dormant during dry periods of several years and its stems and leaves grow rapidly and flower when re-flooded.

At Reedy Lake, Lignum appears to favour saline, seasonally waterlogged habitats rather than seasonally flooded areas. The expansion of Phragmites into Lignum in southern parts of the wetland suggests that the salinity of the lignum shrubland is decreasing (Ecological Associates, 2014) which is consistent with the groundwater salinity measurements in this area. Understorey species vary with salinity, hydrology and disturbance history and range from *Poa* or *Distichlis* grassland to *Halosarcia pergranulata* (*Tecticornia*) and *Bolboschoenus caldwellii*.sedgeland. This groundcover vegetation succession was observed in the field.

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[9] https://www.environment.gov.au/biodiversity/threatened/communities/pubs/118-conservation-advice.pdf

[10] https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/water_sss_lignum

3 METHODOLOGY

This section provides an overview of the various methods adopted in this study.

3.1 Satellite imagery classification of wetland vegetation extents

Aerial photo interpretation and field surveys are two traditional methods of wetland vegetation mapping. While they offer some benefits, there are also some limitations to these methods, including:

- **Limited spatial coverage**: Aerial photo interpretation and field surveys are limited in their spatial coverage. This can be time-consuming and expensive when mapping large areas.

- **Subjectivity**: Aerial photo interpretation and field surveys are subjective and can be influenced by the interpreter's biases and experience. This can lead to inconsistencies in mapping results.

- **Temporal limitations**: Aerial photos and field surveys provide a snapshot of vegetation at a specific point in time. They may not capture seasonal changes or long-term trends in vegetation patterns.

- **Difficulties in accessing certain areas**: Field surveys can be difficult to conduct in remote or inaccessible wetland areas and may not provide the level of detail needed across the entire wetland This can limit the accuracy and completeness of vegetation mapping which can result in misclassification of or the failure to detect certain vegetation types.

- **Cost**: Both aerial photo interpretation and field surveys can be expensive in terms of equipment, personnel, and time, which may be a limitation for some wetland mapping projects.

Satellite imagery can be used in combination with these methods to overcome some of these limitations and provide a more comprehensive understanding of wetland vegetation patterns and processes. Wetland vegetation mapping using remotely sensed satellite imagery offers several benefits, including:

- **Improved spatial coverage and resolution**: the imagery covers large areas and provides high-resolution (0.1m^2 to 100m^2) data. This allows for a more comprehensive and accurate mapping of wetland vegetation compared to ground-based mapping methods.

- **Cost-effectiveness**: the imagery is a cost-effective method of mapping wetland vegetation compared to traditional ground-based methods. It can cover large areas quickly and efficiently, reducing the need for expensive and time-consuming field surveys.

- **Monitoring and change detection** the imagery can be used to monitor changes in wetland vegetation over time. This is useful for identifying areas of degradation, detecting the effects of climate change, and evaluating the effectiveness of conservation measures.

- **Multi-temporal analysis**: the imagery can be used to analyse vegetation patterns over time, allowing for the identification of seasonal changes and long-term trends.

- **Data integration**: the imagery can be integrated with other data sources such as GIS and field data to provide a comprehensive understanding of wetland vegetation patterns and processes.

Using satellite imagery as the basis of wetland vegetation mapping advances our understanding of wetland ecosystems and their dynamics to inform wetland management and conservation efforts.

In Australia, the use of this technology is becoming increasingly common there have been many studies that have used satellite imagery for wetland vegetation mapping. These include projects conducted by government agencies, research institutions, and non-governmental organizations. Some examples of these projects are:

The Australian Wetlands and Rivers Centre (AWRC) has conducted several projects using satellite imagery for wetland vegetation mapping, including mapping of wetlands in the Murray-Darling Basin.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has used satellite imagery to map wetland vegetation in the Northern Territory and Western Australia.

- The Australian Government's National Landcare Program has funded several projects that use satellite imagery for wetland vegetation mapping, including projects in Victoria and Queensland.
- The University of New South Wales has conducted research using satellite imagery for wetland vegetation mapping in the Hunter River Estuary.

3.1.1 Image classification in ArcGIS

In this study, the ArcGIS suite of software was used. The method[11] employed mirrored that described by ESRI (2021) for a supervised classification, as shown in Figure 3-1.

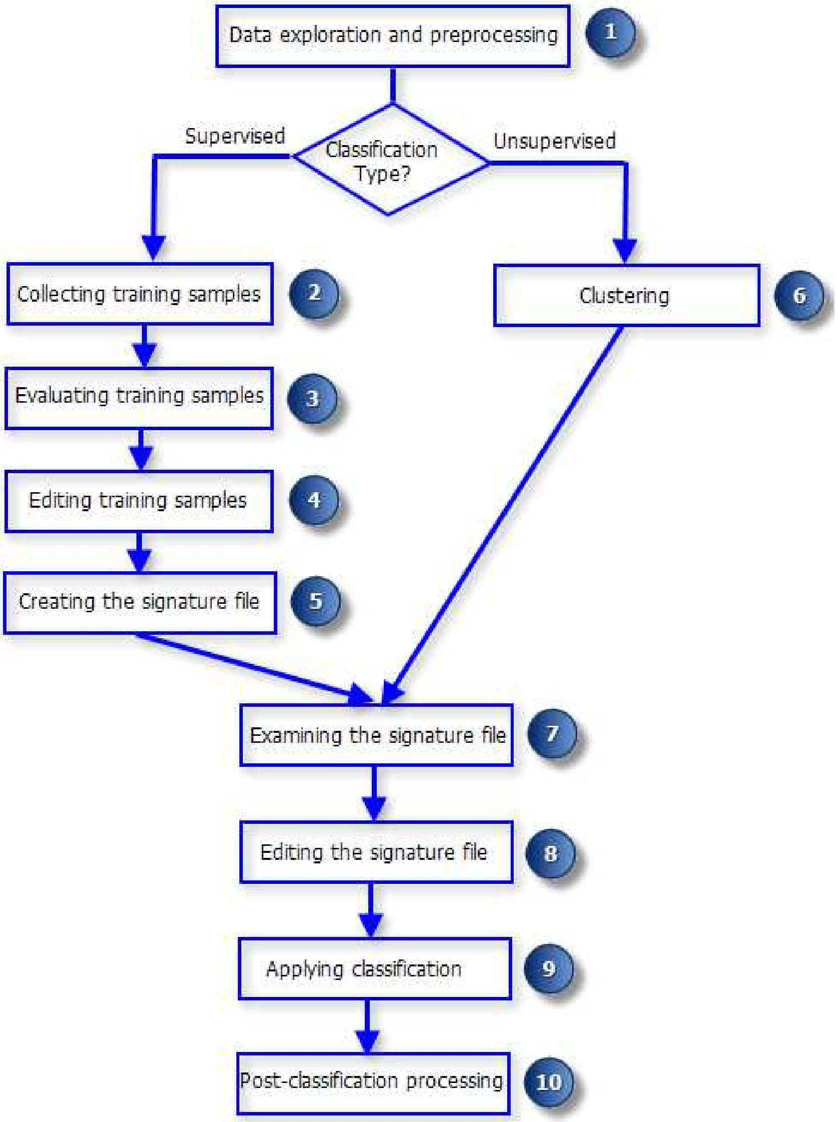

Figure 3-1 – image classification in ArcGIS using the Spatial Analyst extension (ESRI, 2021)

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[11] https://desktop.arcgis.com/en/arcmap/latest/extensions/spatial-analyst/image-classification/image-classification-using-spatial-analyst.htm

Supervised classification of satellite imagery for wetland vegetation mapping is a robust method if the following factors are taken into consideration:

- **Pre-processing of satellite imagery**: Pre-processing of satellite imagery can improve the accuracy of the classification. This includes geometric correction, atmospheric correction, and radiometric correction.
- **Selection of appropriate bands**: The selection of appropriate spectral bands is important for accurate classification. Different bands are sensitive to different vegetation types, and therefore the appropriate bands should be selected for the classification.
- **Quality of training data**: The accuracy of supervised classification largely depends on the quality of the training data used. The training data should be representative of the wetland vegetation classes that are to be mapped[12]. It should also be spatially and temporally consistent.
- **Selection of classification algorithm**: The selection of the appropriate classification algorithm is important for the accuracy of the classification. Some algorithms work better with certain types of data than others. For example, decision-tree classifiers work well with categorical data, while support vector machines work well with continuous data.
- **Validation of the classification**: The accuracy of the classification should be validated using ground-truthing data. This involves comparing the classified results with field data to assess the accuracy of the classification.

These criteria underpinned the method used in this study, as described below.

3.1.2 Analysis Ready Data

All satellite imagery acquired for use in this study (refer Section 3.2) was pre-processed and 'analysis ready' meaning that it can be imported into ArcGIS and immediately used in the supervised classification process.

3.1.3 Band selection

Careful consideration was given to which of the available spectral bands were to be used in the supervised classification process. A combination of appropriate bands was selected based on previous research that employed supervised classification of satellite imagery for wetland vegetation mapping and from operator experience of what has worked well for coastal wetlands around Port Phillip and Western Port Bays. To accurately identify wetland vegetation, a combination of visible bands (red, green, blue); and invisible red-edge, near- and short-wave infrared bands are used. The use of infrared bands allows for reflectance contrasts between water and vegetation and within vegetation according to chlorophyll concentration.

3.1.4 Creation of training samples

The supervised classification process required training samples to be created of the different vegetation types to be classified. The following classes were used:

- Phragmites
- Typha association
- Phrag/Typha (where it was difficult to distinguish between the two types
- Sedges/Rushes
- Lignum
- Open water

The location, number, and size of these training samples for these vegetation classes were selected manually by the operator to generate a sufficient range of pixel reflectance values typical of that vegetation type in the image being classified. Where previous mapping has been completed, the operator selected locations for training samples based on a subset of known occurrences of the vegetation types of interest.

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[12] If desired, non-target vegetation types can be mapped to create a more complete picture.

A signature file was then created. This file trains the classification algorithm to search for all pixels in the image that are most like that signature thus identifying other areas in the image where that vegetation type is likely to occur.

3.1.5 Spectral profiles

For the Sentinel-2 imagery only, because the composite image contained the infrared bands of interest, ArcGIS Pro was used to generate a spectral profile across each of the bands used in the supervised classification for each vegetation class of interest. These spectral profiles act like fingerprints, enabling the Maximum Likelihood classification algorithm to recognise pixels that satisfy the spectral characteristics of the vegetation classes in the training samples. An example is shown in Figure 3-3. This figure shows the similarities between the pixel reflectance values across the visible bands (1, 2 and 3), but the markedly different pixel reflectance values in the infrared bands (4, 5, and 6). The names of the band numbers are provided in Table 3-3.

3.1.6 Selection of the supervised classification algorithm

A Maximum Likelihood[13] classification was performed because this assigns each pixel to one of the different vegetation classes based on the means and variances of the class signatures that are stored in the signature file. The statistical likelihood is computed for each class to determine the membership of the pixels to the class.

3.1.7 Batch processing

A batch process was run using ModelBuilder to apply the classification to the band selection for all images for which vegetation extents were to be mapped.

3.1.8 Results validation

The results were then validated using a combination of methods: (i) by comparing with high resolution aerial imagery and by ground truthing, and (ii) by comparison with existing vegetation mapping, where available.

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[13] https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/how-maximum-likelihood-classification-works.htm

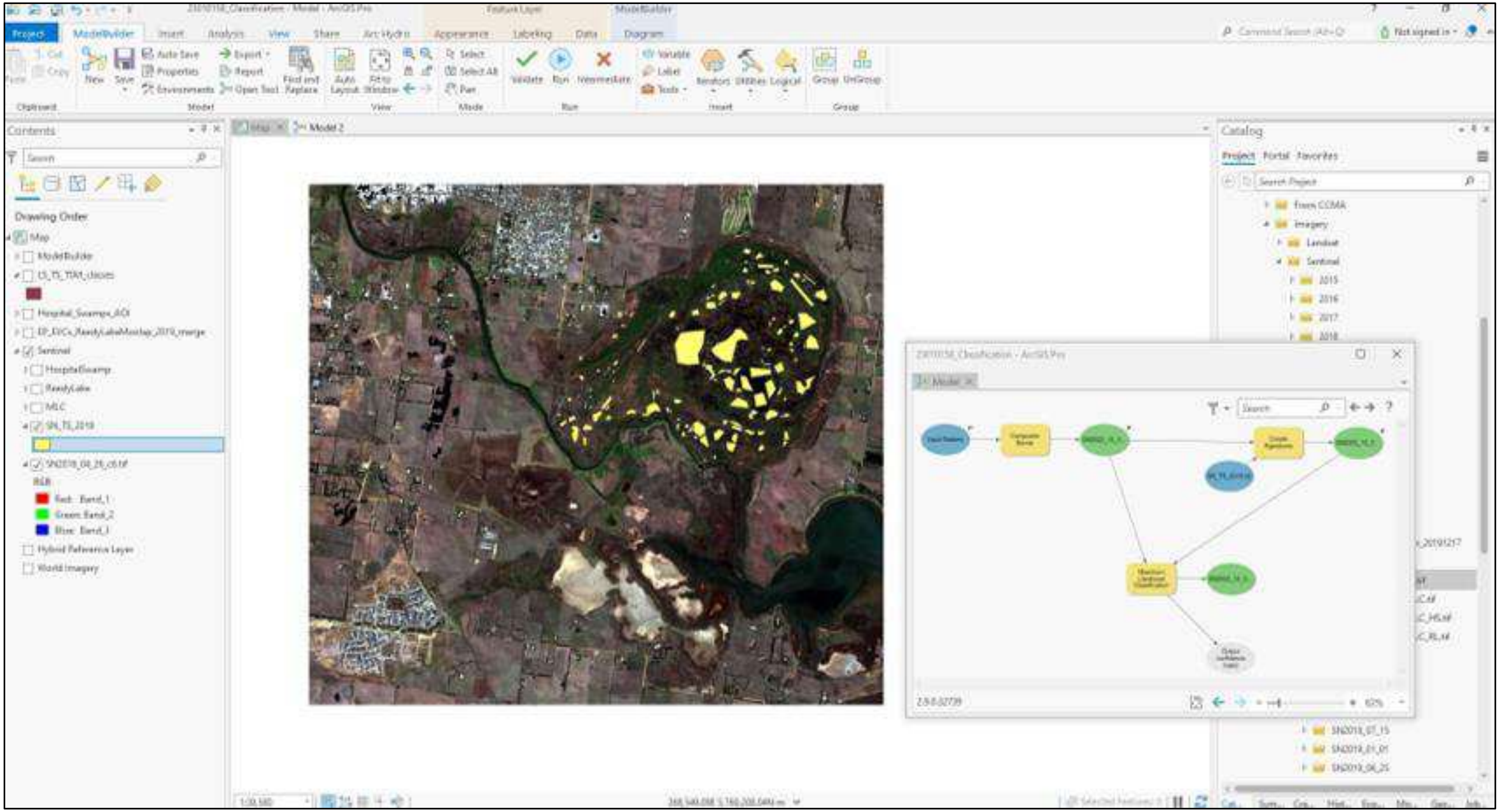

Figure 3-2 – Screen shot of ArcGIS software showing the image classification window, training sample locations and the batch processing tool in ModelBuilder

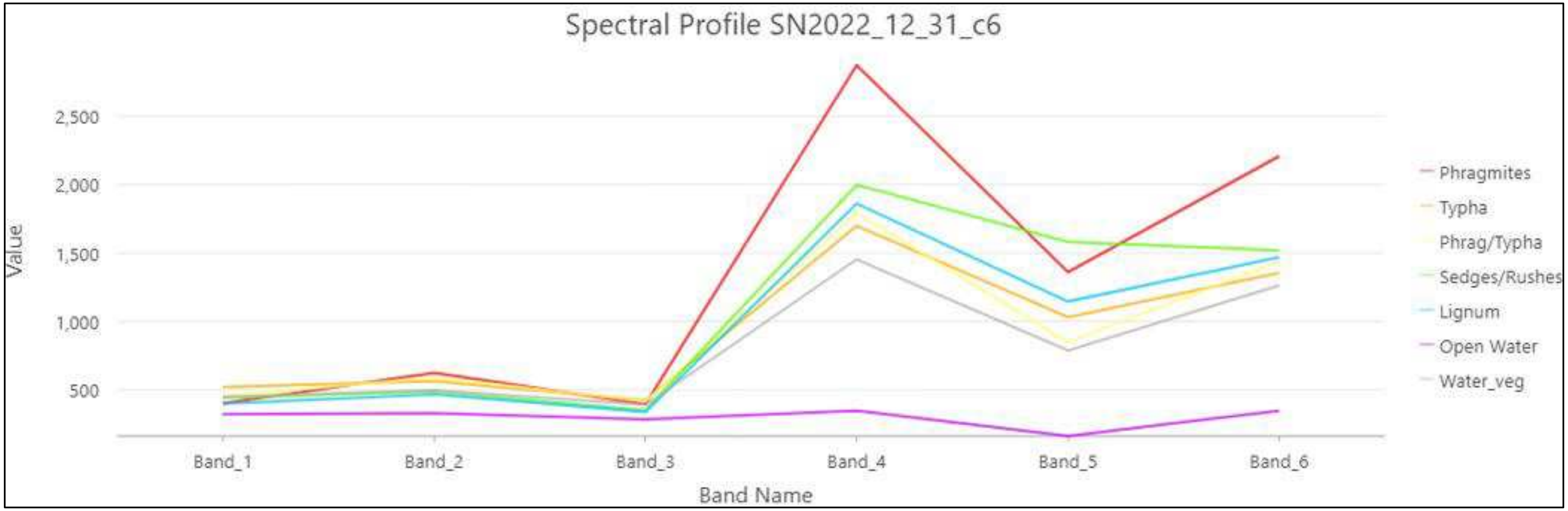

Figure 3-3 – Example spectral profile for the 6-band December 2022 Sentinel-2 image (SN2022_12_31)

3.2 Satellite imagery acquisition and analysis

3.2.1 Landsat

The Landsat mission commenced in July 1972 with the launch of Landsat 1. The most recent Landsat platform, Landsat 9, became operable in September 2021. This project required Landsat imagery between 1983 and 2018. Landsat platforms 4, 5 7 and 8 were used to acquire imagery due to their overlapping mission timeframes and the need to find suitable imagery for key timesteps for this study.

- Landsat 4 – July 1982 to June 2001
- Landsat 5 – March 1984 to June 2013
- Landsat 7 – April 1999 to present
- Landsat 8 – February 2013 to present.

Landsat carries the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). It provides imagery with 30m spatial resolution.

3.2.1.1 Image acquisition, selection, and spectral parameters

For the period 1988 onwards, Geoscience Australia processes all Landsat imagery into ‘Analysis Ready Data’ (ARD) and makes this freely available to users through its Digital Earth Australia (DEA) Sandbox[14]. This powerful cloud computing platform allows users to search for, acquire and analyse imagery online. For this project, the DEA Sandbox was used to search for and download imagery from 1988 for further analysis in ArcGIS.

Geoscience Australia Landsat Collection 3 imagery was sourced for the period 1988 to 2018. The specific NBART[15] surface reflectance products used were ‘ga_ls5t_ard_3’, ‘ga_ls7e_ard_3’, ‘ga_ls8c_ard_3’. A surface reflectance product is the analysis ready dataset containing all available images from the satellite platform.

The band selection for the imagery sourced from this surface reflectance product is shown in Table 3-1. These bands were selected because they are the most useful for classifying wetland vegetation.

Table 3-1 – Landsat band selection

Downloaded Band Ref	Satellite Band	Band Name
1	4	RED
2	3	GREEN
3	2	BLUE
4	5	NIR
5	6	SWIR_1
6	7	SWIR_2

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[14] https://app.sandbox.dea.ga.gov.au/hub/login?next=%2Fhub%2F
[15] Nadir corrected Bidirectional reflectance distribution function Adjusted Reflectance Terrain corrected.

For 1983, imagery was sourced from the USGS 'Earth Explorer' portal and from Landsat 4. This imagery is not pre-processed and is made freely available to users as a Level 1 product[16]. Imagery was acquired and some further processing was performed in ArcGIS to make it 'analysis ready'. Unfortunately, image quality was an issue and only one suitable image for 1983 was available. A better image was available for January 1984. Given the limitations of image quality, further analysis of this imagery has not been completed at this stage.

Of the 58 images acquired, 8 were selected. Images were selected based on the best image quality, and the closest month in each 5-year time-step across the period for seasonal comparability. These are listed below for reference.

Table 3-2 – Landsat image selection

Year	Image reference
1983	LS1983_05_15
1988	LS1988_09_25
1993	LS1993_08_22
1998	LS1998_08_04
2003	LS2003_08_02
2008	LS2008_03_08
2013	LS2013_09_15
2018	LS2018_08_12

3.2.1.2 Band combination

All six bands were used in the classification.

3.2.1.3 Creation of training samples

Training samples for the supervised classification of Landsat imagery were based on identifying areas of the subject vegetation classes within the wetland that were likely to have always been present, thus providing a consistent basis of selecting pixels representative of that vegetation class in imagery over time. This was achieved by using the original Yugovic extent mapping from 1983 combined with the Ecological Associates mapping from 2007 and 2014.

3.2.1.4 Vegetation extent mapping

The results of the supervised classification output a raster file that when visualised in ArcGIS is symbolised to visually distinguish the different vegetation classes. Areas (in Ha) for these vegetation extents were then able to be calculated with the results being exported to MS Excel. The results for each time step were symbolised according to the Yugovic equivalent vegetation class to allow for comparison with the previous mapping.

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[16] https://www.usgs.gov/landsat-missions/landsat-levels-processing

3.2.2 Sentinel-2

The Sentinel 2A and 2B satellite constellation, launched in 2015, provides 10m spatial resolution imagery at a return frequency of 5-days. The Multi-Spectral Instrument (MSI) on board these two platforms collect earth surface reflectance data across 13 spectral bands.

3.2.2.1 Image acquisition, selection, and spectral parameters

Geoscience Australia processes all Sentinel-2 imagery into 'Analysis Ready Data' (ARD) and makes this freely available to users through its Digital Earth Australia (DEA) Sandbox. This powerful cloud computing platform allows users to search for, acquire and analyse imagery online. For this project, the DEA Sandbox was used to search for and download imagery for further analysis in ArcGIS.

Geoscience Australia Sentinel-2 Collection 3 imagery was sourced for the period 2016 to 2022. The specific NBART surface reflectance products used were 'ga_s2am_ard_3' and 'ga_s2bm_ard_3'. A surface reflectance product is the analysis ready dataset containing all available images from the satellite platform.

The initial band selection for the imagery sourced from this surface reflectance product is shown in Table 3-3. These bands were selected because they are the most useful for classifying wetland vegetation.

Table 3-3 – Sentinel-2 band selection.

Downloaded Band Ref	Satellite Band	Band Name
1	4	RED
2	3	GREEN
3	2	BLUE
4	8	NIR_1
5	8a	NIR_2
6	11	SWIR_2
7	12	SWIR_3
8	5	RED_EDGE_1
9	6	RED_EDGE_2
10	7	RED_EDGE_3

Of the 90 images acquired, 15 were selected. Images were selected based on the best image quality, and the closest month in each winter and summer time-step from each year across the period for seasonal comparability. These are listed below for reference.

Table 3-4 – Sentinel-2 image selection.

Timestep	Winter fill	Summer drawdown
Baseline / Before trial watering regime	SN2016_04_26	
2016	SN2016_06_15	SN2016_12_12
2017	SN2017_08_24	SN2017_12_12
2018	SN2018_07_15	SN2019_01_01
2019	SN2019_06_25	SN2019_12_17
2020	SN2020_06_19	SN2020_12_26
2021	SN2021_07_09	SN2021_12_31
Current (for updated EVC map) 2022	SN2022_07_24	SN2022_12_11

3.2.2.2 Band combination

Image composites for the classification were created from the following 6-band combination.

Table 3-5 – Sentinel-2 band combination.

Downloaded Band Ref	Satellite Band	Band Name
1	4	RED
2	3	GREEN
3	2	BLUE
4	8	NIR_1
6	11	SWIR_2
9	6	RED_EDGE_2

3.2.2.3 Creation of training samples

Training samples were selected based on the acquired imagery and previous mapping by Ecological Perspectives in 2019 (the middle year in the period 2016 to 2022). The rationale was that such samples would allow for earlier and later timesteps to be classified appropriately across the period.

3.2.2.4 Vegetation extent mapping

The results of the supervised classification output a raster file that when visualised in ArcGIS is symbolised to visually distinguish the different vegetation classes. Areas (in Ha) for these vegetation extents were then able to be calculated with the results being exported to MS Excel. The results for each time step were symbolised according to the Yugovic equivalent vegetation class to allow for comparison with the previous mapping.

3.3 Deriving vegetation class elevation associations

The January 2017 1m resolution Digital Elevation Model (DEM)[17] was used as the basis for deriving elevation associations for the Sentinel-2 image classification results of vegetation class extents for 2017. This provides an indication of the range of elevations preferred by the different vegetation classes located in different parts of the wetland. Typically, wetland vegetation types colonise a wetland surface according to a hydrological and salinity gradient, which is the case at Reedy Lake (Ecological Associates, 2007). Elevation associations are important because they allow information to be derived on the range of inundation depths (at different water levels) and frequencies (according to the water regime) for the different vegetation classes.

Calculations were performed in ArcGIS using the Zonal Statistics as Table tool. Input data were the DEM and the mapped vegetation extent as a categorical (integer) raster (or polygon shapefile).

3.4 Deriving modelled water extents and depths

The January 2017 1m resolution Digital Elevation Model (DEM) was used as the basis for deriving water extents (to mAHD) using the water level monitoring data (to mAHD) for the Reedy Lake gauge (233603). A series of calculations were performed in ArcGIS Raster Calculator to create raster (*.tiff) outputs showing the modelled water extent at 0.1m intervals from 0.1mAHD to 0.8mAHD. Once water extent rasters were generated for specific water levels, water depths could be calculated by subtracting the wetland surface elevation (indicated by the DEM raster) from the water surface elevation (indicated by the water extent raster). This calculation was performed for several water levels of interest (being 0.4m, 0.5m and 0.8m). The water regime was then used to infer the seasonality and frequency with which the wetland experienced different inundation extents and depths.

Table 3-6 – water extent and depth calculation

Data being derived	Raster Calculator expression
water extent binary raster (water = 1, dry = 0)	DEM raster <= water level to mAHD
water extent elevation raster	DEM raster * water extent binary raster (from above)
water depth raster	water level to mAHD * water extent binary raster – water extent elevation raster

3.5 Deriving vegetation class spectral profiles and indices

The following analyses were performed on a sub-set of the Sentinel-2 imagery from 2022. The intent was to determine if information of use to a future remote sensing-based monitoring program could be derived. Of particular interest was deriving spectral indices indicative of plant health or stress.

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[17] The DEM has a vertical accuracy of 0.1m and a horizontal accuracy of 0.2m

Using band combinations comprising visible and infrared parts of the electromagnetic spectrum allows for different properties of the wetlands vegetation cover to be emphasised. A simple visualisation using false-colour symbolisation of the band selection contrasts the vegetation health based on greenness but doesn't provide any data on pixel reflectance values. Using specific bands in a spectral index calculation provides pixel reflectance values that can be used to quantify the health characteristics within and between different vegetation types.

3.5.1 False-colour imagery

To emphasise different aspects of vegetation from other landcover in an image it is commonplace to use different three-band combinations to visualise the image with.

A typical natural colour image is R-G-B, which for Sentinel-2 images is RED (B4), GREEN (B3), and BLUE (B2), where 'B*' is the band number. Two visualisations using specific band combinations that are particularly good for highlighting vegetation are colour infrared and short-wave infrared.

- The ***colour infrared*** visualisation (Figure 3-4uses band combination NIR (B8), RED (B4), GREEN (B3). The chlorophyll content in vegetation results in a high reflectance in the near-infrared (NIR) band, and strong absorption in the green band. When symbolised with a red palette, in general, the redder shades indicate greater chlorophyll content and thus denser / healthier vegetation.
- The ***short-wave infrared*** visualisation uses band combination SWIR (B12), NIR (B8A), and RED (B4). This composite shows vegetation in various shades of green. In general, darker shades of green indicate denser / healthier vegetation.

Two false colour images for 2022 were generated to investigate whether any insights could be gained into the spectral characteristics of the vegetation classes of interest, using these band combinations.

Figure 3-4 – example false colour visualisation of Reedy Lake.

3.5.2 Spectral indices

A spectral index was created for the same 2022 image used in the false colour analysis. The spectral index chosen was one that is known to highlight vegetation: Normalised Difference Vegetation Index (NDVI). NDVI is particularly good at highlighting plant stress due to the impact of stress on the chlorophyll content in plant leaves that the index detects. High NDVI values indicates healthy (green) plants. Two versions of this index were explored, using different red band combinations. Red light is absorbed by chlorophyll however near infra-red is strongly reflected. Red-edge light penetrates leaves and stems better than red light, providing a better indication of overall chlorophyll absorption in dense stands of vegetation, such as those found at Reedy Lake.

3.5.2.1 Normalised Difference Vegetation Index (NDVI)

The normalized difference vegetation index (NDVI) was calculated as follows.

$$\text{NDVI} = \frac{(\text{near-infrared - red})}{(\text{near infrared + red})} \tag{1}$$

3.5.2.2 Normalised Difference Red Edge Vegetation Index (NDVIre)

The red-edge normalized difference vegetation index (NDVIre) was calculated as follows.

$$\text{NDVIre} = \frac{\rho_{\text{NIR}} - \rho_{\text{RE1}}}{\rho_{\text{NIR}} + \rho_{\text{RE1}}}. \tag{2}$$

The MSI onboard Sentinel-2 has 13 bands, including three red-edge bands (RE1: central wavelength = 705 nm; RE2: central wavelength = 740 nm; and RE3: central wavelength = 783 nm) each with a spatial resolution of 20 m. For this NDVIre analysis, the RE2 band was used.

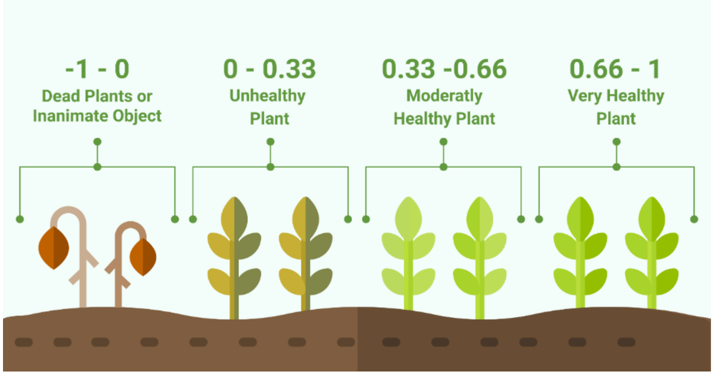

Figure 3-5 - typical NDVI value ranges in relation to plant health/stress (source: Phenospex[18], 2019)

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[18] https://phenospex.com/blog/digital-disease-quantification-in-plants-a-tailored-method/

3.6 Creating a satellite imagery time-series animation

A Jupyter Notebook[19] from Geoscience Australia's Digital Earth Sandbox was used to generate two time-series animations, one each for the Landsat and Sentinel-2 satellite imagery over the two periods of interest, being 1983 to 2022 and 2016 to 2022.

3.7 Investigating the influence of environmental variables on vegetation extents

3.7.1 Water levels, extents, and depths

As discussed earlier in this section, available water level records were plotted for the entire monitoring period (2016 to 2022) and for the specific timesteps of interest to the Sentinel-2 vegetation analysis. Water levels were also mapped as extents and depths. Water levels, extents and depths were compared with the mapped extents and total areas of the different vegetation classes to discern whether there were any relationships to the water regime. Relevant information in previous studies was also drawn upon to inform this analysis.

3.7.2 Rainfall

Available rainfall records were plotted for the same monitoring period as the water level data. Of interest to this study is understanding the seasonal rainfall patterns, particularly spring and summer.

3.7.3 Temperature

Available temperature records were plotted for the same monitoring period as the water level data. Of interest to this study is understanding the seasonal temperature patterns, particularly spring and summer temperatures.

3.7.4 Salinity

Soil salinity was not measured in this study, nor is a continuous dataset of soil salinity available for the period 2016 to 2022. Instead, soil salinity measurements from the Ecological Associates studies of 2007 and 2014 were drawn upon to inform this study. Of interest to this study are the likely soil salinities in different parts of the wetland in relation to the mapped extent of vegetation classes according to the known salinity tolerance of the constituent species.

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[19] https://docs.dea.ga.gov.au/notebooks/Real_world_examples/Generating_satellite_animations.html

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