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Report: Part 2

Reedy Lake Flora Assessment – Environmental Water

Corangamite Catchment Management Authority

4 August 2023

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Project Name	Reedy Lake Flora Assessment – Environmental Water
Client	Corangamite Catchment Management Authority
Client Project Manager	Sharon Blum-Caon
Water Technology Project Manager	Leigh Smith
Water Technology Project Director	Julian Martin
Authors	Leigh Smith, Jamie Kaye, Lance Lloyd
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51 Little Fyans Street
Geelong VIC 3220
Telephone (03) 8526 0800
ACN 093 377 283
ABN 60 093 377 283

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Sharon Blum-Caon
Senior Project Officer – Estuaries and Environmental Water
Corangamite Catchment Management Authority
64 Dennis St
Colac VIC 3250

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 2: Results, discussion, conclusion, and recommendations.

I have really enjoyed working with you on this project.

Yours sincerely

Leigh Smith
Principal Environmental Scientist
leigh.smith@watertech.com.au
WATER TECHNOLOGY PTY LTD

CONTENTS

APPENDICES

4 RESULTS

This section reports on the results of the satellite classification.

The table below provides a conversion between the Yugovic equivalent vegetation class (that has been used to present most of the mapping of vegetation extents) and the Ecological Vegetation Class (EVC) to which it belongs.

Table 4-1 – Yugovic equivalent vegetation class and Ecological Vegetation Class

Yugovic equivalent	Dominant species	Ecological Vegetation Class (EVC)
Tall Reed	Phragmites australis	Tall Marsh (821)
	Typha orientalis	Tall Marsh (821)
Sedges/Rushes	Bolboschoenus caldwellii	Brackish Sedgeland (13)
Lignum	Duma florulenta	Brackish Lignum Swamp (947)
Open Water	Submergent and floating macrophytes	Open Water (990)

4.1 Satellite derived vegetation extents

Vegetation extents were derived for two time-periods using two satellite platforms.

4.1.1 Landsat time series: 1983-2018

Due to issues with acquiring suitable quality Landsat imagery from 1983/84 for the time the original Yugovic mapping was completed, the 1983 time-step has been omitted from the results.

4.1.1.1 Observed changes and trends over time

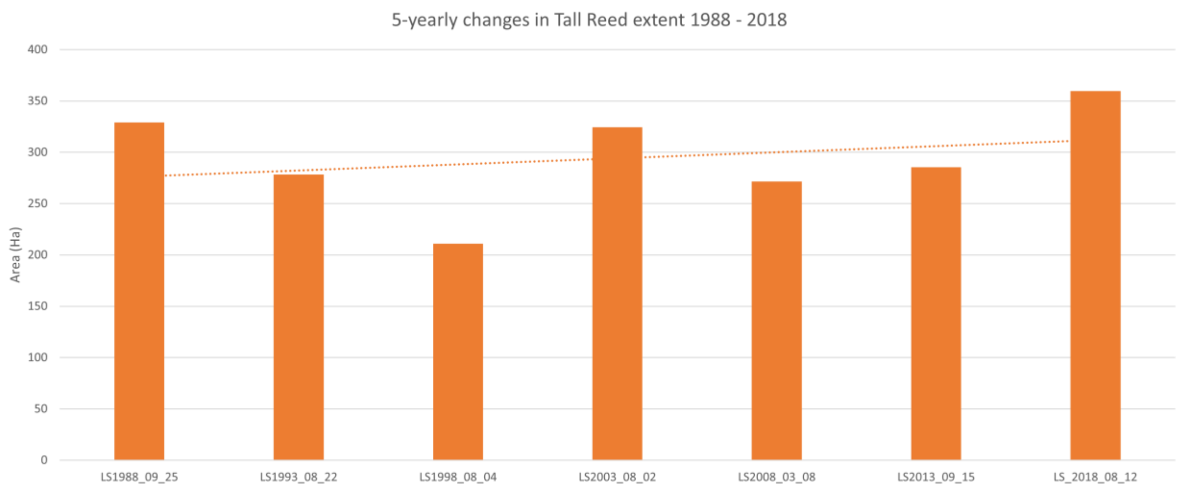
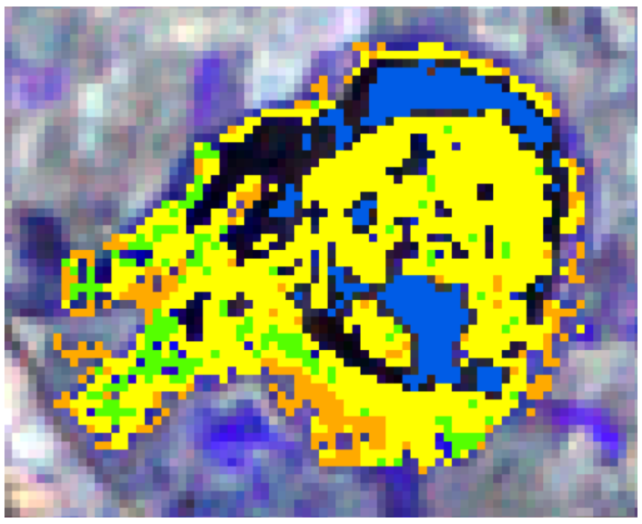
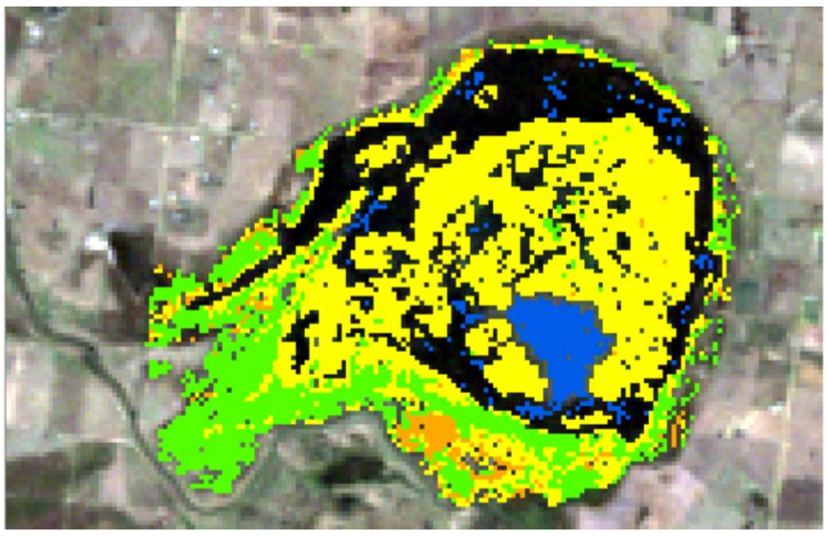
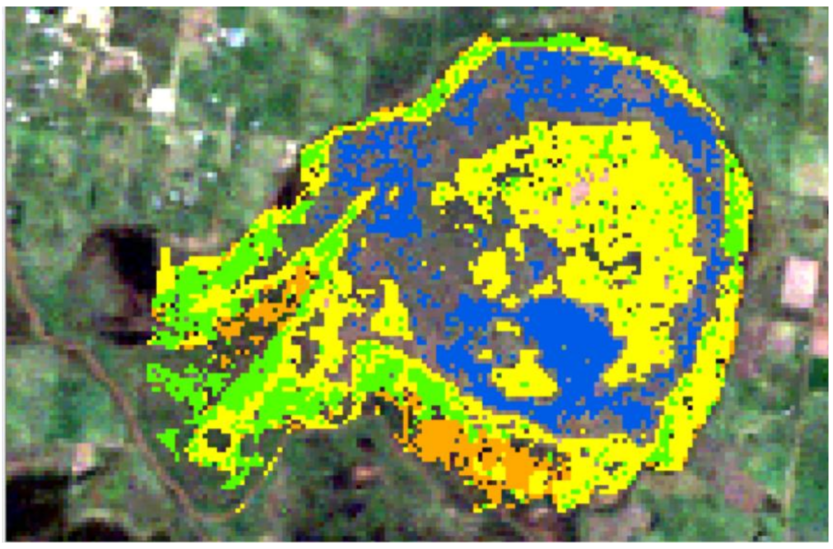
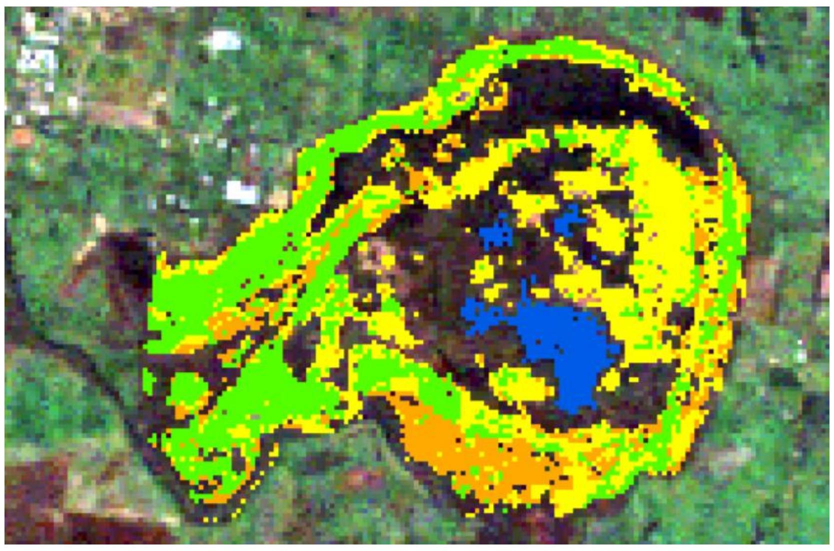
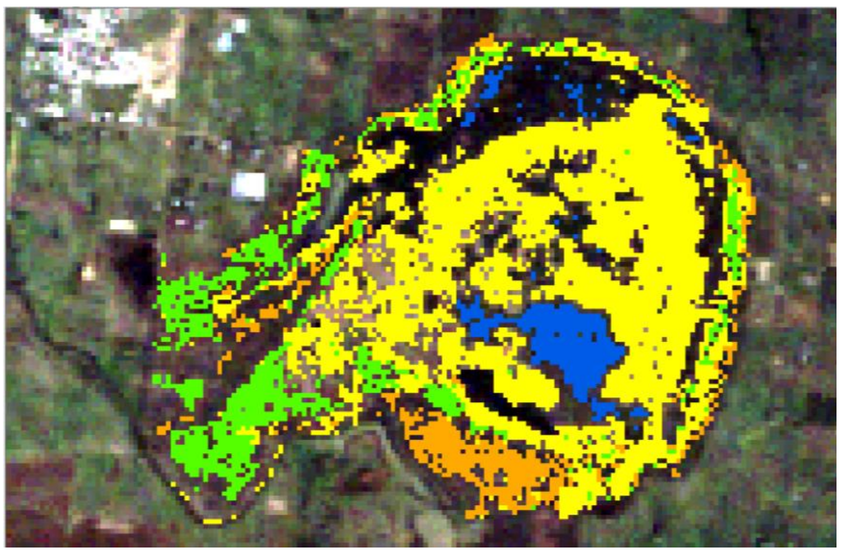
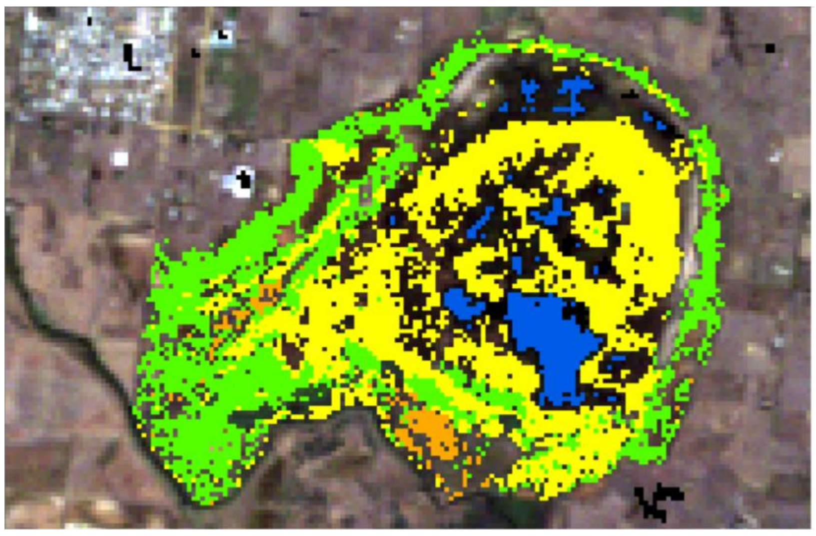
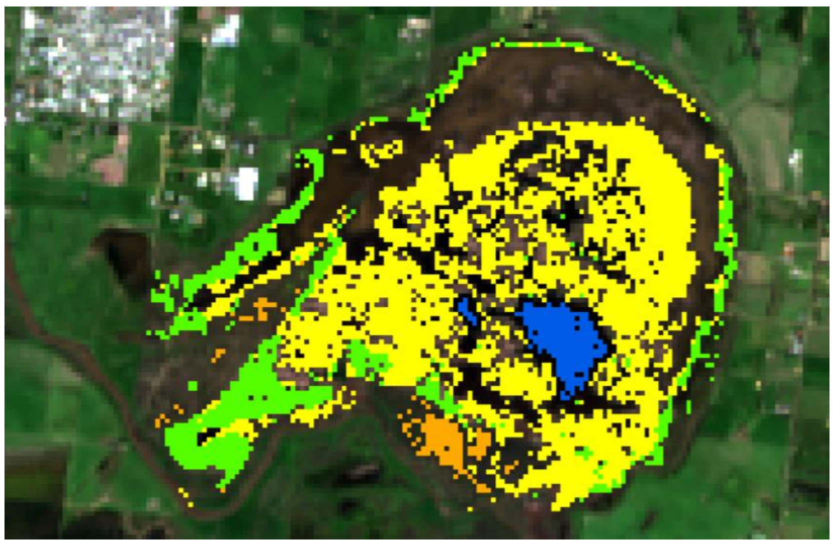
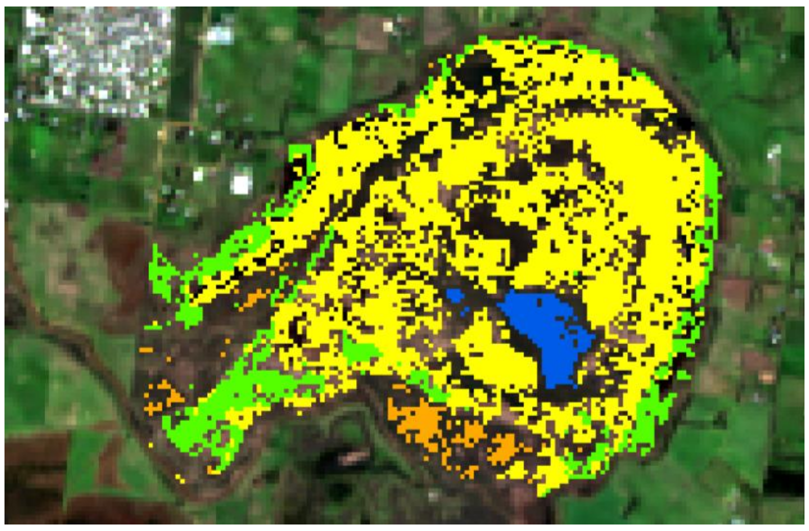


Figure 4-1 – 5-yearly changes in Tall Reed extent 1988-2018

The above chart indicates the overall changes and trend in Tall Reed extent over 30 years between 1988 and 2018. There have been significant contractions and expansions in the order of 70Ha with extents ranging between 280Ha and 350Ha. There has been a trend toward increasing extent during this period.

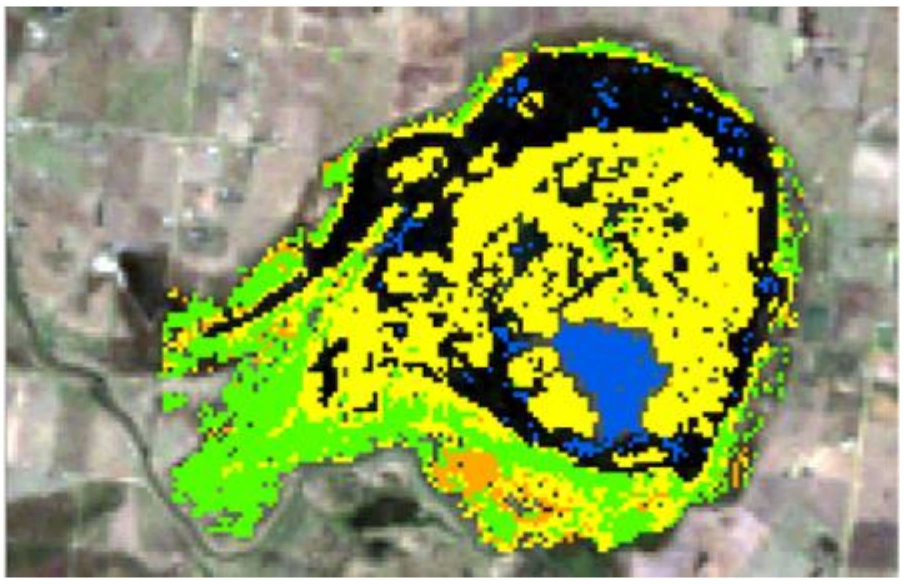
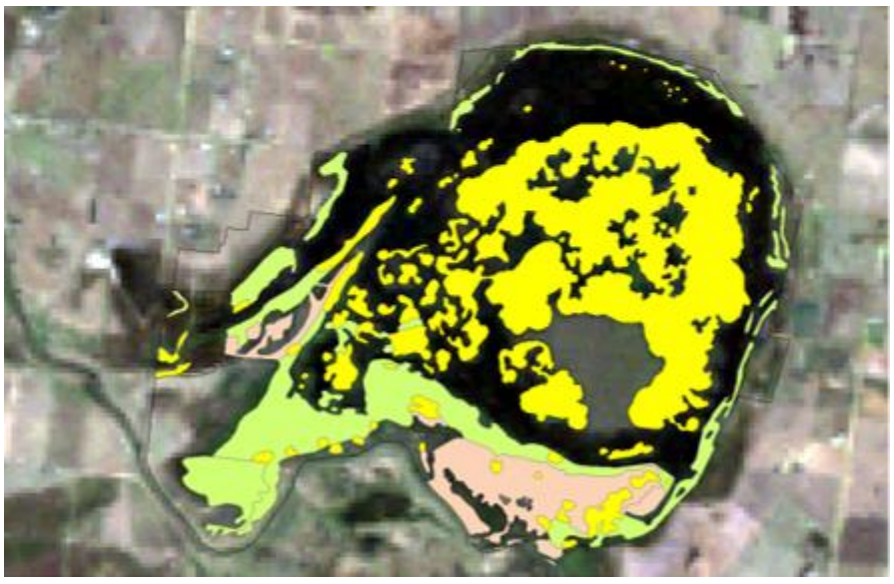
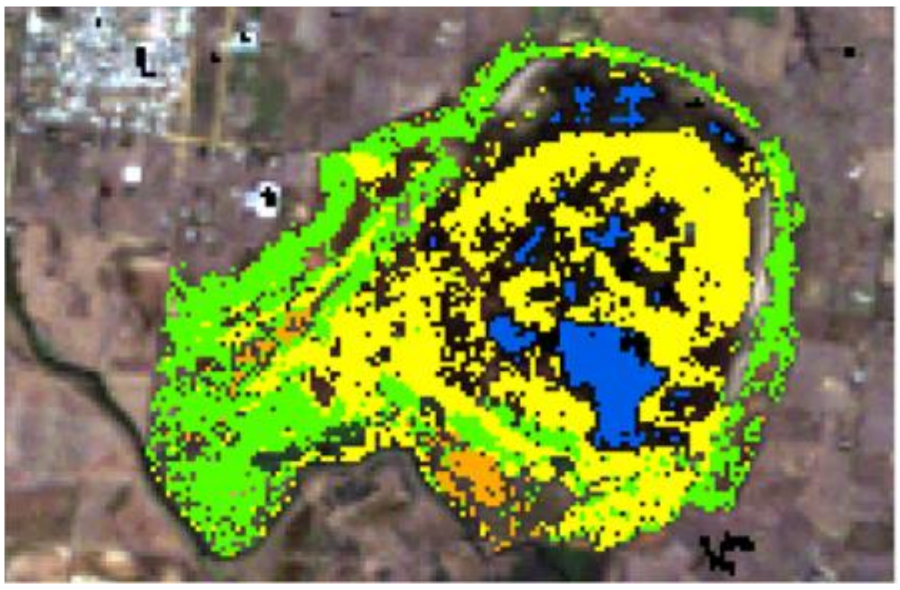
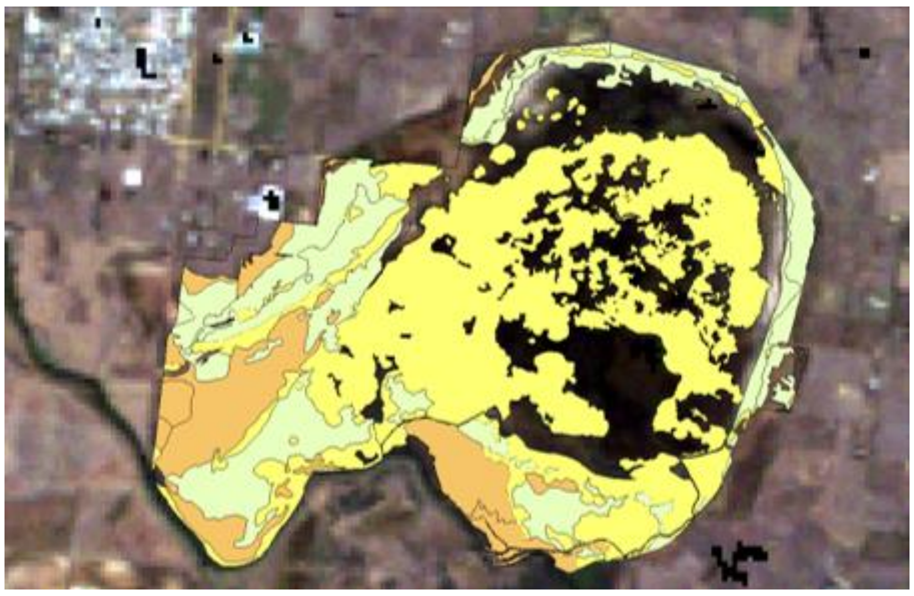
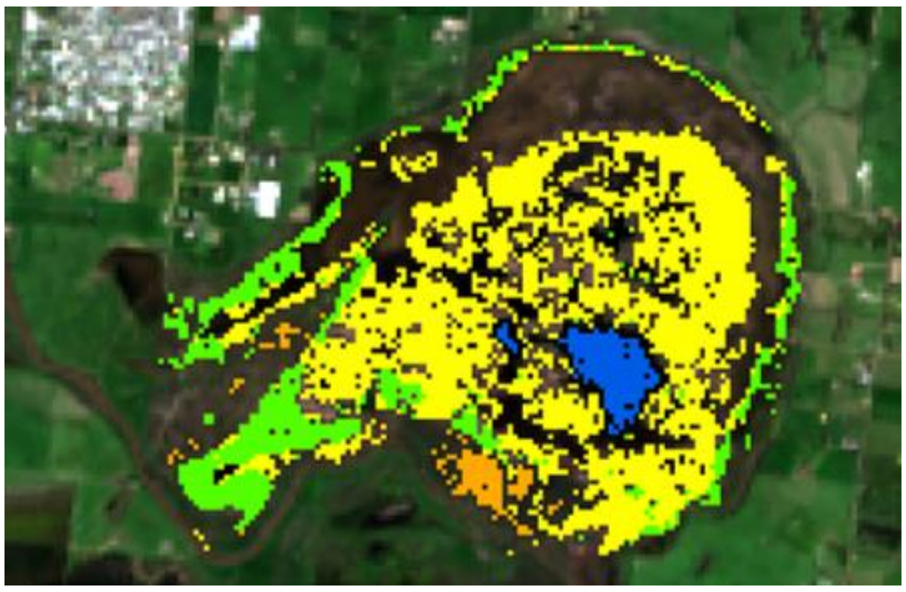
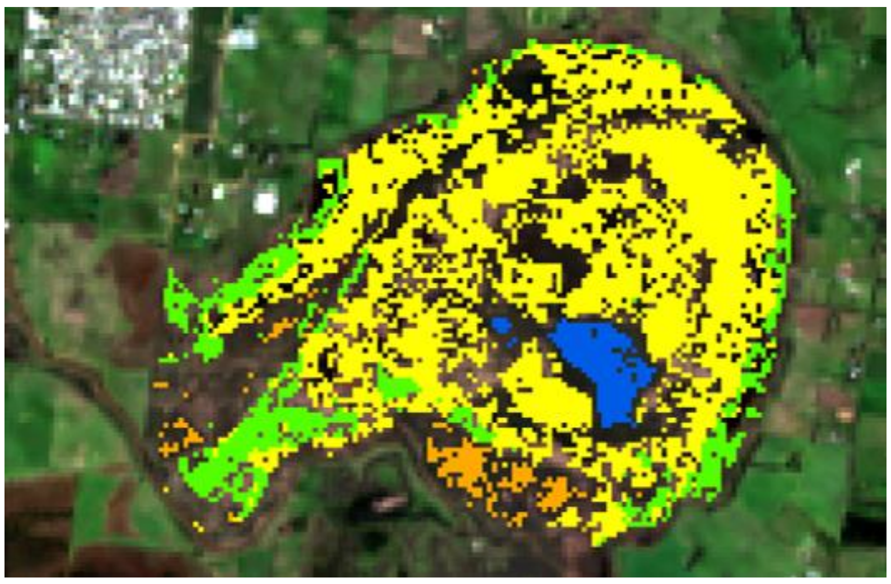
Table 4-2 – Time-series of classified Landsat imagery 1983 to 2018

	
1983 (January 1984)	September 1988
	
August 1993	August 1998
	
August 2003	March 2008
	
September 2013	August 2018

KEY: Yellow = Tall Reed; Green = Sedges/Rushes; Orange = Lignum; Blue = Open water (or dry)

The above results show significant changes in the extent of Tall Reed (yellow) and Sedges/Rushes (green) over time. Lignum is shown in orange and water in blue. Extent changes are evident for Lignum and water extent changes with periods of wetting and drying. Note, the extent of water shown in blue is not necessarily the full extent of water in the imagery due to issues with detecting shallow water using Landsat.

Table 4-3 – comparison of vegetation extents symbolised to Yugovic equivalent. Classified Landsat imagery (left) and previous mapping (right)

	
Landsat 1988	Yugovic 1983
	
Landsat 2008	Ecological Associates 2007
	
Landsat 2013	Ecological Associates 2013
	
Landsat 2018	Ecological Perspectives 2019

4.1.1.2 Change detection

Table 4-4 highlights the direction of change in vegetation extent for each vegetation class between each 5-year time-step as being either towards expansion, contraction or stable. The time-lapse animation of Landsat imagery also serves to highlight some of these changes.

Table 4-4 – approximate directions of vegetation extent change in Reedy Lake 1983 to 2018

5-yearly timestep	Tall Reed	Sedges/Rushes	Lignum
1983 to 1988	Stable	Expansion	Stable
1988 to 1993	Contraction	Contraction	Expansion
1993 to 1998	Contraction	Expansion	Expansion
1988 to 2003	Expansion	Contraction	Stable
2003 to 2008	Contraction	Expansion	Contraction
2008 to 2013	Stable	Contraction	Stable
2013 to 2018	Expansion	Stable	Stable

Table 4-6 shows the total area in Hectares (Ha) of each vegetation class that was classified in each 5-year time-step. Table 4-7 shows the relative proportions (%) of the areas classified in each 5-year timestep. Table 4-8 shows the proportions (%) of the areas classified in each 5-year timestep relative to the total area of Reedy Lake at 876Ha. The key thing to note is that these results demonstrate the no one vegetation class is exceeding the Limit of Acceptable Change, which is 70%. This is summarised by the year-on-year changes in proportions between timesteps in Table 4-5.

Table 4-5 – relative changes in area (positive or negative) between each 5-year time-step

Classes	Net change in area (Ha) classified year-on-year						
	LS1988_09_25	**LS1993_08_22**	**LS1998_08_04**	**LS2003_08_02**	**LS2008_03_08**	**LS2013_09_15**	**LS_2018_08_12**
Tall Reed	base year	-50.67	-67.41	113.67	-52.92	13.86	74.07
Lignum	base year	15.21	49.5	-36.45	-33.84	-2.52	4.59
Sedges/rushes	base year	-42.21	80.37	-101.43	117.81	-118.89	-2.7
Open Water / Dry	base year	81.27	-83.52	-0.54	3.69	-19.44	1.71
Total	**0**	**3.6**	**-21.06**	**-24.75**	**34.74**	**-126.99**	**77.67**

Table 4-6 – showing the total areas (Ha) of each vegetation class in each 5-year time-step (note: the total area classified varies)

	Total Area (Ha) classified						
Classes	**LS1988_09_25**	**LS1993_08_22**	**LS1998_08_04**	**LS2003_08_02**	**LS2008_03_08**	**LS2013_09_15**	**LS_2018_08_12**
Tall Reed	328.86	278.19	210.78	324.45	271.53	285.39	359.46
Lignum	21.96	37.17	86.67	50.22	16.38	13.86	18.45
Sedges/rushes	149.49	107.28	187.65	86.22	204.03	85.14	82.44
Open Water / Dry	37.44	118.71	35.19	34.65	38.34	18.9	20.61
Total	**537.75**	**541.35**	**520.29**	**495.54**	**530.28**	**403.29**	**480.96**

Table 4-7 – showing the relative proportions (%) of the areas classified in each 5-year timestep.

	Proportions of Vegetation Classes (%) relative to Total Area (Ha) classified						
Classes	**LS1988_09_25**	**LS1993_08_22**	**LS1998_08_04**	**LS2003_08_02**	**LS2008_03_08**	**LS2013_09_15**	**LS_2018_08_12**
Tall Reed	61.15%	51.39%	40.51%	65.47%	51.21%	70.77%	74.74%
Lignum	4.08%	6.87%	16.66%	10.13%	3.09%	3.44%	3.84%
Sedges/rushes	27.80%	19.82%	36.07%	17.40%	38.48%	21.11%	17.14%
Open Water/Dry	6.96%	21.93%	6.76%	6.99%	7.23%	4.69%	4.29%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 4-8 – showing the proportions (%) of the areas classified in each 5-year timestep relative to the total area of Reedy Lake at 876Ha.

	Proportions of Vegetation Classes relative to Total Area (Ha) of Reedy Lake (as per Ecological Perspectives, 2019)						
Classes	**LS1988_09_25**	**LS1993_08_22**	**LS1998_08_04**	**LS2003_08_02**	**LS2008_03_08**	**LS2013_09_15**	**LS_2018_08_12**
Tall Reed	37.54%	31.76%	24.06%	37.04%	31.00%	32.58%	41.03%
Lignum	2.51%	4.24%	9.89%	5.73%	1.87%	1.58%	2.11%
Sedges/rushes	17.07%	12.25%	21.42%	9.84%	23.29%	9.72%	9.41%
Open Water/Dry	4.27%	13.55%	4.02%	3.96%	4.38%	2.16%	2.35%
Total	**61.39%**	**61.80%**	**59.39%**	**56.57%**	**60.53%**	**46.04%**	**54.90%**

4.1.2 Sentinel-2 time series: 2016-2022

Vegetation extent change during the period the environmental watering regime has been in place was investigated using higher spatial (10m) and spectral resolution Sentinel-2 imagery, which became available in 2015. Because of the higher spatial and spectral resolution, Phragmites and Typha association as two distinct vegetation classes could be discerned in the analysis. For comparison with the Landsat (30m) results and with the Yugovic equivalent vegetation classes, Phragmites and Typha were combined into a Tall Reed class as shown in Figure 4-2.

4.1.2.1 Observed changes and trends over time

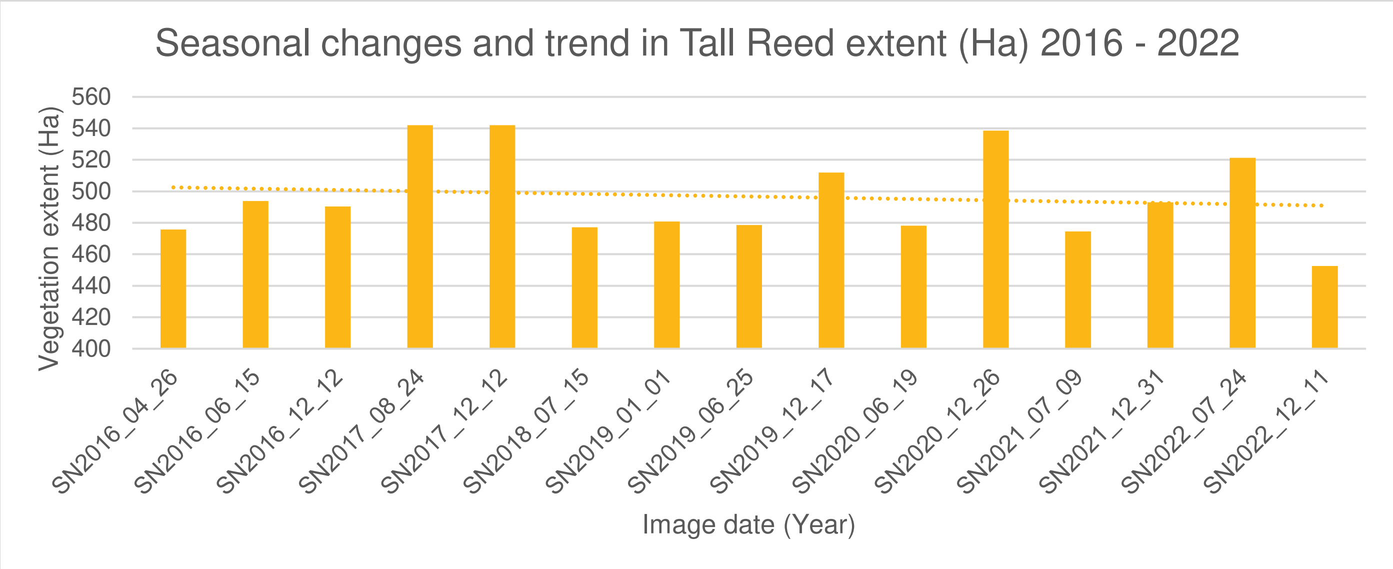


Figure 4-2 – Seasonal changes and trend in Tall Reed extent 2016 – 2022

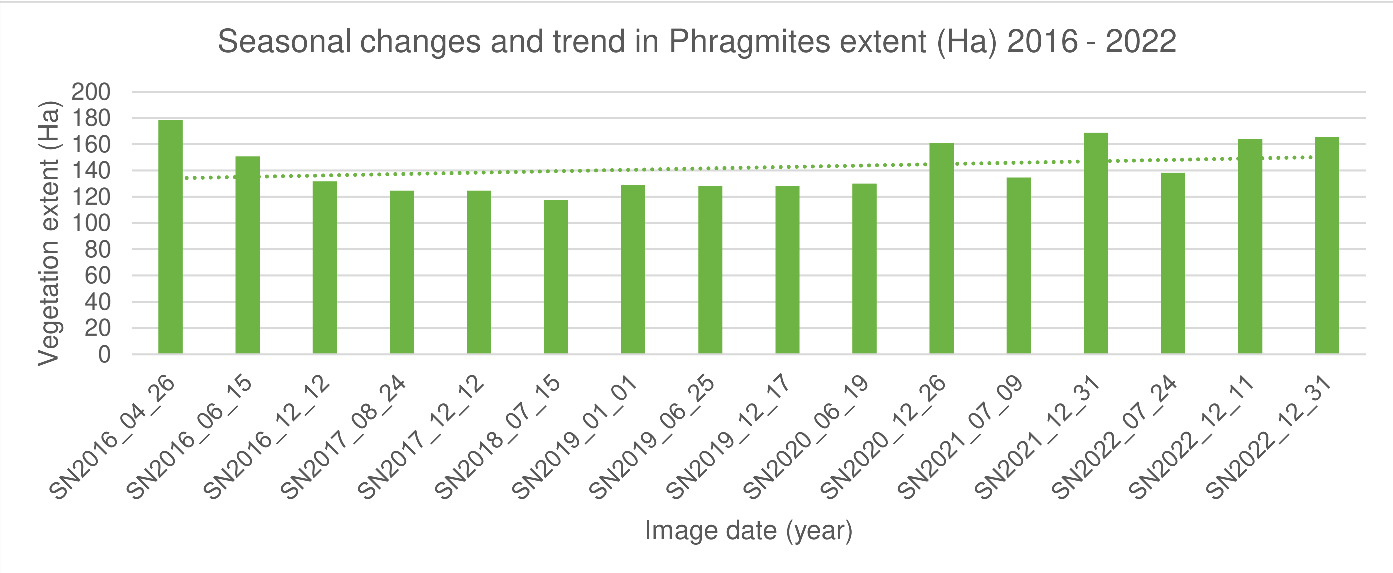


Figure 4-3 – Seasonal changes and trend in Phragmites extent 2016 – 2022

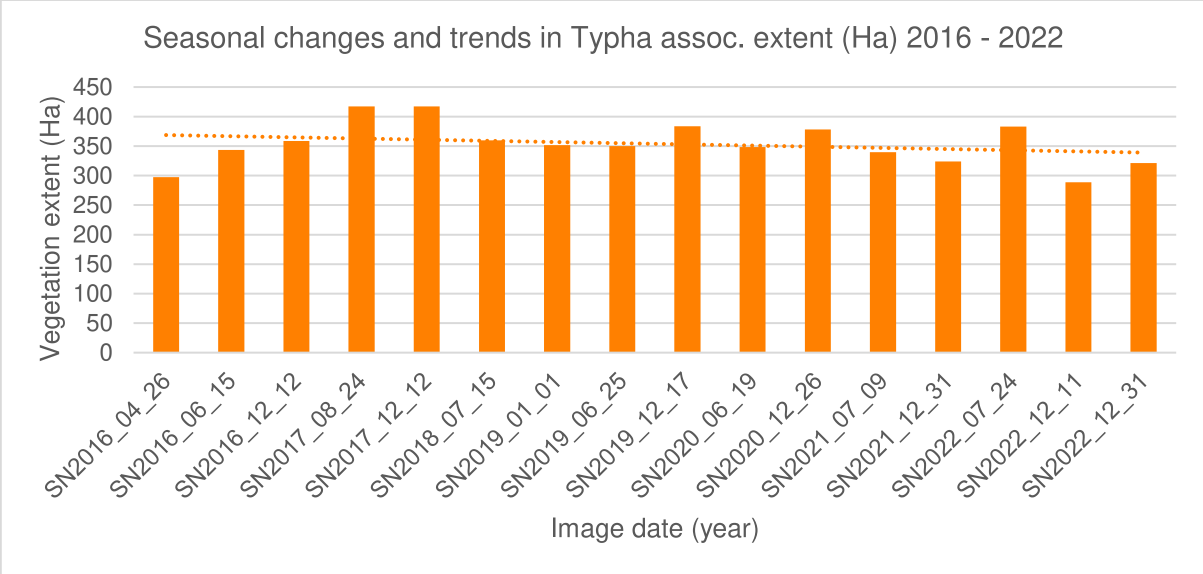


Figure 4-4 – Seasonal changes and trend in Typha association extent 2016 – 2022

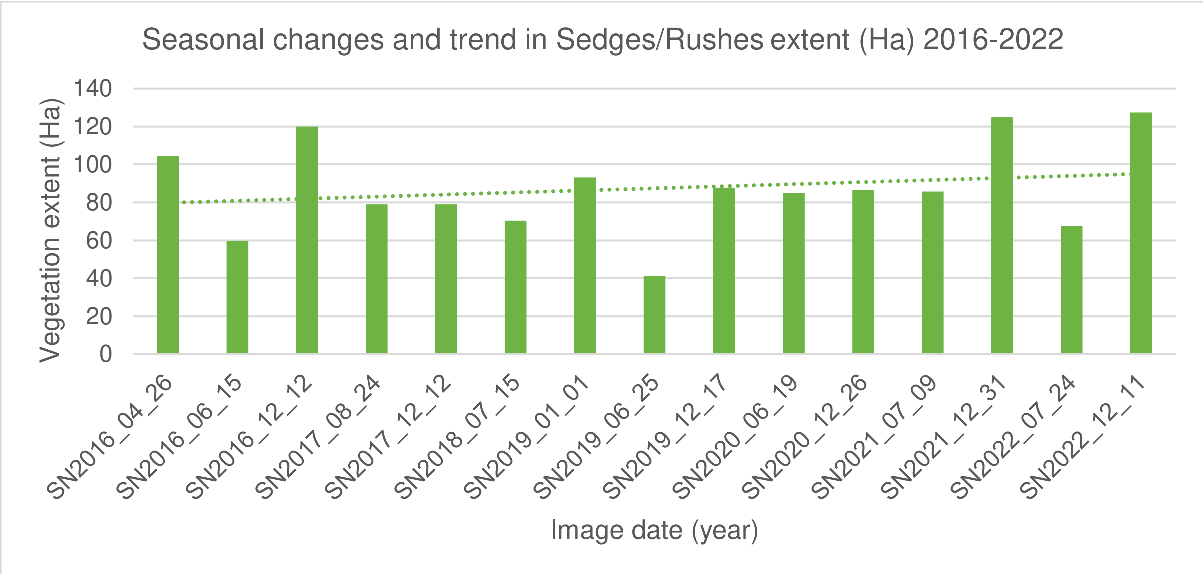


Figure 4-5 – Seasonal changes and trend in sedge/rush extent 2016 – 2022

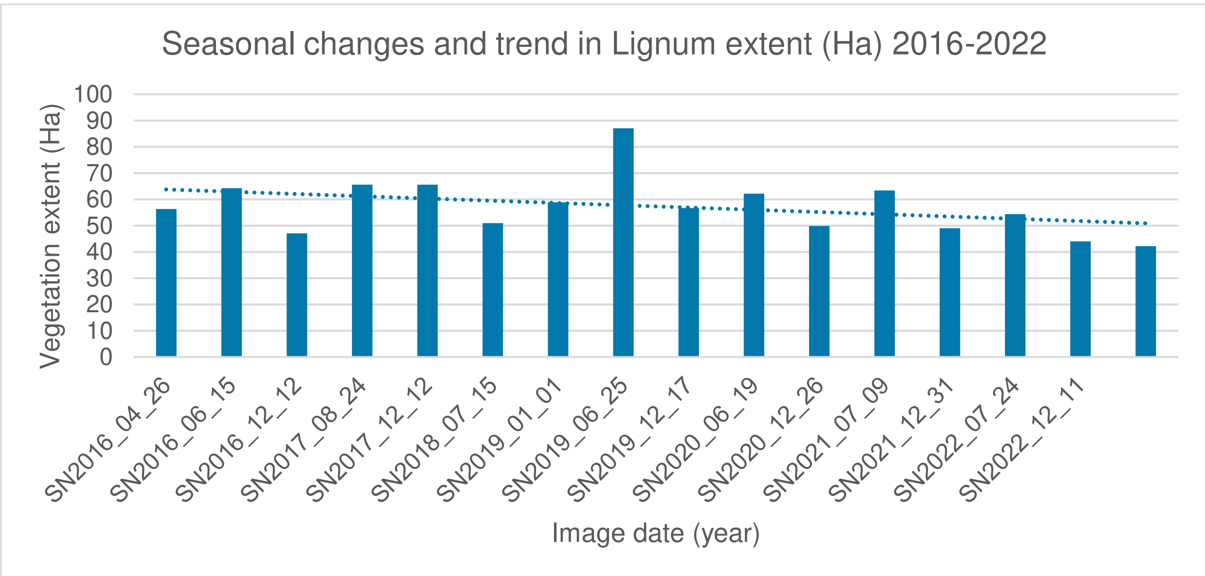


Figure 4-6 – Seasonal changes and trend in Lignum extent 2016 – 2022

The chart in Figure 4-2 indicates the overall changes and trend in Tall Reed extent over the past 6 years. There have been significant contractions and expansions in the order of 60Ha with extents ranging between 480Ha and 540Ha. There has been a trend toward decreasing extent during this period. The charts in Figure 4-3 and Figure 4-4 respectively show the overall changes and trends for Phragmites, which is increasing in extant and Typha association which is decreasing in extent.

The greater overall extents of Tall Reed indicated in Figure 4-2 as compared to the Landsat results in Figure 4-1 is due to the improved detection in Sentinel-2 imagery because of its higher spatial and spectral resolution and not necessarily because the overall extent has changed between the periods for which Landsat and Sentinel-2 imagery has been used. For example, the Landsat extent for Tall Reed in 2018 was ~350Ha whereas for Sentinel-2 it was ~480Ha. In the assessment of the overall cover and trend of Tall Reed (and the other vegetation types) since 2016, the Sentinel-2 results have been used over Landsat due their greater level of accuracy.

Figure 4-5 indicates that the extent of sedges/rushes typically fluctuates between 60Ha in winter and 120Ha in summer with an overall increasing trend across the period. Figure 4-6 indicates that the extent of Lignum typically varies between 40Ha and 60Ha except for 90Ha in winter 2019 with a slight decreasing trend over the period. These changes are discussed further in Section 4.1.2.2

Table 4-9 shows the summer (maximum) extents for the Yugovic equivalent vegetation classes. It is evident from these results that there have been changes in vegetation extents during the period 2016 to 2022. Table 4-10 compares the classification results with the previous mapping by Ecological Perspectives (2019). Table 4-11 presents the results for 2022 in both Yugovic equivalent and with Phragmites and Typha association classified separately.

Table 4-12 quantifies the proportion (%) of vegetation classes relative to total area of Reedy Lake (876Ha). These results demonstrate the no one vegetation class is dominating the vegetation cover at Reedy Lake being below the Limit of Acceptable Change of 70%.

Table 4-13 shows the direction of change (positive or negative) year-on-year for maximum (summer) vegetation extents between 2016 and 2022.

Table 4-9 – Time-series of classified Sentinel-2 imagery 2016 to 2021 (summer extents shown to portray the maximum extent in each year)

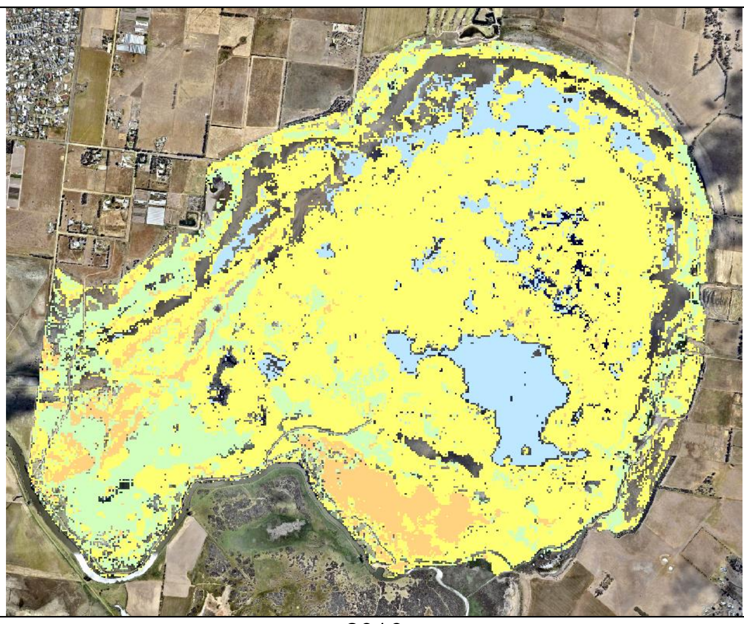
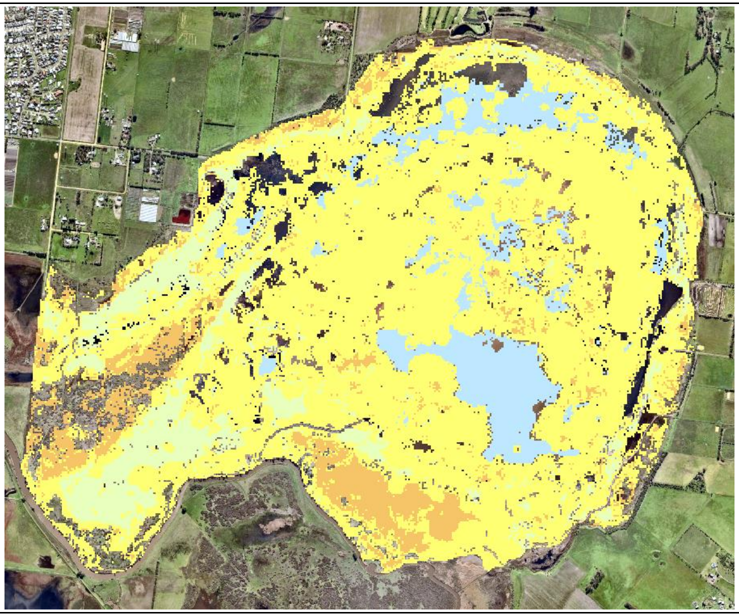
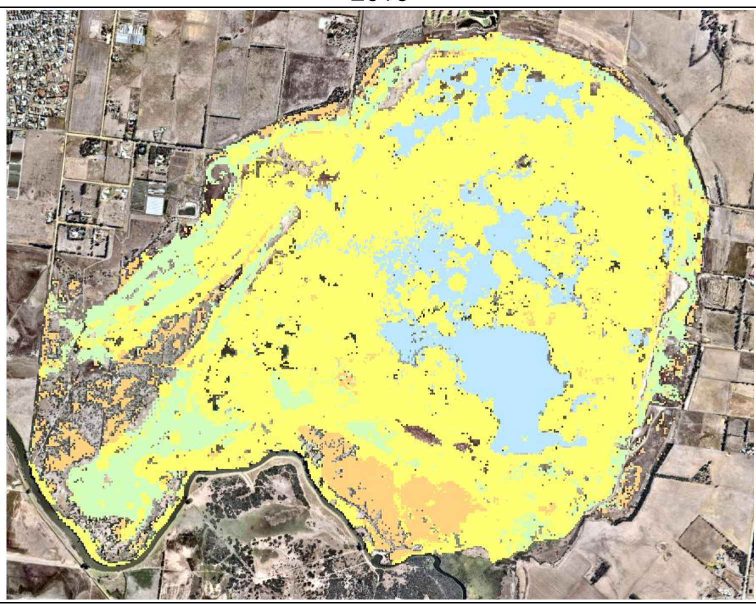
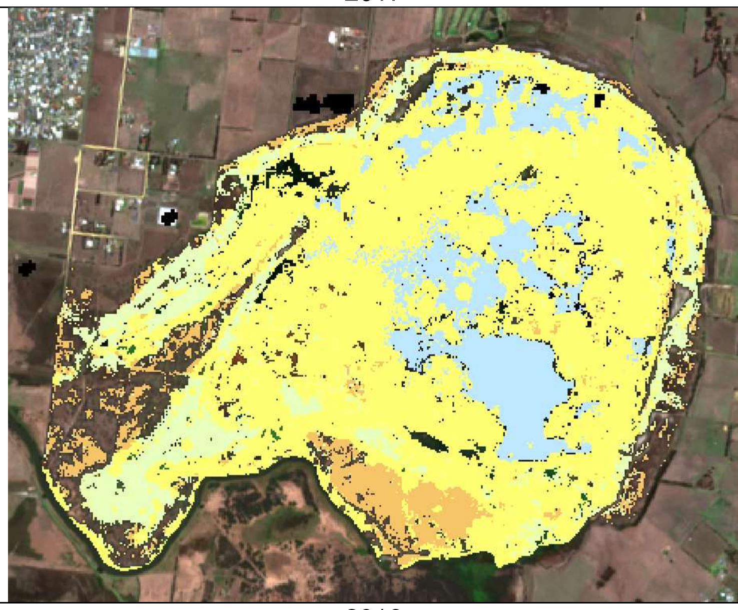
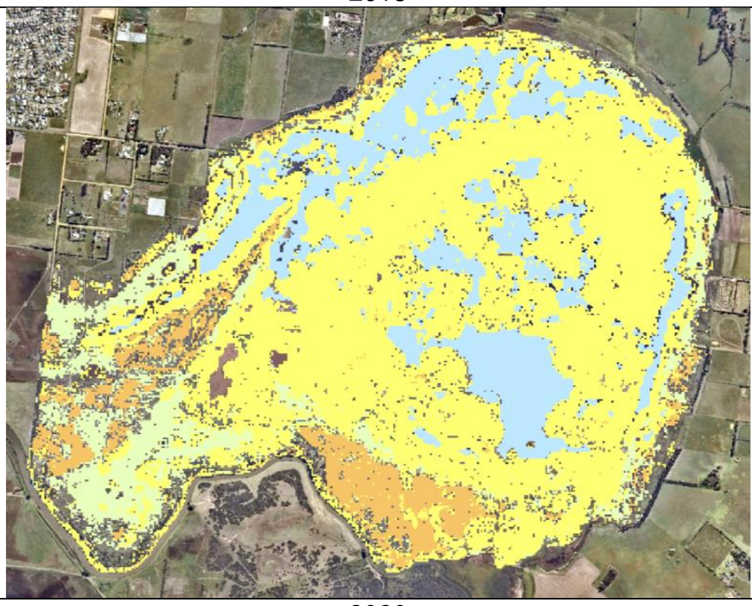
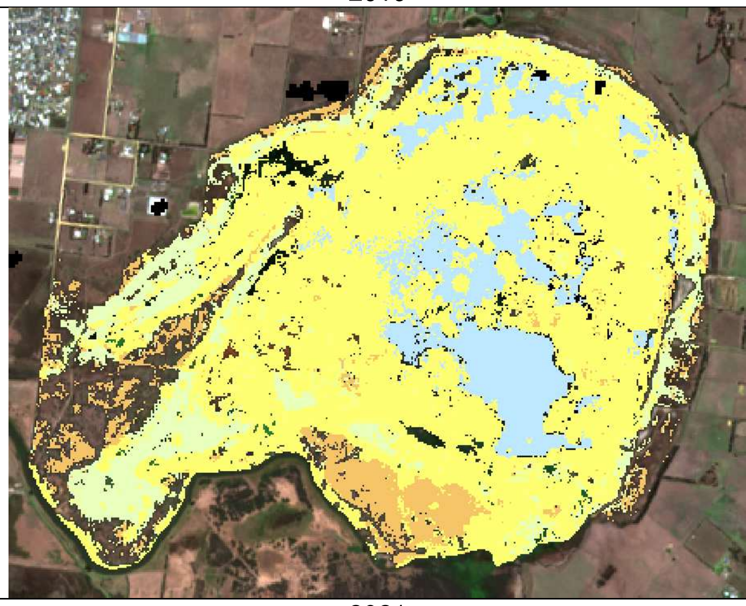
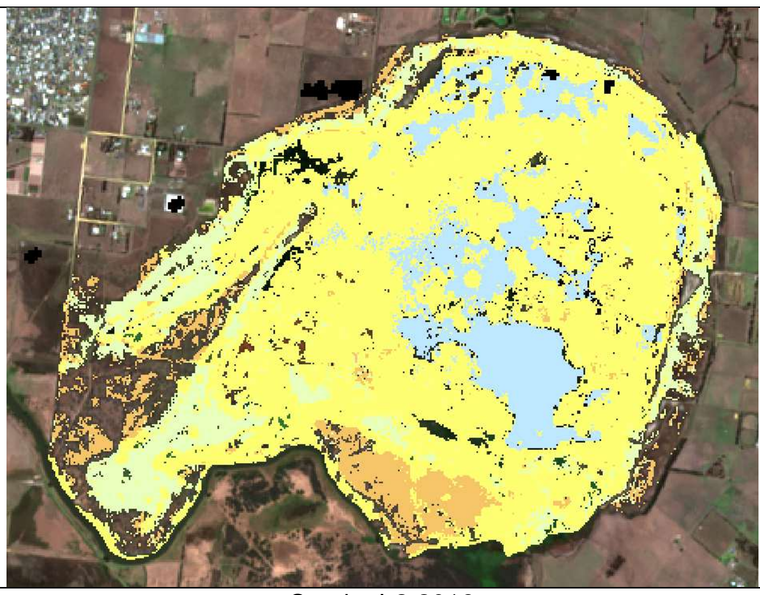
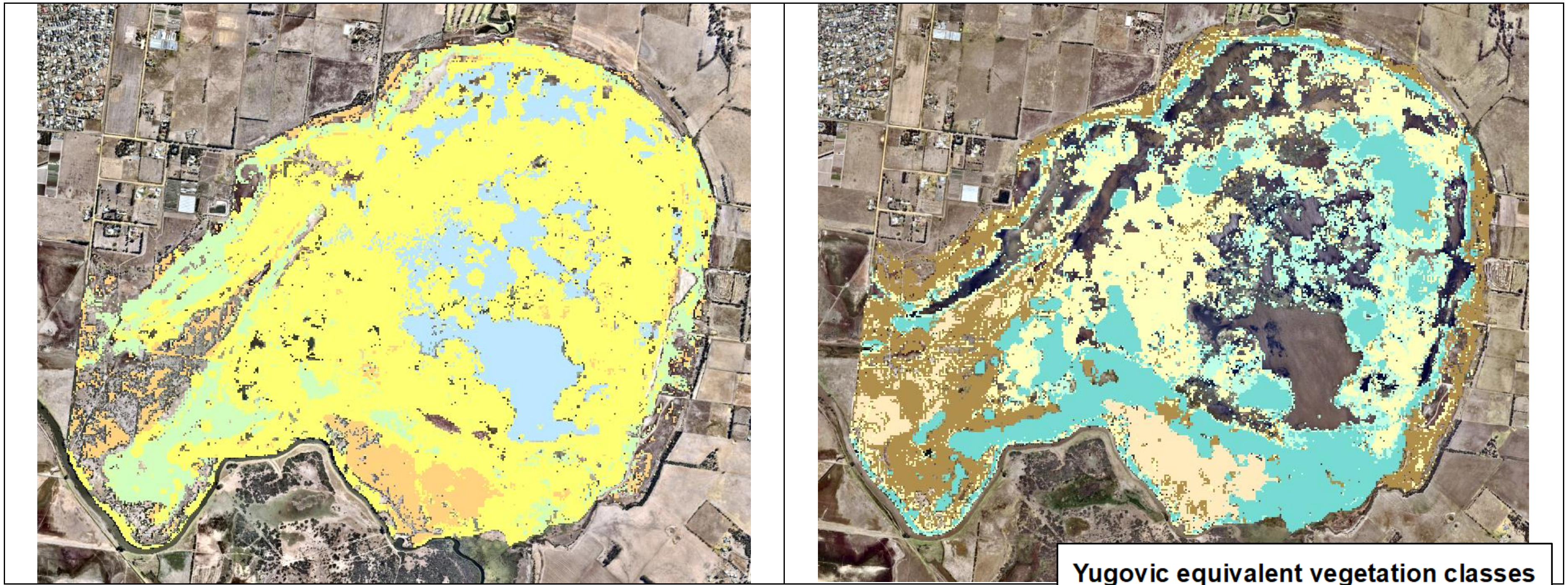
	
2016	2017
	
2018	2019
	
2020	2021

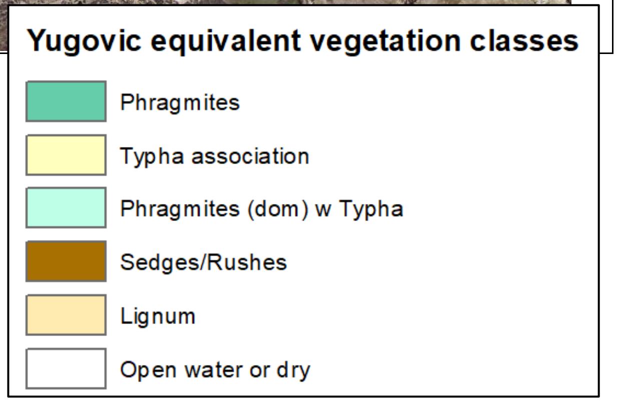
Table 4-10 – comparison of vegetation extents symbolised to Yugovic equivalent. Classified Sentinel-2 imagery (left) and previous mapping (right)

	
Sentinel-2 2019	Ecological Perspectives 2019

KEY: Yellow = Tall Reed; Green = Sedges/Rushes; Orange = Lignum; Blue = Open water (or dry)

Table 4-11 – 2022 Sentinel-2 imagery symbolised to Yugovic equivalent (left) and to the individual vegetation classes (right)





The symbolised image in the right panel distinguishes between Phragmites and Typha association.

The classified extents of the vegetation classes concur well with that visible in the aerial imagery.

The 2022 results were used as the basis of the updated Ecological Vegetation Class map in Appendix A.

Table 4-12 – proportion (%) of vegetation classes relative to total area of Reedy Lake (876Ha)

Classes	Proportion (%) of vegetation classes relative to total area (Ha) of Reedy Lake														
	SN2016_04_26	SN2016_06_15	SN2016_12_12	SN2017_08_24	SN2017_12_12	SN2018_07_15	SN2019_01_01	SN2019_06_25	SN2019_12_17	SN2020_06_19	SN2020_12_26	SN2021_07_09	SN2021_12_31	SN2022_07_24	SN2022_12_11
1_Phrag	20	17	15	14	14	13	15	15	15	15	18	15	19	16	19
2_Typha	22	20	22	22	22	27	20	21	28	23	27	17	26	24	22
3_Phrag/Typha	12	19	19	25	25	14	20	19	15	17	16	21	11	20	11
4_Sedges/Rushes	12	7	14	9	9	8	11	5	10	10	10	10	14	8	15
5_Lignum	6	7	5	7	7	6	7	10	6	7	6	7	6	6	5
6_Open Water	11	10	5	5	5	5	6	2	6	6	6	9	8	6	10
7_Shallow water with veg	5	8	3	3	3	7	5	10	3	10	7	7	8	12	14
Total	**89**	**89**	**84**	**87**	**87**	**81**	**84**	**81**	**84**	**87**	**90**	**88**	**92**	**92**	**95**
Tall Reed (class 1, 2 & 3)	54	56	56	62	62	54	55	55	58	55	61	54	56	60	52

Table 4-13 - relative changes in area (positive or negative) between each time-step (summer/maximum extents)

Classes	Net change in area (Ha) classified year-on-year						
	SN2016_12_12	SN2017_12_12	SN2019_01_01	SN2019_12_17	SN2020_12_26	SN2021_12_31	SN2022_12_11
1_Phrag	base year	-7.06	4.44	-0.8	32.4	8.26	-5.05
2_Typha	base year	4.41	-20.24	73.12	-9.61	-7.75	-34.99
3_Phrag/Typha	base year	54.29	-45.43	-41.28	3.97	-46.05	-0.39
4_Sedges/Rushes	base year	-40.86	14.1	-5.34	-1.31	38.32	2.53
5_Lignum	base year	18.53	-6.66	-2.22	-6.8	-0.9	-4.93
6_Open Water	base year	2.36	2.77	4.52	-1.16	17.54	12.99
7_Shallow water with veg	base year	-4.28	22.7	-21.56	31.49	8.11	61.21
Total	**0**	**27.39**	**-28.32**	**6.44**	**48.98**	**17.53**	**31.37**

4.1.2.2 Change detection

The higher resolution of the Sentinel-2 imagery afforded the opportunity to perform some change calculations in ArcGIS by comparing the summer vegetation extents in 2016 and 2022. Summer represents the maximum extent from the growth season in each year. The results highlight key areas within Reedy Lake where overall change was detected for each of the four key vegetation classes, being Phragmites, Typha association, Sedges/Rushes, and Lignum. Change results are reported as being either expansion, contraction, or no change. Commentary is made regarding observed inter-annual and seasonal change, where applicable.

Change was investigated for:

- Summer to summer in consecutive years
- Winter to winter in consecutive years
- Winter to summer
- Summer to winter

4.1.2.2.1 Tall Reeds

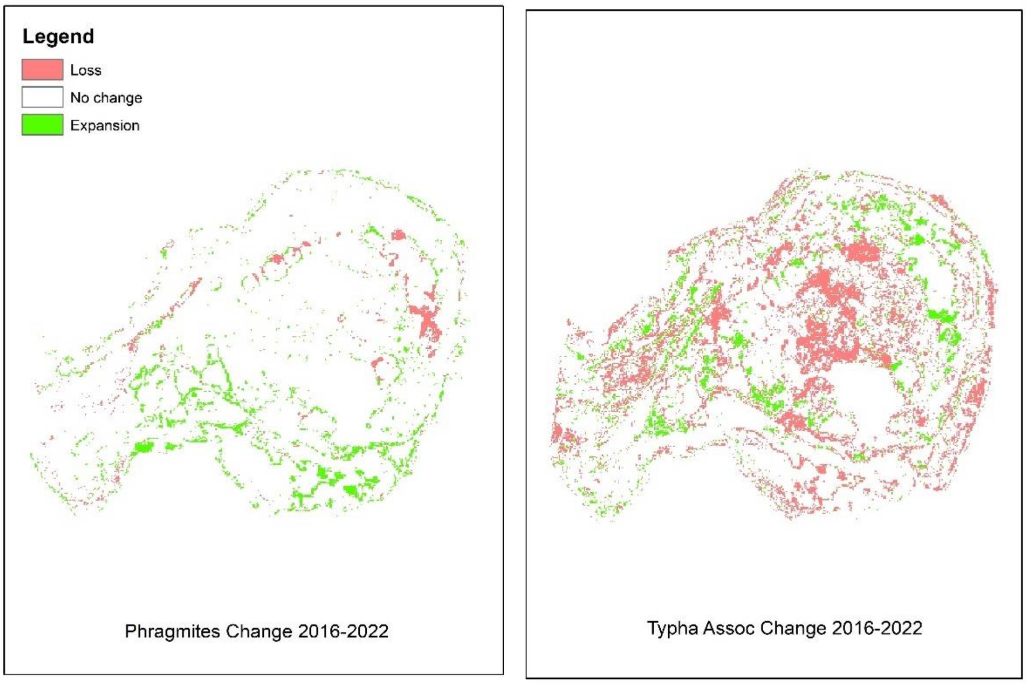


Figure 4-7 – overall change in extent of Tall Reed (Phragmites and Typha) 2016 - 2022

Phragmites

Phragmites has expanded significantly in the southern parts of the wetland and around the wetland perimeter. Patches within the northern semi-circle and south western peninsula have altered to Typha association.

Summer to Summer and Winter to Winter extents are similar year to year for much of the period and there is a subtle Winter to Summer increase and Summer to Winter decrease in extent as would be expected with the seasonal growth and die back of vegetation. The latter winter extent is typically slightly greater than the previous winter extent each year because of the previous summer's growth. Much of the contribution to the increase in overall extent has occurred in the southern part of the wetland and during 2020 to 2022, coinciding with the recent wetter years. However, the losses of extent has occurred incrementally over the entire period.

Typha association

There has been a significant overall reduction in Typha association in many parts of the wetland. Some areas of expansion include into existing Phragmites stands and around the southern and south western margins of the wetland. Summer to Summer and Winter to Winter extents exhibit small negative changes year to year and there is a subtle Winter to Summer increase and Summer to Winter decrease in extent as would be expected with the seasonal growth and die back of vegetation. This indicates the incremental nature of the extent change of Typha association in the wetland.

4.1.2.2.2 Sedges/Rushes

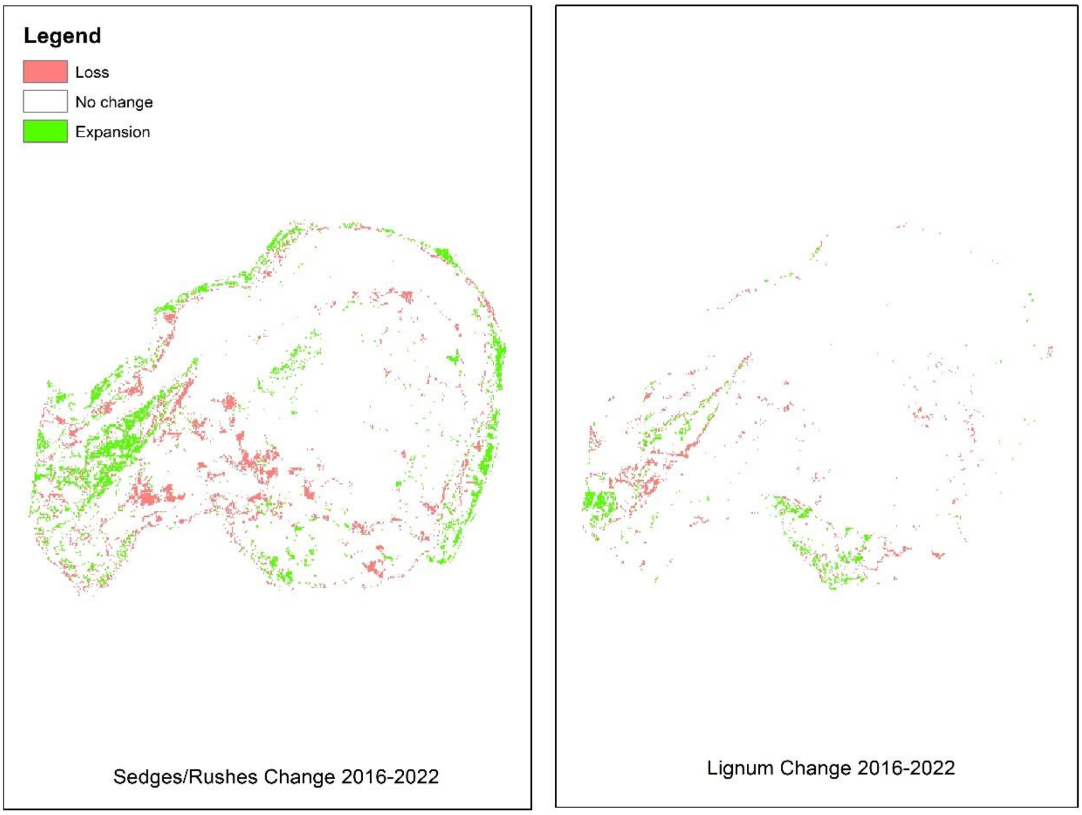


Figure 4-8 - overall change in extent of Sedges/Rushes (esp. Bolboschoenus caldwelli) and Lignum 2016 – 2022

The narrow bands of sedges/reeds around the north western, northern and eastern perimeter appeared to have slightly shifted elevations. There was also an apparent contraction in range around the southern perimeter, especially to the east of the peninsula feature protruding into the south west part of the wetland.

The large bed in the central southern part of the wetland appeared relatively stable over time, losing some extent to Typha association. Between 2020 and 2022, during the wetter period, sedges/rushes expanded, particularly around the perimeter and into the south western peninsula feature. There is a strong seasonal variation in extent, with summer extents being significantly greater than winter extents. Summer to summer and winter to winter extents have incrementally increased.

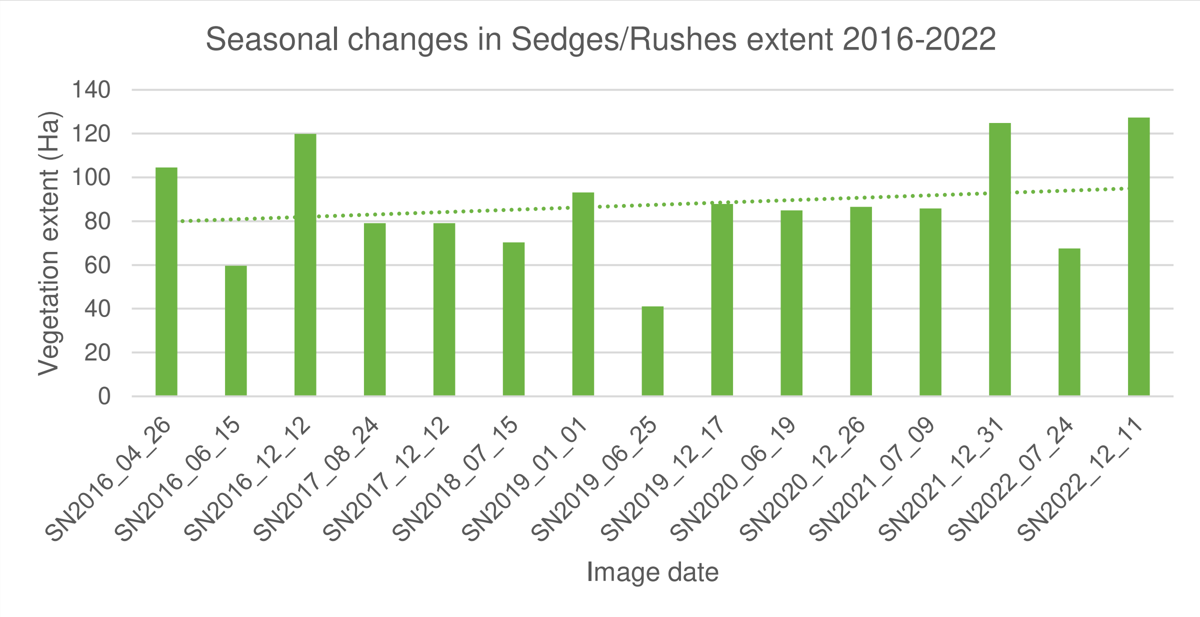


Figure 4-9 – seasonal changes and trend for Sedges/Rushes 2016 to 2022

4.1.2.2.3 Lignum

There are two large contiguous areas of Lignum at Reedy Lake, both existing in the southern part of the wetland at elevations above 0.8mAHD. These areas changed slightly in their extents over time, with minor localised expansions and contractions. The southern patch has expanded slightly overall around its perimeter but has experienced incursion of Phragmites and some Typha.

The results for the patch on the south western peninsula appear to show that it has contracted significantly along its central and eastern margins. Further investigation of the imagery and on-ground revealed that the significant expansion of sedges/rushes in the understorey of this area between 2020 and 2022 overwhelmed the spectral signature of the Lignum and caused it to show as a relative loss of extent. This is presumed to have occurred because Lignum has woody stems, compared to sedges/rushes that form dense beds of highly reflective leafy stems. This effect was potentially coupled with certain patches of Lignum experiencing water stress due to the significantly wetter period, with the spectral reflectance of these patches reducing as the woody Lignum stems changed from green to red and/or grey as they senesced. This is shown in Figure 4-10.

A third occurrence of Lignum is in narrow bands around the wetland perimeter and lastly, as isolated individual plants or patches occurring across the bed of the wetland. Overall, Lignum was the most stable vegetation class in terms of relative changes in extent over time. There is little observed seasonal variation in Lignum extent.

Figure 4-10 – different Lignum stem colours according to growth phase. The bush in the foreground has red and grey stems whilst the bushes in the background have green stems. Senescent bushes will have a different spectral signature to healthy Lignum.

Figure 4-11 –the dense Bolboschoenus beds that are typically found surrounding Lignum in the south western parts of Reedy Lake. These beds will be influencing the spectral signatures of the Lignum in these areas.

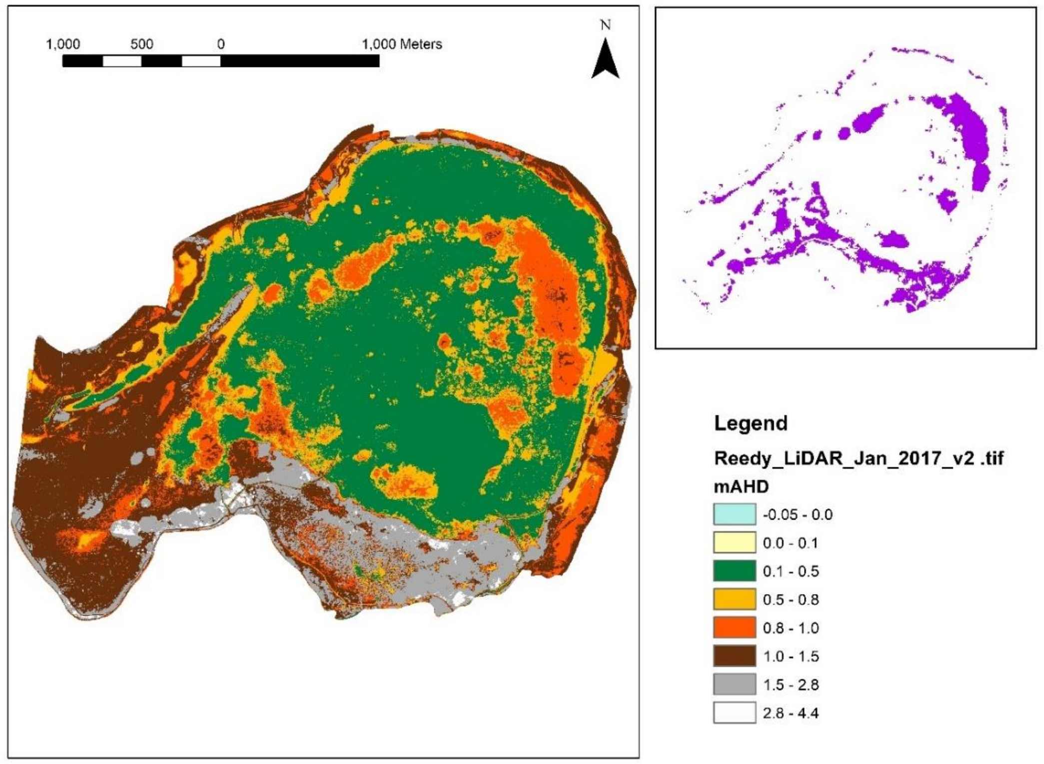
4.2 Vegetation class elevation associations

The 2017 Digital Elevation Model (with a spatial resolution of 1m and vertical accuracy of 0.1m) and the Sentinel-2 derived vegetation extents for 2017 (shown in purple in Figure 4-12) were used to explore the relationship between vegetation classes and wetland surface elevation. The results are summarised in Table 4-14 and shown in Figure 4-12. By visually cross referencing the purple extents in Figure 4-12 with the elevation ranges in the legend, gives an indication of which areas in the wetland are occupied by the different vegetation classes and what the elevation range is in those areas. There is a strong elevation association indicated in these results.

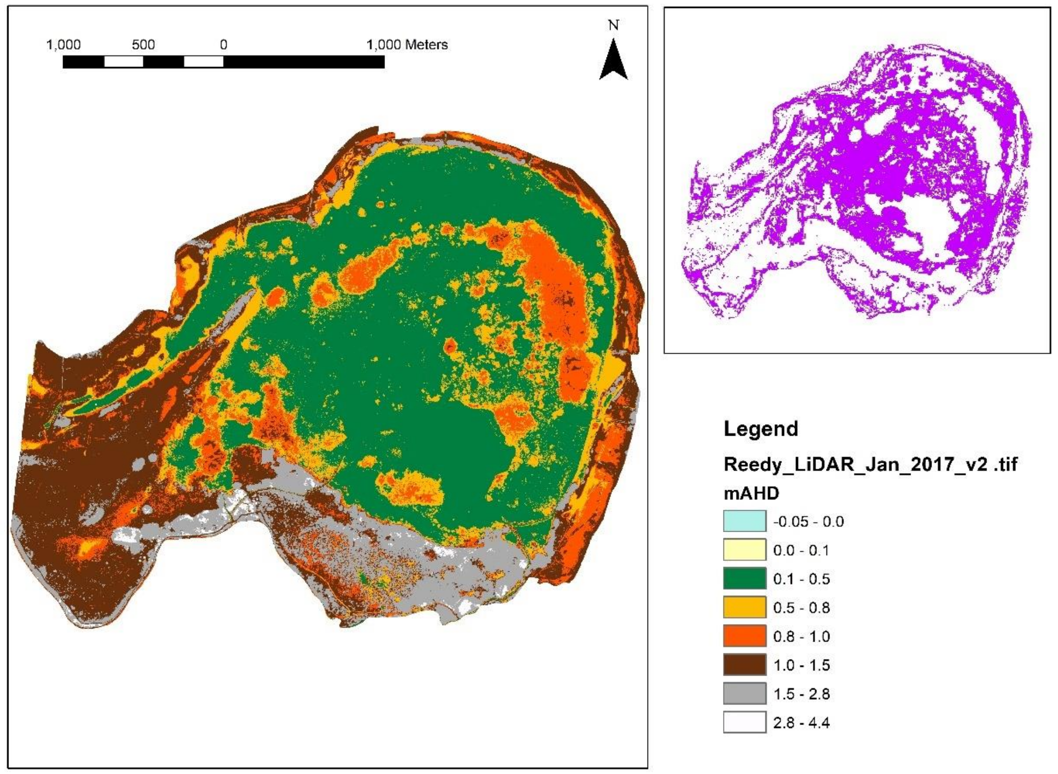
Phragmites within the wetlands northern and southern semi circles occurs at elevations between 0.5 and 1.0mAHD. Typha association typically occurs up to 0.5mAHD but can occur at higher elevations around the wetland perimeter. Sedges and rushes are largely restricted to the wetland perimeter between 0.8 and 1.5mAHD and Lignum to between 1.0 to 1.5mAHD in the south western peninsula and >1.5mAHD in the large stand in the southern perimeter between the wetland and the Barwon River.

Table 4-14 – typical vegetation class elevation associations at Reedy Lake. Note the elevation range is the difference between the minimum and maximum elevations (to mAHD) preferenced by each vegetation class.

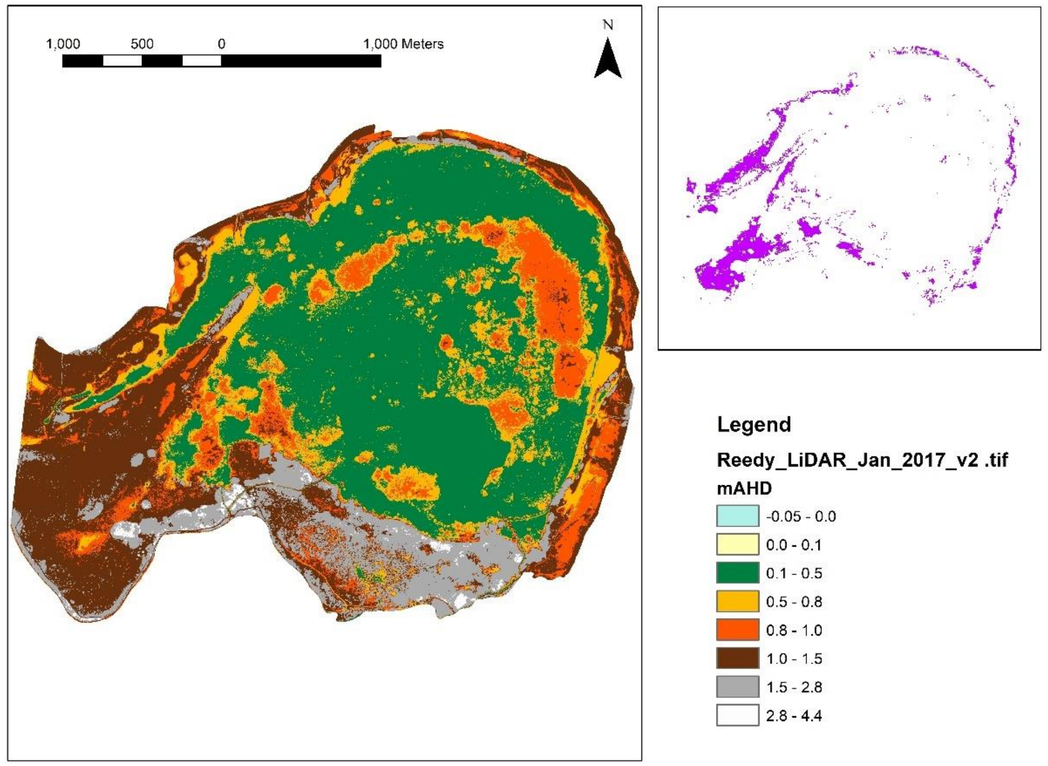
Vegetation Class	Min elevation (mAHD)	Max elevation (mAHD)	Elevation range (m)
Phragmites	0.5	1.0	0.5
Typha association	0.0	0.5-0.8	0.5-0.8
Sedges/Rushes	0.8	1.5	0.7
Lignum	1.0	1.5	0.5
Open water	0.0	0.8	0.8



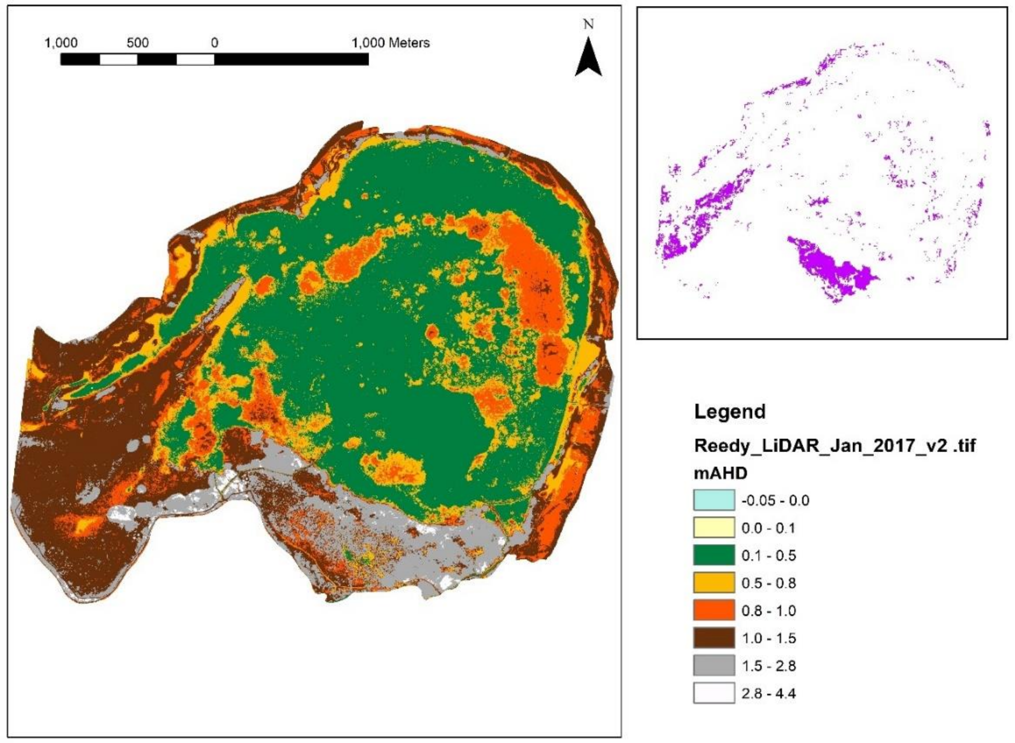
Phragmites elevations and extents (purple)



Typha association elevations and extents (purple)



Sedges/Rushes extent and elevations and extents (purple)



Lignum extent and elevations and extents (purple)

Figure 4-12 – Vegetation class elevation associations and extents for 2017. Visual cross-reference of the purple extents for each vegetation type with elevation ranges depicted in the classified DEM (as per legend) gives their preferred elevation ranges.

4.3 Water levels, extents, and depths to mAHD

4.3.1 Water levels and inundation frequency

A series of analyses were performed on the water level data to help visualise the dynamics of the watering regime that was implemented during the 2016-2022 period.

Figure 4-13 shows that during the years 2016 to 2019 where the wetland was able to be drawn down, there were less than 90 days when water levels were at or above 0.8mAHD and that most water levels were <0.8mAHD. Also indicated during that period were instances where water levels at the Big Hole gauge were >0.8mAHD which would have partly correlated with spilling events from and back into the Barwon River where levels were >1.1mAHD. During the La Nina years (2020-2022), there is a greater frequency of days per year in the higher water levels (>0.7m AHD). During this time the wetland was not able to be drawn down during summer in 2020/21 and 2021/22 due to the higher water levels in the Barwon River. For 2019/20, which was a planned non-draw-down year, this was not an issue. A similar seasonal pattern is indicated by Figure 4-14.

Figure 4-15 shows that for the entire period of 2439 days, 60% of the time (1465 days), water levels exceeded 0.8mAHD, 38% of the time (925 days), water levels were between 0.2m and 0.8mAHD.

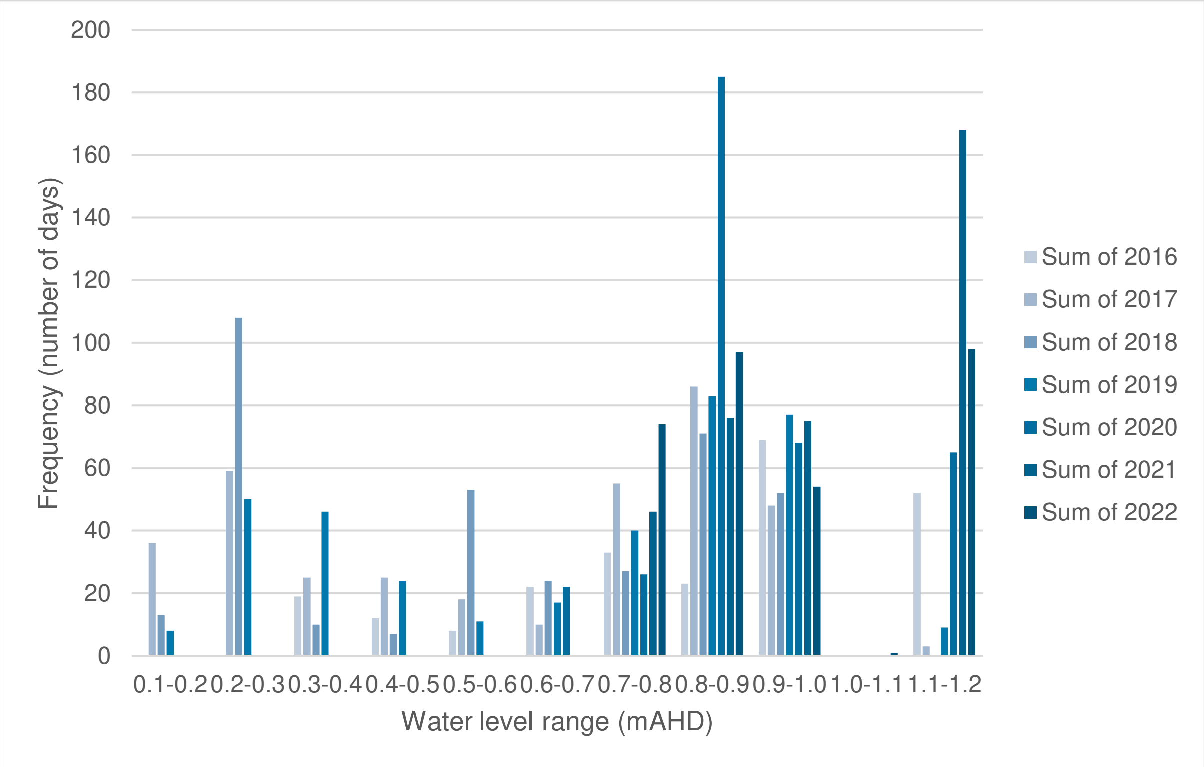


Figure 4-13 – frequency chart of the number of days in each year water levels were in the ranges specified. Lighter coloured years are early in the period and darker coloured years are more recent. In more recent years, known to have been wetter, there have been more frequent water levels above 0.7m AHD in Reedy Lake and during the period 2016 to 2019, water levels were ranging <0.8mAHD

Table 4-15 – Mean water level per Quarter in each year (2016-2022) (same data used in Figure 4-14)

Year	Qtr1 (Jan-Mar)	Qtr2 (Apr-Jun)	Qtr3 (Jul-Sep)	Qtr4 (Oct-Dec)	Average
2016	No data	0.77	1.02	0.70	0.84
2017	0.21	0.74	0.84	0.58	0.59
2018	0.23	0.46	0.89	0.67	0.57
2019	0.31	0.55	0.94	0.79	0.65
2020	0.76	0.87	0.92	0.97	0.88
2021	0.87	0.86	1.04	1.04	0.95
2022	0.85	0.76	1.00	1.27	0.97
Average	**0.54**	**0.71**	**0.95**	**0.86**	**0.78**

Table 4-16 – frequency of water levels across entire period (2016-2022) (sane data used in Figure 4-15)

Water Level m AHD	# Days
0.1-0.2	57
0.2-0.3	217
0.3-0.4	100
0.4-0.5	68
0.5-0.6	90
0.6-0.7	95
0.7-0.8	301
0.8-0.9	621
0.9-1.0	443
0-0.1	0
1.0-1.1	6
1.1-1.2	395
1.2-1.3	11
1.3-1.4	8
1.4-1.5	12
1.6-1.7	7
1.7-1.8	6
1.8-1.9	2
Grand Total	**2439**

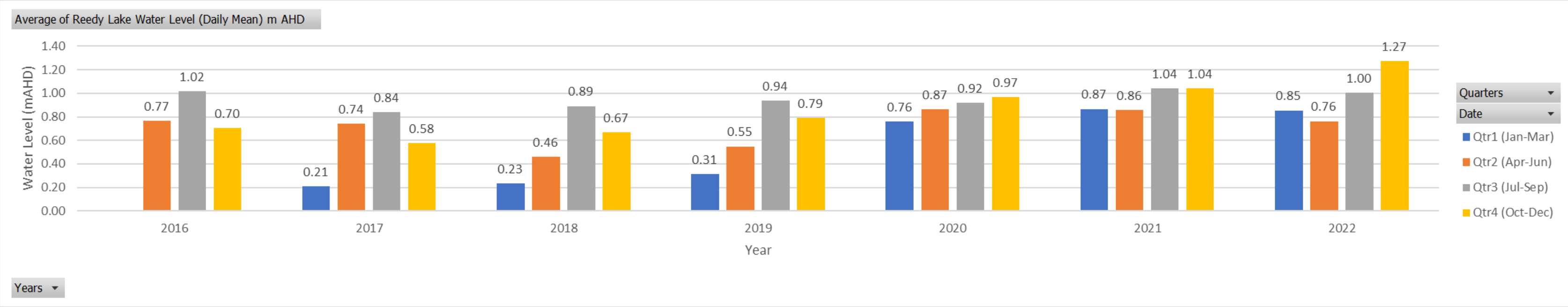


Figure 4-14 – mean daily water levels per season (Quarter). Note: water level monitoring commenced 28/04/2016 so there is no data for Qtr 1 2016.

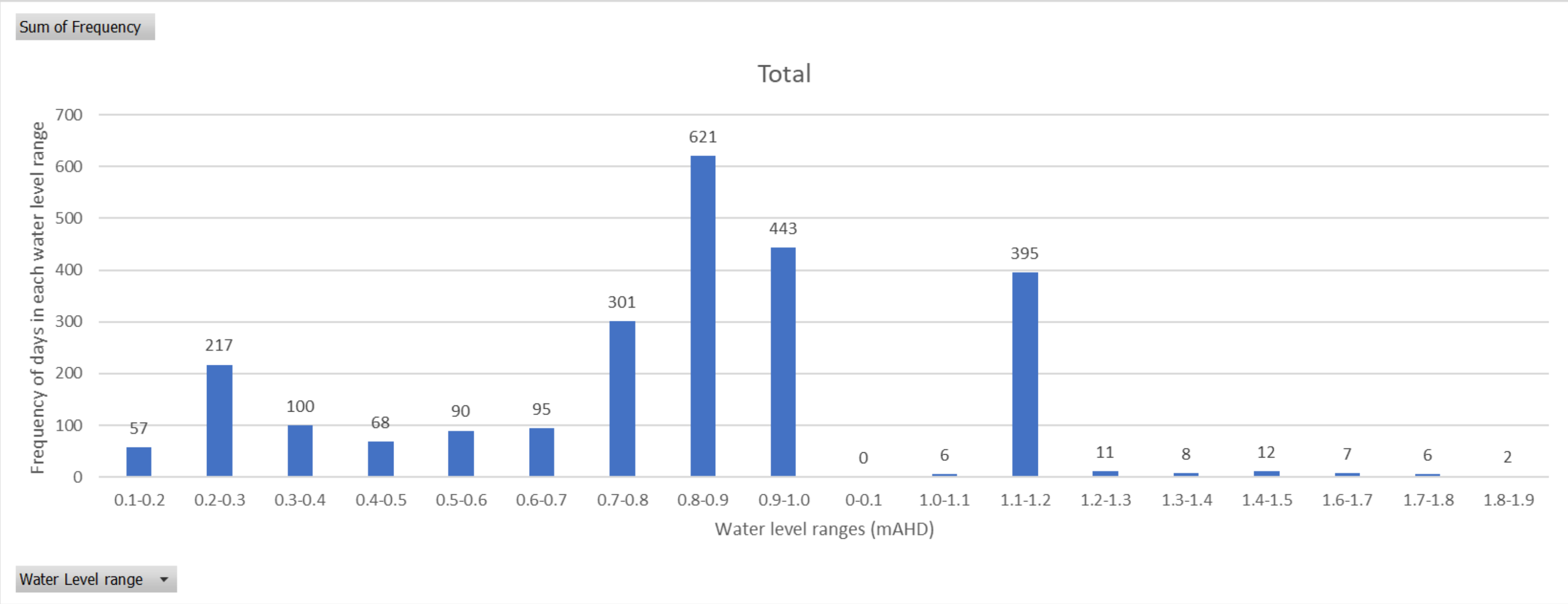


Figure 4-15 – frequency of different water levels at Reedy Lake across the entire (2439 day) period (2016-2022)

4.3.1.1 Water extents and depths

The 2017 DEM was used to model water ***extents*** of the surface of Reedy Lake based on the recorded water levels to mAHD. A visual assessment of water extents in the available high resolution aerial imagery combined with these modelled water extents was compared against the mapped vegetation extents for selected timesteps from the Sentinel-2 imagery to gain an impression of the relationship between water levels and extents, and vegetation extents. There was good agreement between recorded water levels at the Reedy Lake gauge, the water extents visible in the imagery and the extents mapped over the DEM. Secondly, water ***depths*** were calculated for water levels where the associated mapped extents inundated different locations/areas of the wetland bed around vegetation classes located in different parts of the wetland. Water depths were calculated for water extents equivalent to water levels of 0.8mAHD, 0.5mAHD, 0.4mAHD and 0.3mAHD as these levels created the greatest differences in extent and thus depths.

Results of the water extent and water depth mapping are shown in Figure 4-16 and Figure 4-17; and Table 4-17 provides a summary of the available water level, extent and depth data in relation to the vegetation classes. The water **depths** favoured by the different vegetation classes *within* the wetland appear to be:

- Phragmites frequent inundation 0.1-0.2m deep
- Typha association frequent inundation 0.2-0.3m (up to 0.5m) deep
- Sedges/Rushes occasional inundation when water levels exceed 0.8mAHD

Table 4-17 – summary of water level, extent, and depth mapping in relation to vegetation classes

Water extent and depths for 0.3m AHD	Water levels up to 0.3mAHD occurred for a total of 274 days (0, 95, 121, 58 days in 2016, 2017, 2018 and 2019). Areas inundated to <0.1m depth. These levels occur during draw down periods (Quarter 1 Jan-Mar)
Water extent and depths for 0.4m AHD.	Water levels up to 0.4mAHD occurred for a total of 100 days (19 120, 131, 104 days in 2016, 2017, 2018, 2019). Much of the area inundated is favoured by the Typha association vegetation class, which would have received water up to 0.2m deep during those inundation events. Many of those events occurred during the summer growing season (Quarter 1 Jan-Mar).
Water extent and depths for 0.5m AHD.	Water extents up to 0.5mAHD occurred less frequently, totalling 58 days (12, 25, 7, 24 days in 2016, 2017, 2018, 2019). Water depths in these events are also typically up to 0.2m deep, but some areas of the wetland, particularly around the north and some central locations are inundated to 0.3m deep. The deeper inundation areas (to 0.4m) are existing pools. These events typically occurred during Autumn (Quarter 2 Apr-Jun).
Water extent and depths for 0.8m AHD.	Water levels greater than 0.5mAHD up to 0.8mAHD occurred for a total of 318 days (63, 83, 104, 68 days in 2016, 2017, 2018, 2019). Water depths in these events are typically 0.3-0.5m deep across much of the wetland, with some locally deeper areas inundated to 0.5-0.7m.

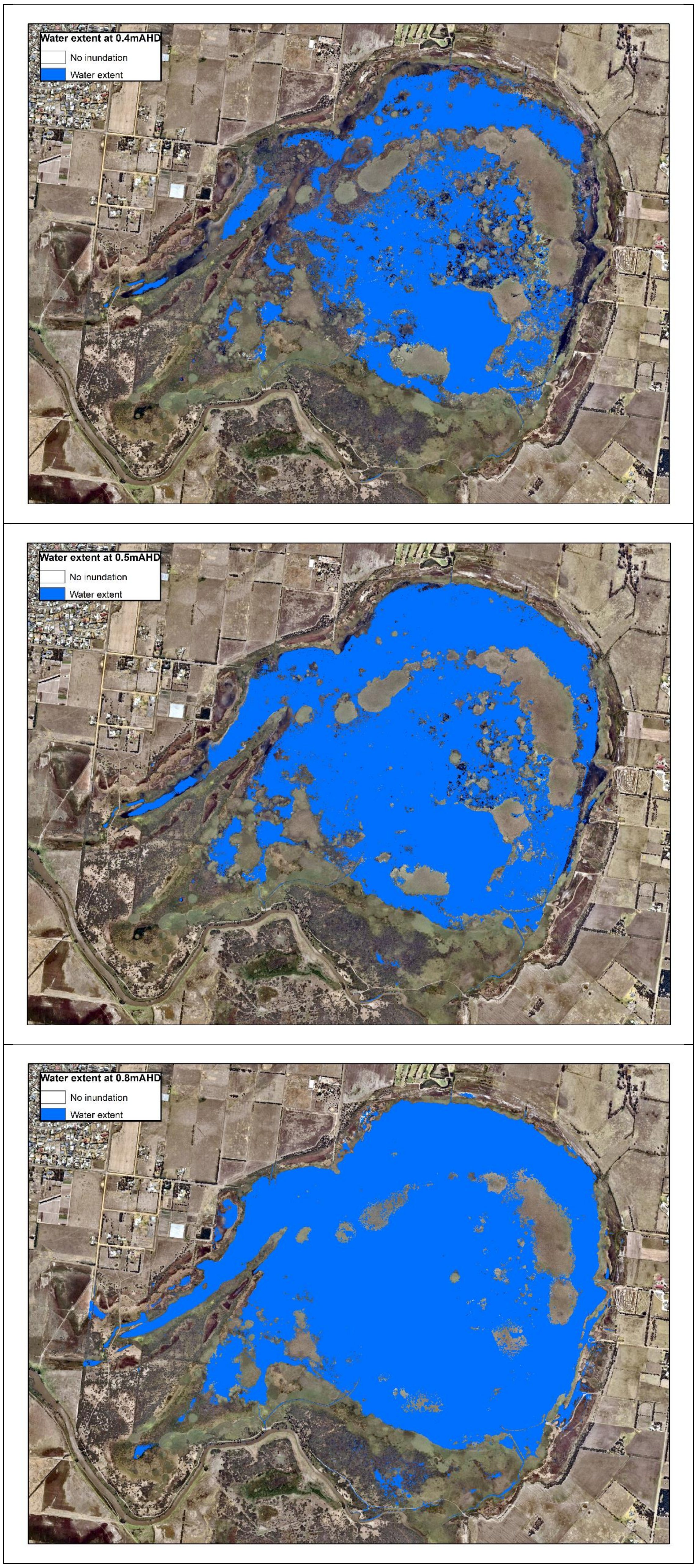


Figure 4-16 – water extents for water levels between 0.4mAHD and 0.8mAHD

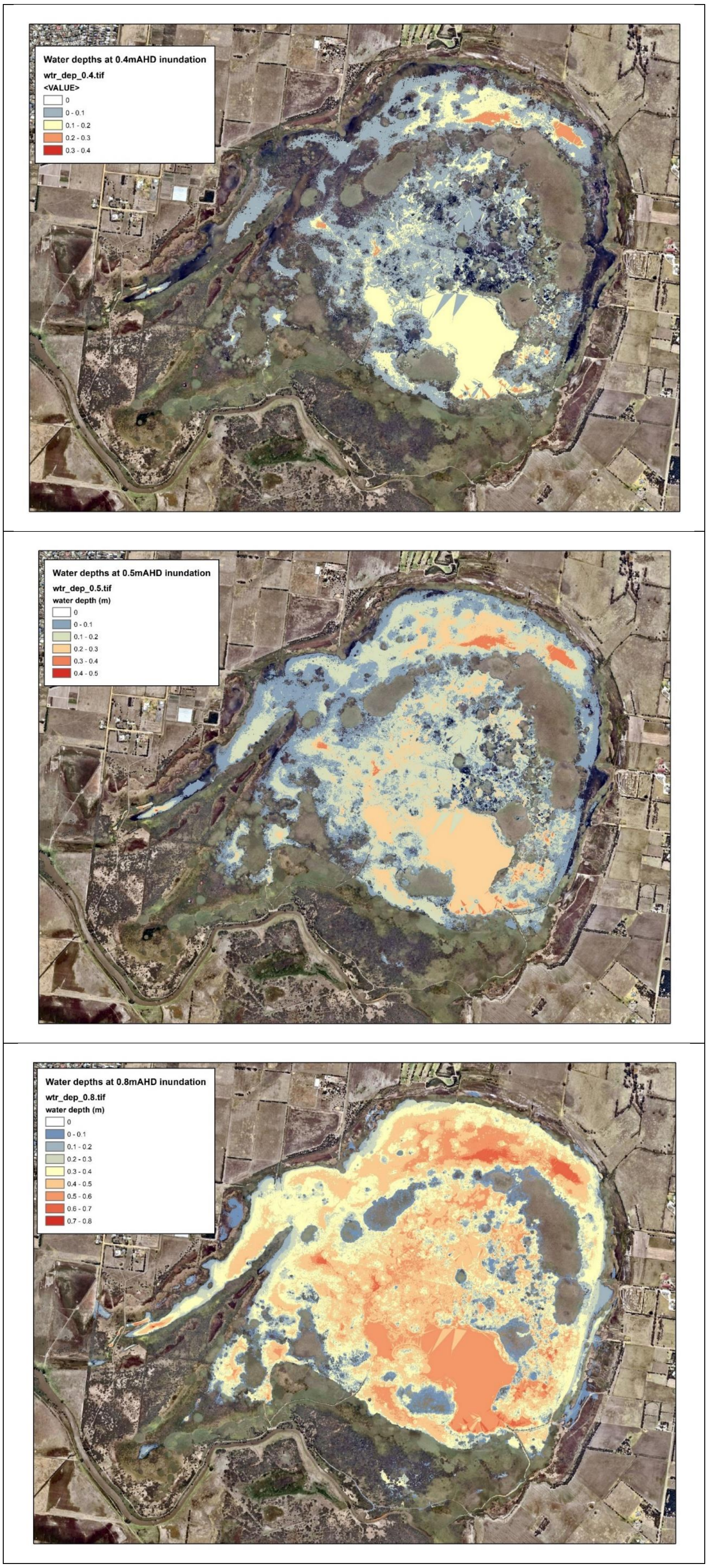


Figure 4-17 – water depths for water levels between 0.4mAHD and 0.8mAHD

The critical water level of 0.3mAHD

The watering regime for Reedy Lake requires summer draw down to 0.3mAHD to support achievement of the environmental objectives[1] (VEWH, 2022). This level has been shown in this study to be a critical water level given the drastically reduced extent of water across the bed of the wetland compared to 0.4mAHD. At 0.3mAHD, much smaller areas are covered by water up to 0.1m deep. At a water level of 0.4mAHD, large areas of the wetland bed are covered with 0.1-0.2m of water. If this water level occurs during the spring-summer growth season, where temperatures are warmer, this provides ideal conditions for germination of Typha from seed. In the interests of maintaining a balance in vegetation types between Tall Reed and other vegetation communities which provide important habitat for birds and fish, periodic drawing down to 0.3m AHD is required to dry the wetland bed sufficiently to promote increase in soil salinity preferencing other vegetation types, and constraining Typha germination.

The difference between these two water levels is illustrated in Figure 4-18.

[1] https://www.vewh.vic.gov.au/rivers-and-wetlands/central-region/lower-barwon-wetlands AND https://ccma.vic.gov.au/wp-content/uploads/2022/07/CCMA-Fact-Sheets-Water-for-the-Environment-Lower-Barwon-Wetlands.pdf

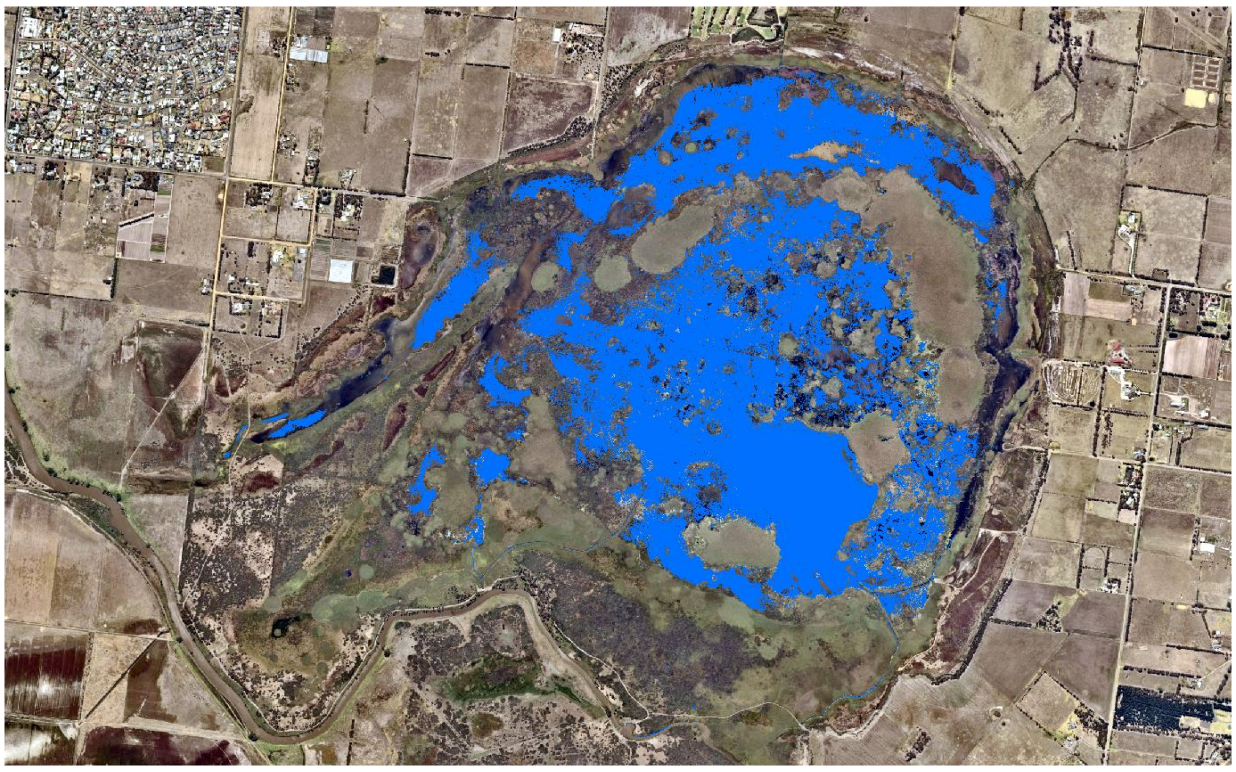
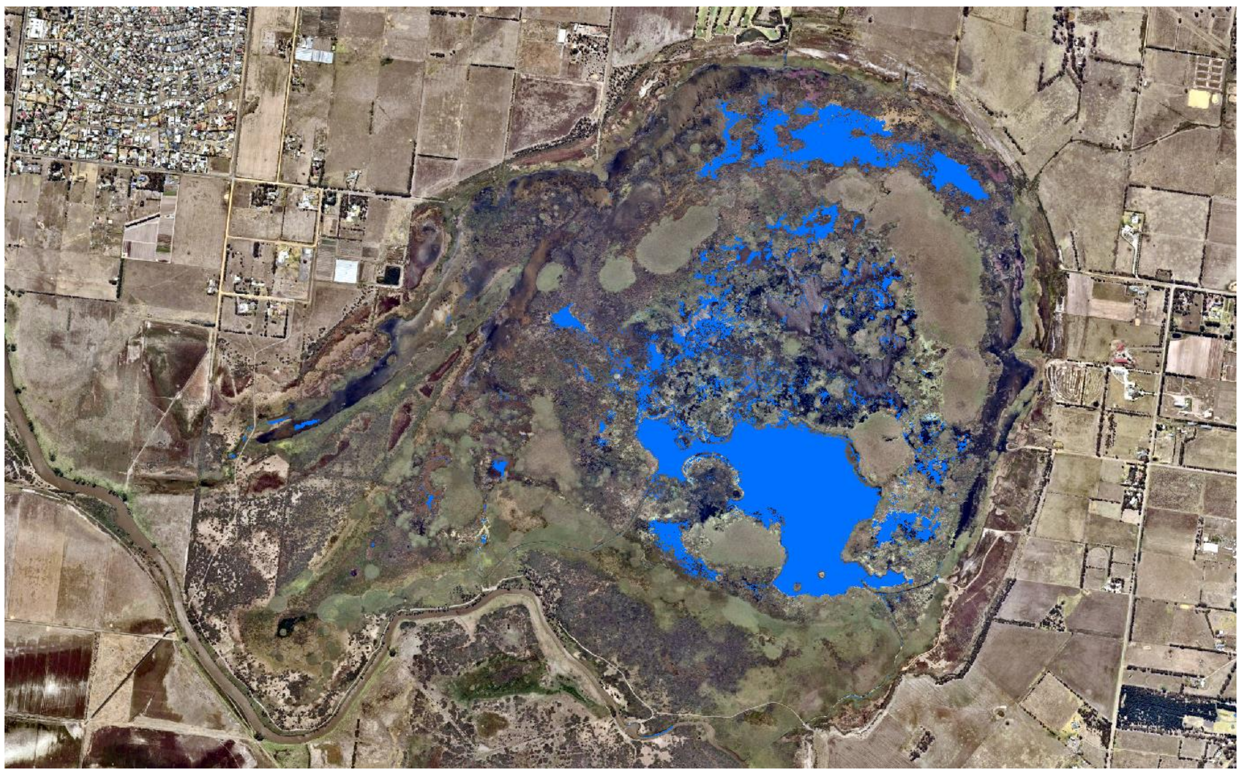
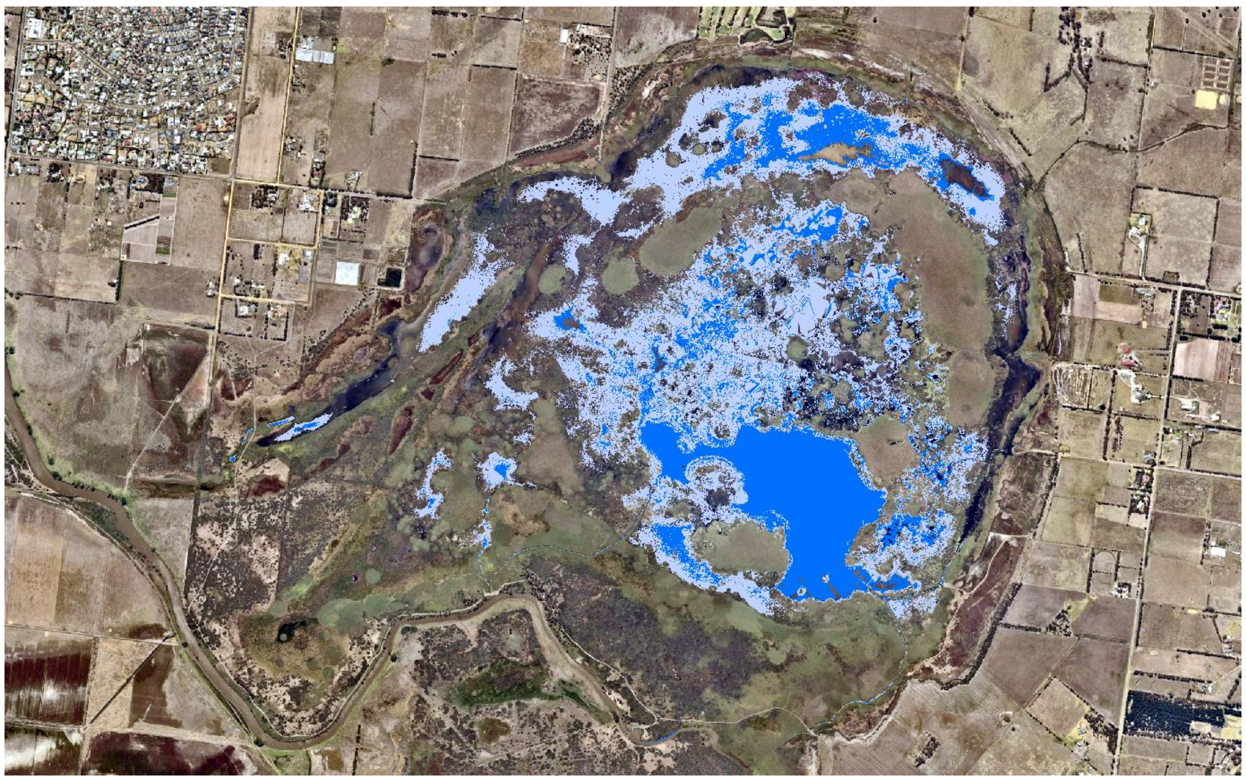

0.4m AHD water extent

0.3mAHD water extent

0.4mAHD (light blue) and 0.3mAHD (dark blue) water extents compared

Figure 4-18 – the difference in water extents between the water levels of 0.4mAHD and 0.3mAHD

4.4 Vegetation class spectral indices

The following spectral results were obtained using false colour images and spectral indices. False colour images provide a simple visual representation of plant health, by showing variations in reflectance that are accentuated using infrared parts of the electromagnetic spectrum; whereas NDVI is a quantitative measure of plant vigour based on reflectance values for visible light and infrared.

4.4.1 False-colour imagery

Figure 4-19 shows the results of a simple band recombination to create false colour images that utilise infrared parts of the electromagnetic spectrum to highlight aspects of vegetation of interest. There is stronger reflectance in both the colour and short-wave infrared in summer for Phragmites in the southern parts of the wetland. This correlates with the NDVI results below. Such band combinations can therefore provide a quick and simple indication of vegetation health for some vegetation classes.

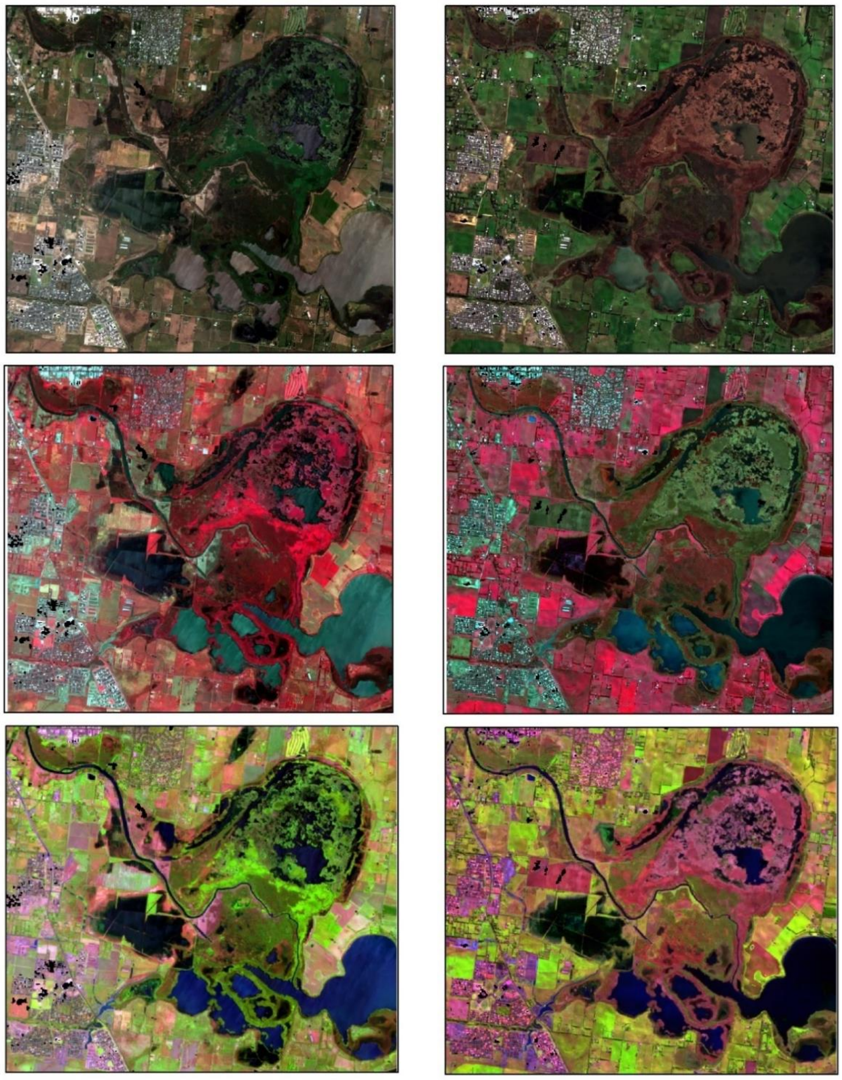


Figure 4-19 – summer imagery (left panel) and winter imagery (right panel) was compared using natural colour (top), colour infrared (middle) and short-wave infrared (bottom)

4.4.2 Spectral indices

Results for NDVI and NDVIre are presented below.

4.4.2.1 Normalised Difference Vegetation Index (NDVI)

- Low winter values as expected due to die-off/dormancy of the vegetation classes.
- Summer values highest in southern parts of wetland for Phragmites stands.

4.4.2.2 Normalised Difference Red Edge Vegetation Index (NDVIre)

- Low winter values as expected due to die-off/dormancy of the vegetation classes.
- Summer values highest in southern parts of wetland for Phragmites stands.

Southern stands of Phragmites, Typha and Sedges/Rushes are under less stress than stands elsewhere within the wetland. This is most likely due to their proximity to the Barwon River and the influence of shallow groundwater.

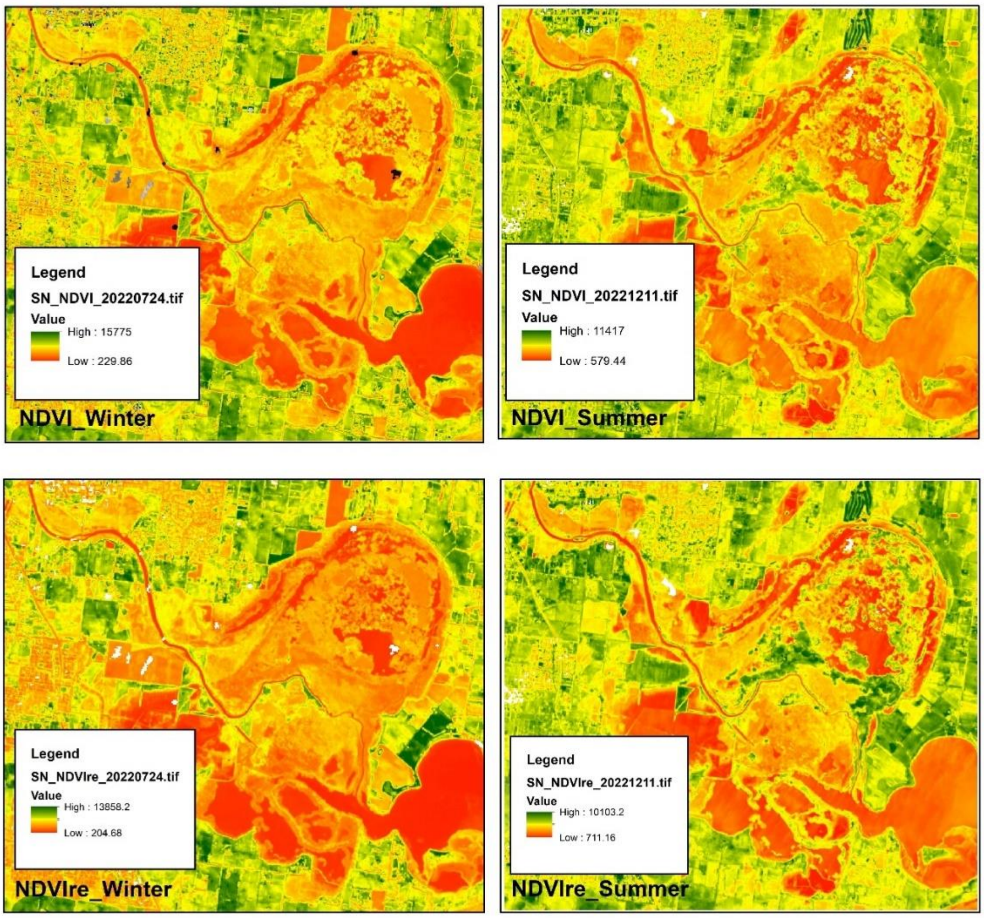


Figure 4-20 – example of seasonal NDVI value ranges in and around Reedy Lake. High NDVI (greens) means healthier more vigorous growth. Yellows to oranges indicate stress or die-off. Dark orange is typically open water or very wet soil.

4.4.3 Spectral profiles

The below spectral profile is from the summer growth season (December). It serves to illustrate how similar the different vegetation classes are across the visible light part of the spectrum (Bands 1, 2 and 3), but how the additional NIR, SWIR and Red-edge bands (4, 5 and 6) available in the Sentinel-2 imagery enable different classes to be distinguished from one another. For example, Phragmites reflects highly in the NIR and Red-edge bands. There is also good value separation (in decreasing value order) for sedges/rushes, then lignum then Typha association. Such profile distinction serves to increase the accuracy of the supervised classification by including these bands in the analysis.

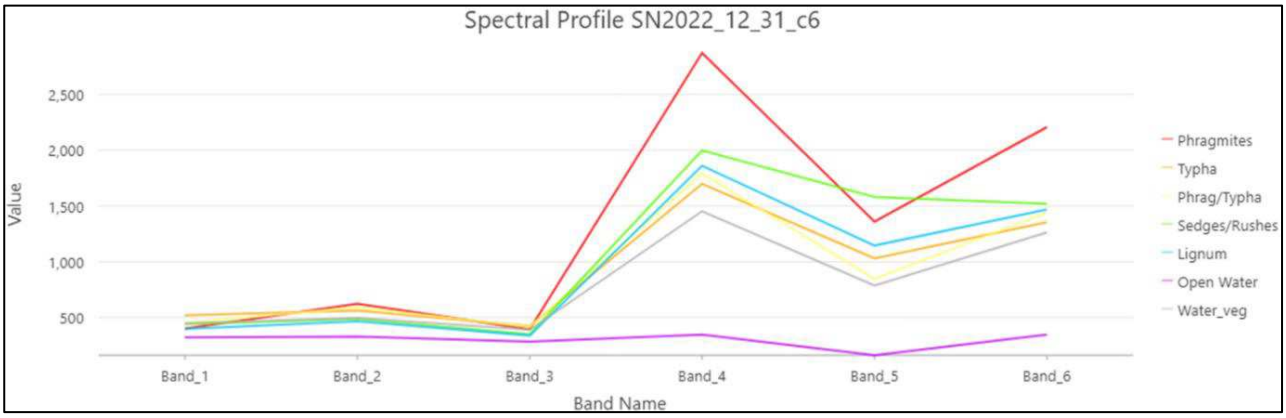


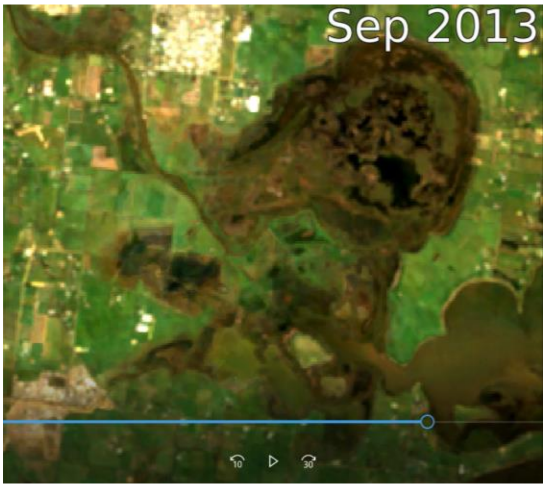
Figure 4-21 – an example of the spectral profiles of the vegetation types assessed in this study

4.5 Satellite imagery time-series animation

An .mp4 file was created for each of the Landsat and Sentinel-2 animations.

These are provided as electronic deliverables. Example stills are shown in Table 4-18.

Table 4-18 – stills from the Landsat time-series animation.

4.6 Records of additional environmental variables of interest

4.6.1 Water levels 1983 to 2016

Water levels in Reedy Lake for the period of Landsat imagery are unfortunately not available. Interestingly the satellite imagery animation showed the occurrence of drying and wetting phases over the period that broadly correlated with anecdotal information on when the wetland has been previously flooded and drawn down. Please view the animation for further information.

4.6.2 Rainfall

- 1983-2011
- 2011-2023

Rainfall measurements nearby to Reedy Lake were sourced from the Grovedale gauge for the period 1983 to 2011 and from the Geelong Racecourse gauge for the period 2011 to 2022. Total annual and total spring rainfall showed a decreasing trend over the period 1983-2011, whilst summer rainfall trended toward an increase. In contrast, since 2011 all three have shown an increasing trend.

4.6.3 Temperature

- 1983-2011
- 2011-2023

Temperature measurements nearby to Reedy Lake were sourced from the Grovedale gauge for the period 1983 to 2011 and from the Geelong Racecourse gauge for the period 2011 to 2022. Maximum annual, spring and summer temperatures all showed an increasing trend over the period 1983-2011. Since 2011, annual and spring temperatures have shown no trend and summer maximum temperatures are trending downwards.

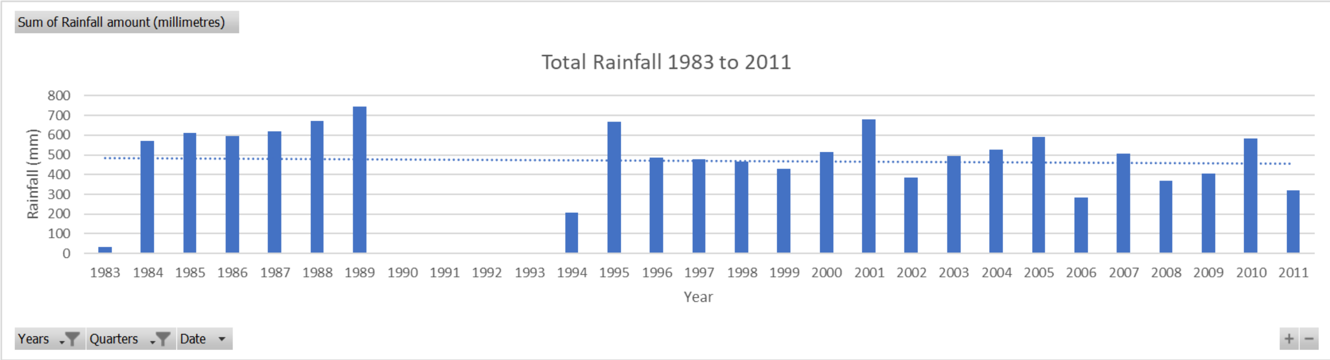


Figure 4-22 – total annual rainfall 1983 to 2011 (Grovedale gauge) indicating and trend towards decreasing total rainfall

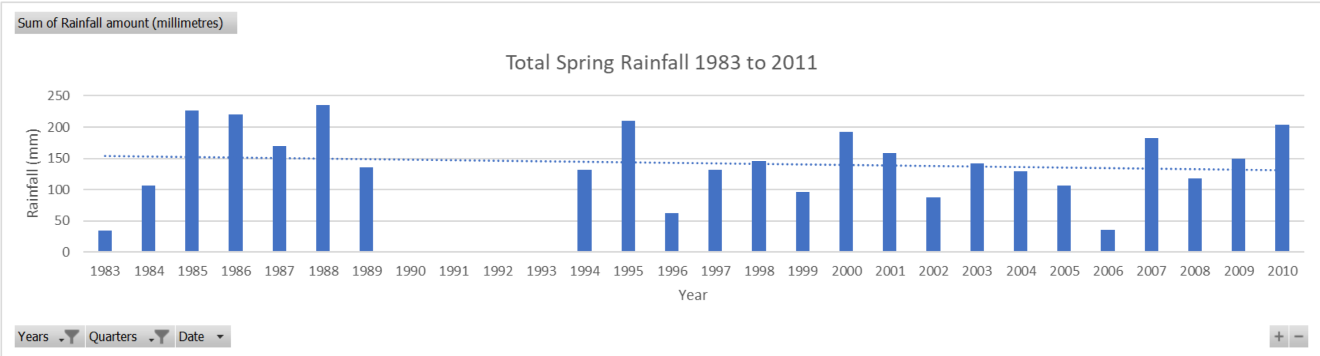


Figure 4-23 – total spring rainfall 1983 to 2011 (Grovedale gauge) indicating a trend towards decreasing spring rainfall

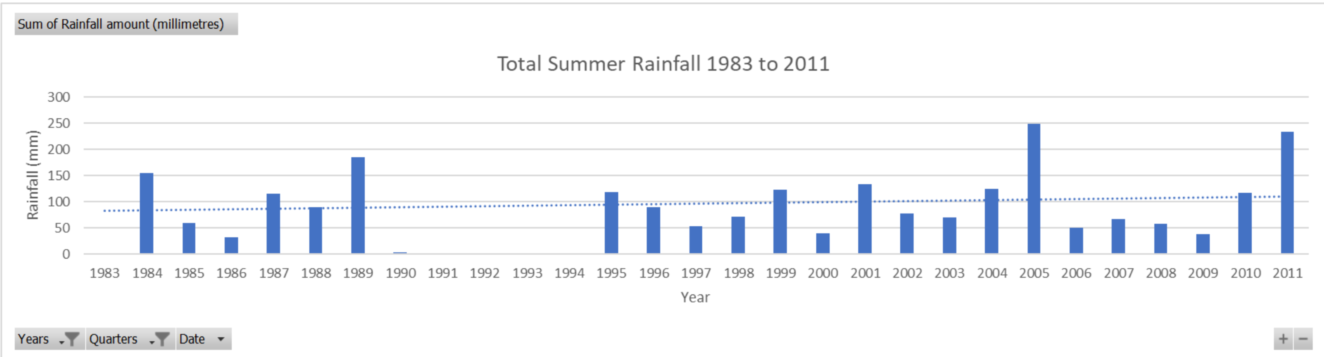


Figure 4-24 – total summer rainfall 1983 to 2011 (Grovedale gauge) indicating and trend towards increasing summer rainfall

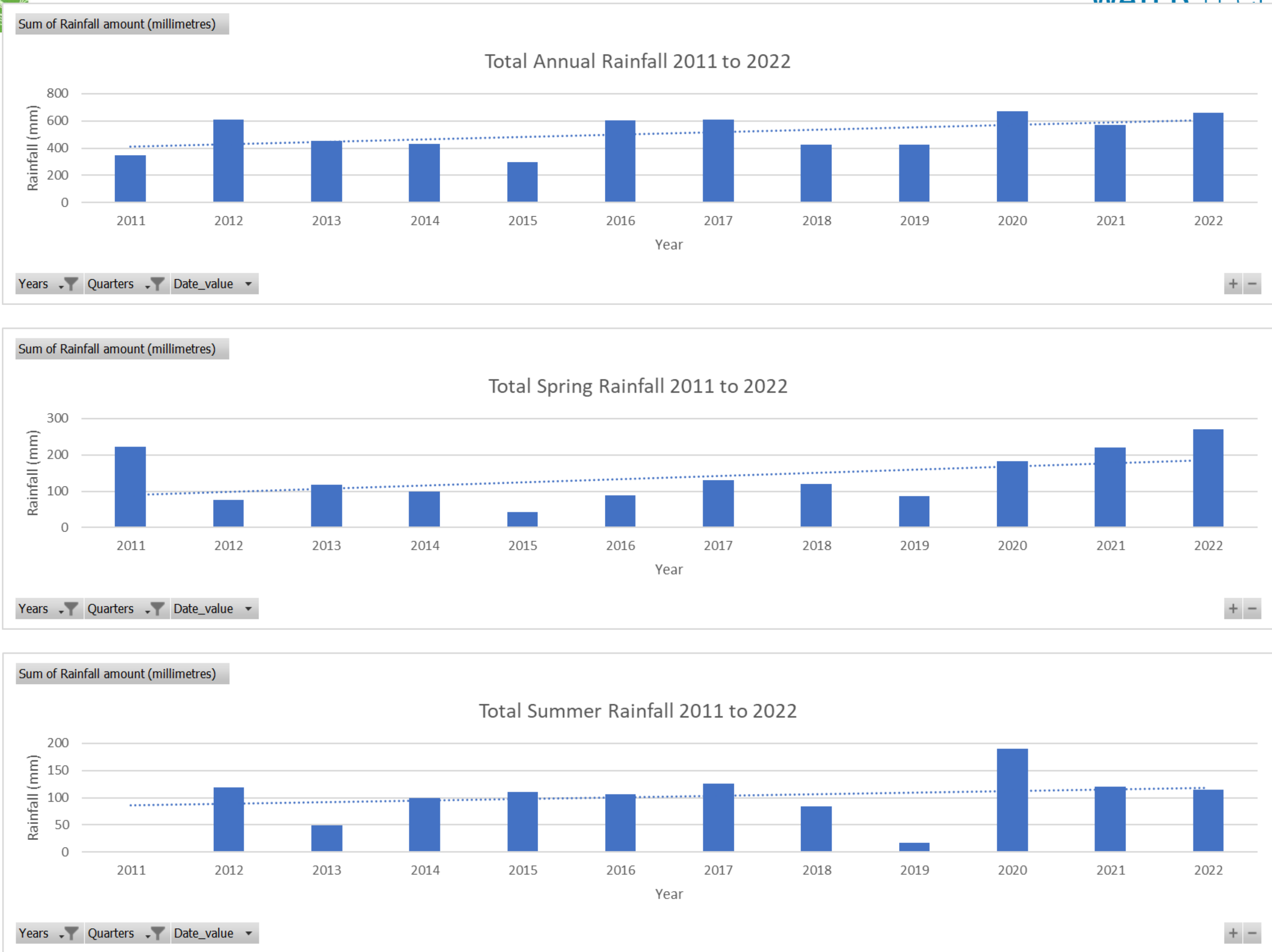


Figure 4-25 – Total annual, spring and summer rainfall 2011 to 2022 (Geelong Racecourse) indicating increasing trends

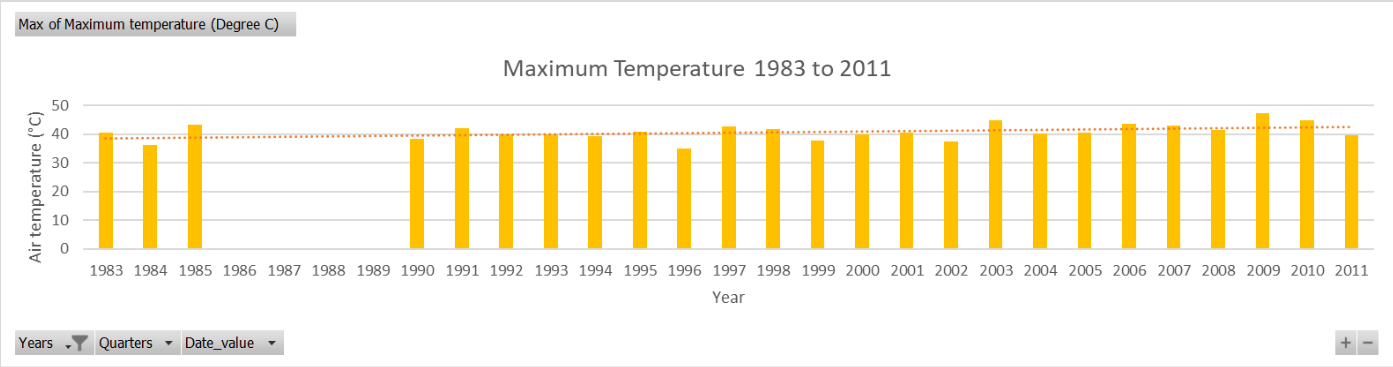


Figure 4-26 – maximum temperatures 1983 to 2011 (Grovedale gauge) indicating an increasing trend.

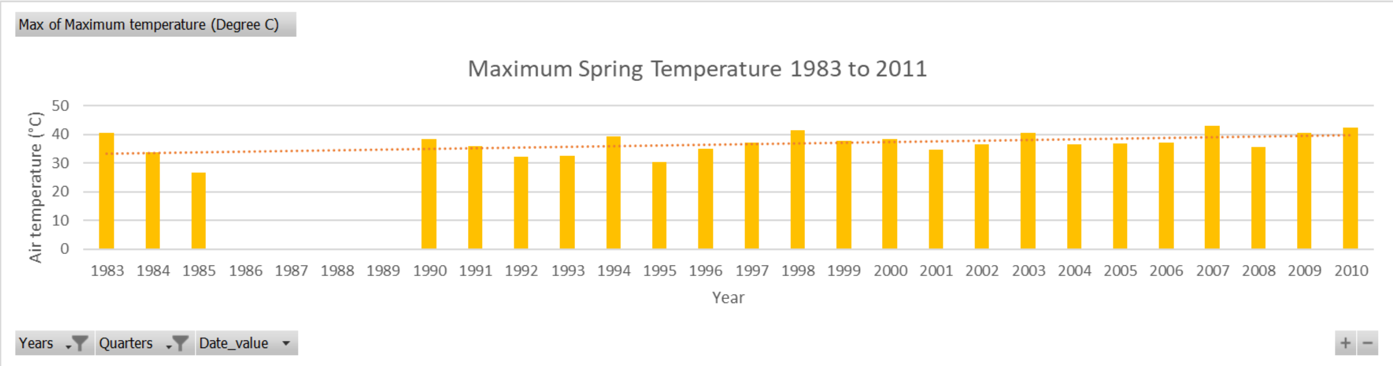


Figure 4-27 – maximum spring temperatures 1983 to 2011 (Grovedale gauge) indicating an increasing trend.

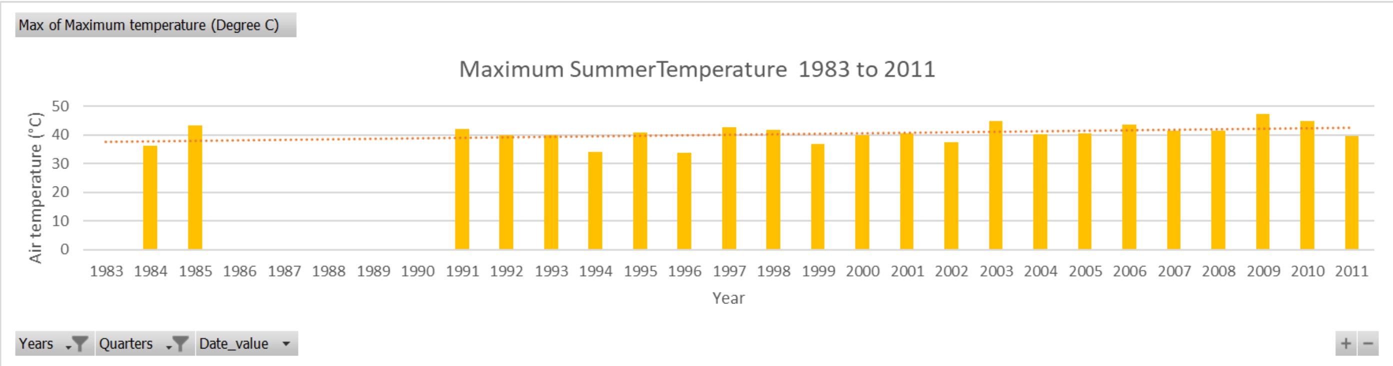


Figure 4-28 – maximum summer temperatures 1983 to 2011 (Grovedale gauge) indicating an increasing trend.

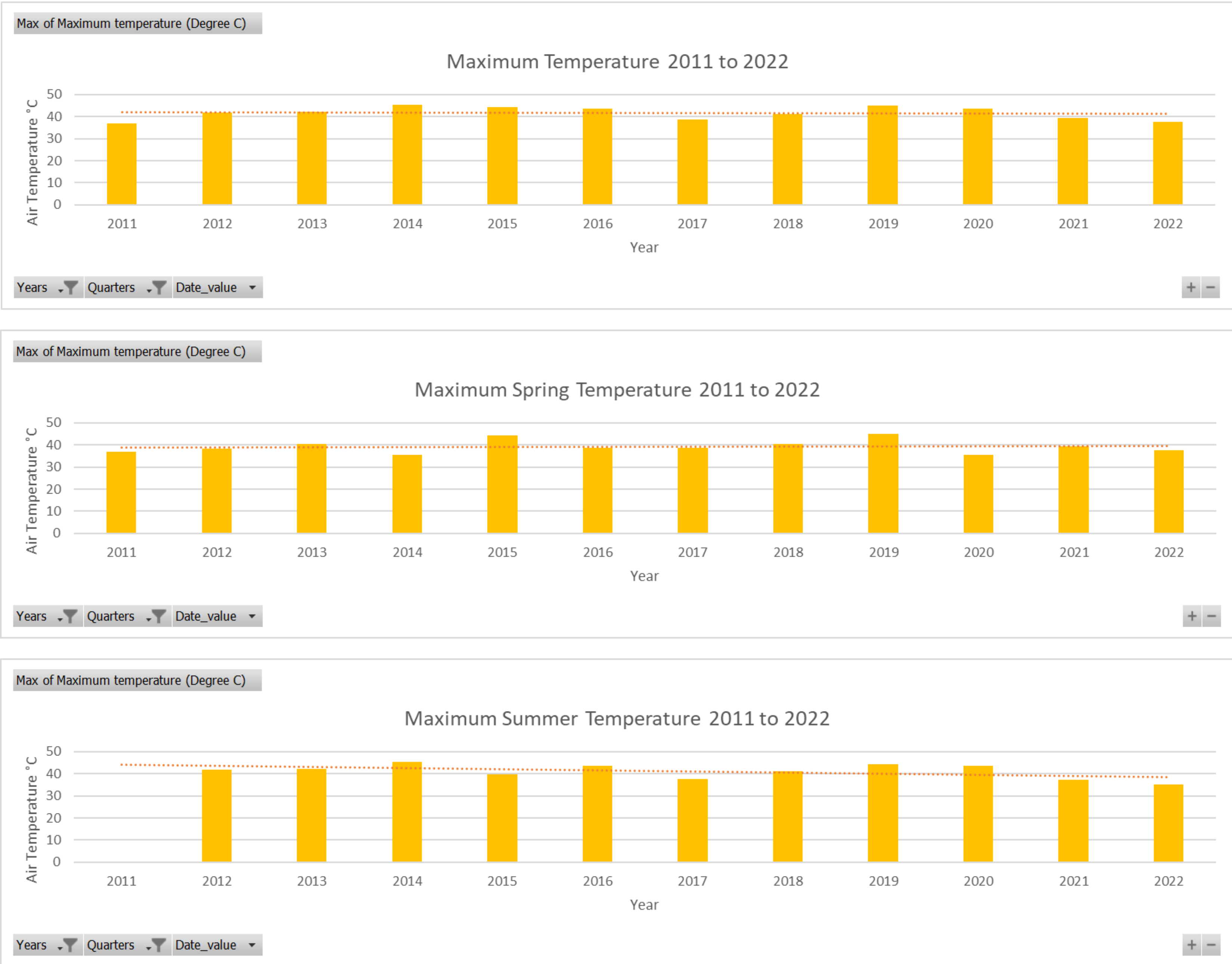


Figure 4-29 – Maximum annual, spring and summer temperatures and trends 2011 to 2022 (Geelong Racecourse) indicating a stable to decreasing trend.

5 DISCUSSION

> *This study provides the first comprehensive spatiotemporal evidence of what has been happening with vegetation across the entire wetland over time. The results have shown how dynamic the vegetation at Reedy Lake is, which is normal and expected for a healthy wetland ecosystem that is within the Limits of Acceptable Change. The seasonal and multi-year wetting and drying regime that Reedy Lake has experienced over the nearly 40 years of this study and the accompanying changes in vegetation extents shows that such as regime is required to maintain this dynamic balance of wetland habitats.*

This section highlights the efficacy of the remote sensing method and draws inferences based on the results regarding the likely factors driving the changes in vegetation extents being observed. The satellite results are discussed first in the context of the lifecycle and habitat preferences of the vegetation classes, to help us to understand the changes at Reedy Lake before the likely environmental influences on vegetation change at Reedy Lake are discussed.

5.1 Comparison of satellite results with previous mapping

The vegetation extents previously mapped at Reedy Lake by Yugovic in 1983 and by Ecological Associates in 2007 and 2012/13, and by Ecological Perspectives in 2019 were used for results validation purposes. The Landsat results for 1983, 1988, 2008, 2013 and 2018 and the Sentinel-2 results for 2019 were therefore compared with this existing mapping.

As shown in the results, the classified extents in the satellite results were in very good agreement with the mapped extents from the previous mapping as demonstrated by visually comparing them based on Yugovic equivalent vegetation classes.

The satellite results varied in the total areas (in Ha) of the Yugovic equivalent vegetation classes classified when compared with the previously mapped extents. This variation is due to the difference in methods used (semi-automated classification versus manual field and aerial photo interpretation) to identify locations of a particular vegetation class in the imagery, and this can be explained as follows:

- Satellite classification identifies individual pixels in the imagery that meet the criteria for being classified as one of the target vegetation types. Pixels not meeting the criteria for classification of any of the target vegetation types remain unclassified. The spatial and spectral resolution of the imagery affects how many pixels are classified. The higher spatial and spectral resolution Sentinel-2 imagery resulted in greater total areas of a vegetation class compared to lower spatial and spectral resolution of Landsat. This is expected because the amount of mixing of spectral signatures in each pixel is reduced with higher spatial resolution.
- When mapping the results of the manual field and aerial photo interpretation, vegetation classes were created as homogenous areas. These areas were often referred to as 'aggregates' or 'mosaics' to justify the delineation of these homogenous areas. Thus, they encompass a greater spatial coverage compared to the satellite classification. Because of the way these areas were mapped, for some vegetation classes, such as Typha association, they might imply dense coverage of Typha, whereas in fact this is not the case.

- The difference in areas between this study and the previous mapping is not an issue because the previous mapping was not necessarily definitive and the objective of this study was to determine relative change using a consistent methodology, which has been achieved.

The results of this study highlight the efficacy of the remote sensing approach in consistently mapping changing vegetation extents over time. The results generated in this study can therefore be used with confidence for interpretation purposes and those for intervening years and seasons to fill the gaps between the mapping completed by the previous studies. Because of the consistent method used, the satellite results are considered a more reliable record of relative change over time than the previous mapping.

5.2 Observable trends in vegetation extent change over time

5.2.1 Landsat time series: 1983-2018

The Landsat results showed distinct changes and overall trend in vegetation extents over time that correlated with anecdotal evidence and the findings of previous investigations. The overall trend in Tall Reed was toward an *increase* (an increase in extent by 9.3% or 30.6Ha between 1988 and 2018*)* however variation between time steps is more significant and of interest because there were large fluctuations in the area (Ha) of the wetland bed covered by Tall Reed over the nearly 40-year period assessed. The impact on Tall Reed extents of Reedy Lake drying out for the two extended periods in the 1990s was dramatic, as was the recovery of Tall Reed during subsequently dry (but with water level fluctuation) and wetter periods. Extents of sedges/rushes have fluctuated significantly over time and trended toward an overall *decrease* over the period to 2018 (44.8% or 67Ha decrease). Lignum appears to have fluctuated but remained relatively stable over time, with little discernible trend.

5.2.2 Sentinel-2 time series: 2016-2022

The Sentinel-2 results also showed distinct changes and overall trend in vegetation extents over time. The overall trend in Tall Reed was toward a *decrease* (7% or 4Ha decrease) however variation between time steps is more significant and of interest because there were large seasonal fluctuations in the area (Ha) of the wetland bed covered by Tall Reed over the six-year period assessed. The impact on Tall Reed extents of Reedy Lake being drawn down between 2016 and 2019 is evident in the results of the total areas of Phragmites and Typha association, with Phragmites extents decreasing and Typha association extents briefly increasing then decreasing. With the return of sustained wetter conditions from 2020 onwards, both Phragmites and Typha increased in extent. Extents of sedges/rushes have fluctuated significantly over time and trended toward an overall *increase* over the period to 2022. Lignum appears to have fluctuated but remained relatively stable over time, with little discernible trend.

5.2.3 Summary

The perceived overall increasing trend of Tall Reed is not as pronounced as previously thought and is very sensitive to annual and seasonal changes in extents that are being driven by environmental factors, as will be explained. Both Phragmites and Typha extents appear to be fluctuating within a range over time. This is evident in both the Landsat and Sentinel-2 results. Further, the locations where Phragmites and Typha are occurring has changed over the period of the Sentinel-2 results, indicating that their overall extent is balanced by gains in some areas and losses in others. Extents of sedges/rushes have fluctuated significantly over time, with annual and seasonal changes being driven by environmental factors. Lignum extents have remained relatively stable over time.

5.3 Influence of the lifecycle and habitat preference of vegetation on extent changes

Detection of the different types of vegetation cover in the satellite imagery relies on the spectral signature of the above ground biomass, specifically, the stems and leaves of the stands of Phragmites, Typha and Sedges/Rushes (predominantly *Bolboschoenus caldwellii*) and the branches and leaves of Lignum. What is important in attempting to interpret the observed changes in extent of these vegetation classes is to understand their above ground and below ground lifecycles.

The change detection results have highlighted that the different vegetation classes have changed in extent at different locations within the wetland over time. This may assist in starting to understand some of the driving influences on extent change once the lifecycle and habitat preferences and tolerances of these vegetation classes is better understood.

Ecological Associates (2014) state that the expansion of reed beds has involved the consolidation of existing stands and the expansion of reeds into shallower water. The results of this study indicate that many of the existing reed bed stands have sustained and that some new areas have been colonised.

5.3.1 Typical lifecycle of Tall Reed

The lifespan of stems and leaves for Phragmites and Typha is less than a year, with leaf growth starting in Spring, peaking in summer and most leaf die-off occurring in later summer and early autumn. A new canopy is formed each year with a new population of shoots emerging from rhizomes in the Spring. Below ground (rhizomatous) biomass of Phragmites and Typha is much greater than above ground biomass. The very rapid growth of Typha and Phragmites in spring is due to mobilisation of energy in rhizomes using it for shoot growth above ground.

Above ground biomass for tall reeds is typically:

- Phragmites ~9900g/m^2 or 200-400 stems per m^2
  - reaches maximum biomass and flowering in Jan-Feb
- Typha ~1500 g/m^2 or 5-10 stems per m^2
  - reaches maximum biomass and flowering in Dec-Jan

Rhizomes of both species typically start their annual growth cycle in Spring (September for Typha) to early Summer (November for Phragmites) which peaks in March for Typha and September for Phragmites. Phragmites has a much longer rhizomatous growing season. Rhizomes grow laterally and then develop shoots at the tip. As the rhizome continues to grow, and to develop new parts, the older parts die off and the newer parts of rhizome are no longer connected to each other. If the rhizomes continue to grow and expand, then eventually the plant will cover a large area. It may even be only one genetic individual. Meanwhile the original plants are sustained in -situ by their root systems (Bell, 2002).

5.3.2 Phragmites expansion

Phragmites increases in extent rapidly due to vegetative expansion with many constraints on successful expansion from seed (Rogers and Ralph, 2010). Because of this, at Reedy Lake it can be assumed that the observed changes in extent are being driven by the expansion of below ground rhizomes into areas of the wetland that are suitable for Phragmites growth.

5.3.3 Typha expansion

Unlike Phragmites, Typha vegetative expansion is slow and requires an existing stand and conditions suitable for growth (Miao et al. 2001; in Rogers and Ralph, 2010). Instead, Typha increases in extent rapidly due to reproduction from seed, which enables Typha to become established at sites some distance from existing stands, given suitable conditions for seed germination, survival, growth, and propagation (Miao et al. 2001; in Rogers and Ralph, 2010).

Flowering of Typha occurs during Summer from November to March, with seed production occurring during late Summer from January to April (Froend and McComb, 1994; Roberts, 2001; in Rogers and Ralph, 2010). Persistence of seeds in the seed bank is typically less than a year (Miao et al. 2001; in Rogers and Ralph, 2010). Germination from seed requires light, moisture and temperatures above 10°C (Roberts and Marston, 2000; in Rogers and Ralph, 2010) and may occur during prolonged drawdown conditions when vegetative growth is limited or while Typha is submerged in shallow water of approximately <0.1m (Froend and McComb, 1994; Roberts, 2001; in Rogers and Ralph, 2010).

Once seeds have germinated, seedlings can continue to grow under drawdown conditions, producing many shoots in their first year. Vegetative growth from newly formed rhizomes became evident after approximately six weeks (Nicol and Ganf, 2000; in Rogers and Ralph, 2010) and may extend the plant to 3m diameter in its first year. Under optimal conditions that are nutrient rich and warm, Typha may reach 1m height in a few months (Roberts, 2001; Roberts and Marston, 2000; in Rogers and Ralph, 2010).

This lifecycle information implies that Typha expansion by seed at Reedy Lake can occur rapidly and that a few months from germination, new Typha plants are mature enough, having reached a stem density and height of ~1m, to begin to be detectable in the satellite imagery if their cover is dominant within patch sizes of $100m^2$ (the spatial resolution of the Sentinel-2 imagery).

Further, in regard to reducing the germination of Typha from seed at Reedy Lake, following draw down periods, where exposed moist substrate has provided the conditions for germination of seed, it will be important to ensure that there is no shallow water (<0.1m deep) in areas of the wetland bed where the objective is to mitigate further expansion of Typha stands. The initial expansion in Typha association observable in the satellite results soon after commencing the watering regime may have resulted from the first draw down event triggering mass germination of Typha across the wetland bed. However, with continuation of further draw downs, the watering regime appears to have reduced the Typha association extent, indicating the influence of other environmental variables on the viability of the Typha stands.

5.3.4 Summary

What we appear to be seeing in the satellite imagery is seasonal fluctuation of the extent of Phragmites and Typha in the wetland at elevations ≤0.8mAHD within an established lateral range influenced by the below ground extent of the rhizomes of both species. Existing Phragmites and Typha stands will readily re-shoot from rhizomes each season. Existing Phragmites stands will grow out laterally each season and Typha may expand sporadically based on germination from seed when conditions are favourable.

Existing Phragmites stands within the wetland bed (≤0.8mAHD) have appeared relatively stable with minor local expansion and indeed an area of contraction in the north east portion of the semi-circle. Most Phragmites expansion has occurred at elevations above 0.8mAHD around the southern perimeter of the wetland. This appears to be related to favourable groundwater conditions that Phragmites is preferencing. Typha has the potential to spread from seed across the wetland bed at elevations where water levels are ≤0.5m-0.8mAHD due to the favourable conditions (i.e., warm, shallow water with reduced soil salinity) created by water level fluctuation in these locations. Careful management of the watering regime and monitoring of soil salinities is going to be required to ensure Typha doesn't inadvertently expand during draw down periods. Drawdowns to ≤0.3mAHD are required to promote increase soil salinity and minimise the favourable water surface area for Typha germination.

5.4 Elevation associations of key vegetation types

Ecological Associates (2014) identify the surface area of open water in the Big Hole as closely following the 0.0 m AHD contour and state that this appears to represent a limit to reed expansion, because there is no shallow water around the margins and under elevated wetland water levels, this deep pool is inundated by a further 1m of water, which may exceed the flood depth tolerances of Typha and Phragmites and it is deemed very unlikely that such reeds will ever colonise the 'Big Hole'.

Rogers and Ralph (2010) state that numerous studies indicate that determining a water depth for optimal Phragmites growth in complex and apparently reliant on the relationship between plant elevation (i.e., growing surface elevation) and the amplitude of water level fluctuation (Alvarex-Cobelas and Cirujano, 2007; Deegan et al. 2007; White et al. 2007; in Rogers and Ralph, 2010).

Phragmites biomass production and stem density was (i) constrained when the amplitude of fluctuations was high (±0.45m) and plants were positioned at lower elevations, presumably due to the reduced capacity of Phragmites to photosynthesise and respire in deeper water (Coops et al. 1996; in Rogers and Ralph, 2010); but conversely was (ii) optimal for such fluctuating water levels when growing at higher elevations, because relative water depths were lower. Deegan et al (2007; in Rogers and Ralph, 2010) found that optimal water level fluctuation for Phragmites was of the order of ±0.3m.

Phragmites rhizomes typically occur in the upper 1.5m of the soil profile thus gaining access to shallow groundwater (Haslam, 2970, 1972; in Rogers and Ralph, 2010), but can extend further to gain access to deeper groundwater (Frankenberg, 1997; in Rogers and Ralph, 2010). Given the groundwater conditions at Reedy Lake and the observed distribution of Phragmites at various elevations (in previous studies and this study), including elevations independent of fluctuating water levels in the Lake, the role rhizomes play in sustaining stands is important.

A couple of constraints on interpreting vegetation elevation associations were imposed from the ecological information available in previous reports. These were:

- no Tall Reed occurring above 0.8mAHD in the north western, northern and eastern perimeter of the wetland due to groundwater salinities; and

- Tall Reed occurring above 0.8mAHD in southern parts of the wetland due to the ability to access fresher shallow groundwater and fresh surface water from the wetland and the Barwon River.

The results of this study concurred with point (b) above, however in contrast to point (a) however found small areas of Phragmites growing above 0.8mAHD in the north western, northern and eastern perimeter.

Table 4-14 presented the elevation ranges of the different vegetation classes at Reedy Lake highlighting that sedges/rushes prefer the fringing areas around the wetland at elevations ≥0.8mAHD and the Lignum can occur anywhere within the wetland but preferences elevations above 1.0mAHD. Sedges/rushes, particularly Bolboschoenus, prefer higher soil salinities, which exist around the edges of Reedy Lake at those higher elevations. Lignum requires occasional inundation but tolerates drier locations especially if its root system is connected to shallow groundwater, which appears to the the case at Reed Lake This information indicates surface elevation and surface water level fluctuation are not the only determinants of vegetation class location at Reedy Lake and that soil salinity and shallow groundwater also play a key role.

5.5 Comparison of NDVI values for key vegetation types

5.5.1 Plant stress and NDVI values

The concept of plant stress is important because changes in the extent of vegetation types where they are subsequently replaced with other plant communities will involve the decline and death of existing stands.

The vegetation types at Reedy Lake can tolerate varying degrees of seasonal and multi-year change in environmental variables which may at times cause stress. Further, there will be a delay between the impact of an event and a change in extent, with plant growth and/or productivity declining before ultimate extent changes. Usually, long-term (chronic) or severe (acute) stress is required to have lasting effects on vegetation extents. Measurements of plant stress can provide leading indicators of vegetation change and early evaluation of event impacts and management effectiveness. (Ecological Associates, 2014).

Measures of plant growth in the field integrate the effects of a range of environmental stresses and provide an overall assessment of plant performance. Persistent trends in vigour are an early indicator of future vegetation extent. Measurements of plant growth will help managers identify sources of stress, how severe stresses are, where stress is most intense and how stressful conditions must be to effect a change in vegetation extent (Ecological Associates, 2014).

Monitoring results from 2013 (Ecological Associates, 2014) found that Phragmites stem density was highest in the shallow sites at the edge of the lake and at the outlet. Density was lower in the deep sites and near the Big Hole. The tallest plant stems were observed in the southern half of the lake, near the inlet and outlet. At similar elevations in the north and east of the lake stems were shorter. The edge sites to the north and east of the lake had the shortest stems while tall stems were found at the inlet, along the inlet channel and at the outlet.

To explore the concept of plant stress, Ecological Associates (2014) determined the range of variation in NDVI values for Phragmites, Typha and Lignum (as a control) using a combination of 30m resolution Landsat imagery for 2003, 2006 and 2009 and 2m resolution GeoEye imagery for 2012. Phragmites NDVI varied between 0.4 and 0.7 (moderate to low stress), Typha varied between 0.1 and 0.5 (moderate to high stress), and Lignum varied between 0.05 to 0.5 (moderate to high stress). Higher NDVI values indicate healthier plants.

The calculation of NDVI values for Typha is likely to be affected by the presence of standing water (or high soil moisture) in the imagery in the areas where Typha occurs, hence why these values may be lower overall (because water has a low NDVI value), however at the same time, Typha's close association with surface water levels ensures its vigour, so the observed range of NDVI values may be an appropriate indicator of healthy Typha. The values for Lignum are also interesting and these may relate to the smaller leaf type and woodier structure of Lignum compared to the large, strappy leaves of Phragmites and Typha.

5.5.2 Summary

Although there is some variation in NDVI (Normalized Difference Vegetation Index) value ranges for the different vegetation types, NDVI results alone cannot be used to distinguish between vegetation classes due to the overlapping value ranges, but they may offer some important insights into plant stress.

To use NDVI as a reliable diagnostic tool as part of a future remote sensing-based monitoring program further field-based information on plant stress indicators and stressors (in particular water level and soil salinity) is required to cross-reference with NDVI values for the different vegetation classes of interest in different locations given the environmental variables at the time of analysis. It would be expected that NDVI values for vegetation types would be different in different locations around Reedy Lake over time, according to the variable influence of environmental stressors.

Once information has been derived on the potential relationships between plant stress, stressors and NDVI values at Reedy Lake it would be worthwhile doing a retrospective analysis of NDVI values from the record of Sentinel-2 imagery to 'back cast' indications of plant stress from 2016 to current.

5.6 Potential influence of environmental variables on vegetation extents

5.6.1 Water levels, extents, and depths

This study has provided insights that water levels as they relate to extents and depths of inundation are likely to exert an influence on vegetation extents, especially Tall Reed and the Open Water association which dominate the wetland cover below 0.8mAHD. Sedges/rushes are less influenced by water level fluctuations being located around the wetland perimeter. Water level variation has the greatest influence on vegetation, particularly the Typha species association, due to its reliance on near-permanent water and the inverse interaction between soil salinity and water levels up to 0.5-0.8mAHD.

Ecological Associates (2014) conclude that low lake levels would be most effective in controlling Typha and Phragmites to the north, south and east of the Big Hole; but crucial to evaluating drying as a control measure in Reedy Lake is an understanding of the distribution and intensity of saline conditions. If lakebed salinities are low, periods with low water levels are likely to promote the growth and spread of Typha and Phragmites. If soils become hypersaline when the lake is dry then this may, over time, reduce their extent. Also important is the extent and rapidity of draw down. As previously mentioned, draw down to ≤0.3mAHD is required as well as that draw own being relatively rapid to promote drying.

Observations by Ecological Associates (2014) indicate that a season of low water level may provide better growing conditions than flooding at these levels, allowing accumulation of carbohydrate and mineral nutrients and the development of roots and stolons that may support more vigorous growth in the subsequent year. Indeed, vegetative expansion is so effective that stands of Phragmites may be one or two entire clones that are well adapted to the site conditions (Frankenberg, 1997; Koppitz et al. 1997; Koppitz and Kuhl, 2000; in Rogers and Ralph, 2010). In south eastern Australia, expansion of rhizomes commences in summer and continues until it peaks in spring (Hocking 1989b; in Rogers and Ralph, 2010). Buds develop on rhizomes year round but remain dormant near the soil surface (Haslam, 1969a; in Rogers and Ralph, 2010). Rapid emergence of buds occurs during Spring, given optimal temperature and access to water, enabling new aerial stems to develop (Frankenberg, 1997; Haslam, 1969a; in Rogers and Ralph, 2010).

Timing of Phragmites stand inundation appears less critical according to Roberts and Marston (2000) although Haslam (1970) observed stands flooded in late Spring performed well. At Reedy Lake, there are typically 3 overbank flooding events in the period July to October, which may create optimal antecedent water level conditions in time for the start of the Spring growing season.

Phragmites can adapt to drier conditions by initially exhibiting a reduction in leaf area and biomass, thereby enabling it to maintain some capacity for photosynthesis, and it may increase the proportion of water absorbing root biomass as another means to exploit available (ground) water resources (Pagter et al. 2005; Saltmarsh et al. 2006).

According to Rogers and Ralph (2010), water stress, particularly during Summer, may limit Typha's ability to expand, which is supported by Nicol and Ganf (2000; in Rogers and Ralph, 2010) who found that vegetative expansion was absent under rapid drawdown conditions at the waterline, static conditions at inundation depths of 0.3m and static and slow drawdown at inundation depths of 0.8m. At Reedy Lake, using draw down to limit vegetative expansion of Typha will likely be similarly effective, however the ability for Typha seed to readily germinate in draw down periods needs monitoring and careful management.

Some stands of tall reed were observed to collapse because of the 2006 draw down (Ecological Associates, 2007). Some of these stands were suspected to have been relatively young, consisting of shoots that emerged in the previous growing season when water levels were higher; and/or had only shallow root systems which failed to access underlying groundwater.

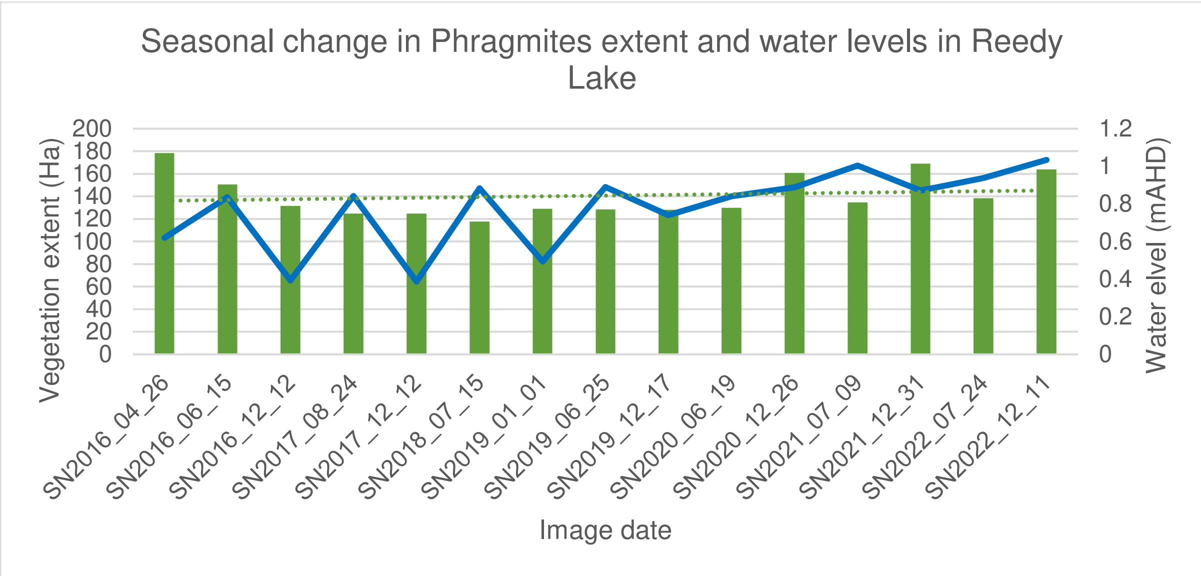


Figure 5-1 – change in Phragmites extent overlaid with water levels. The period of the watering regime can clearly be seen between 2016 and 2019 with the pattern of summer draw down and winter fill. Phragmites initially contracted before increasing in extent. The contraction during the draw down periods was equivalent to Phragmites winter extents. There appears to be a tight seasonal range in extent variation.

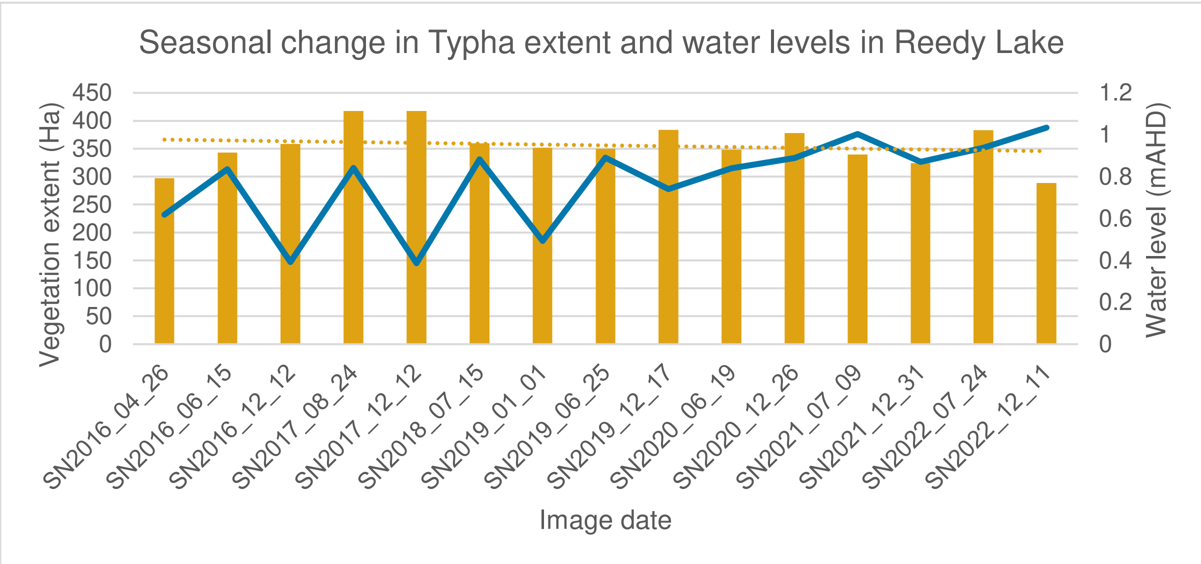


Figure 5-2 - change in Typha extent overlaid with water levels. The period of the watering regime can clearly be seen between 2016 and 2019 with the pattern of summer draw down and winter fill. Typha initially expanded, likely in response to a widespread seed germination event in response to the first draw down, before reducing in extent. There appears to be a tight seasonal range in extent variation.

5.6.2 Rainfall

Rainfall patterns over the entire catchment driving inflows from the Barwon River are important at Reedy Lake. Rainfall patterns at Reedy Lake are likely to have a minor and localised influence on soil conditions around the north western to eastern shoreline dominated by halophytic vegetation above 0.8mAHD, and across the lake bed during extended periods when lake levels are low (e.g., extended summer rainfall during draw down).

Rainfall also influences elevations above 0.8mAHD in the southern perimeter of the wetland where stands of Lignum and Phragmites have colonised and have access to shallow fresh groundwater. Preceding rainfall conditions have been found to be important for soil moisture and the subsequent health of Lignum and Phragmites in these areas as measured by NDVI (Ecological Associates, 2014).

Observations in this study have confirmed the importance of rainfall (likely supported by infrequent inundation from water levels above 0.8mAHD) wetting soils with fresher water in areas of the southern perimeter encouraging Bolboschoenus to expand and dominate over Distichlis grassland that otherwise persists and dominates the understorey during drier periods, when Bolboschoenus dies back (Figure 5-3).

Figure 5-3 – dense beds of senescing Bolboschoenus (left) and Bolboschoenus encroaching into Distichlis (right). Distichlis is bright green and Bolboschoenus is orange-yellow. In both instances, the size and density of ground cover in these beds surrounding the Lignum will influence the spectral signature of the 100m² pixels in this vegetation association. Where Lignum bushes are sparse, the ground cover signature will dominate. Where Lignum bushes are dense and contiguous, their signature will dominate.

5.6.3 Temperature

Temperatures are usually optional for Phragmites, Typha and Sedges/rushes growth in spring (which is coincident with the start of new shoot production in the growth cycle) and summer (Frankenberg, 1997; in Rogers and Ralph, 2010). Temperature patterns at Reedy Lake are likely to continue to influence vegetation lifecycles. The trend toward increasing maximum spring temperatures and decreasing maximum summer temperatures will play a role in the timing of the start of and length of the growing season at Reedy Lake.

5.6.4 Salinity

Fluctuating saline groundwater levels and soil salinity in association changing wetland water levels likely have the greatest influence on vegetation. The ability of Phragmites to survive on groundwater alone, during extended dry periods, depends on the quality of the groundwater (Rogers and Ralph, 2010). Given the persistence of some Phragmites stands at Reedy Lake (e.g., the semi-circle) groundwater conditions must be favourable. Typha is less able to tolerate higher salinities whereas sedges/rushes favour higher salinities. Lignum can tolerate salinity but requires a permanent source of water, either groundwater or inundation from surface water. Again, the enduring stands of Lignum at elevations above typical water levels in Reedy Lake indicate the presence of favourable groundwater conditions.

5.7 Observed changes and the Ramsar Limits of Acceptable Change (LAC)

The act of designating a wetland as a Ramsar site carries with it certain obligations, including managing the site to maintain its "ecological character" and to have procedures in place to detect if any threatening processes are likely to, or have altered, the "ecological character". Definitions for "ecological character" and "change in ecological character" are as follows (Ramsar Convention 2005):

"Ecological character is the combination of the ecosystem components, processes, and benefits/services (CPS) that characterise the wetlands at a given point in time" and

"...change in ecological character is the human induced adverse alteration of any ecosystem component, process and or ecosystem benefit/service."

The Ramsar Convention also establishes the benchmark for the ecological character of listed wetlands as "at the time of designation as a Ramsar Wetland of International Importance" (Resolution VI.1 Para 2.1). Reedy Lake was listed in 1982 thus the Yugovic mapping conducted in 1983 provides the ecological character benchmark.

The mechanism against which change in ecological character is assessed is via comparison with Limits of Acceptable Change (LAC). LAC are defined by Phillips (2006) as:

"...the variation that is considered acceptable in a particular measure or feature of the ecological character of the wetland. This may include population measures, hectares covered by a particular wetland type, the range of certain water quality parameter, etc. The inference is that if the measure or parameter moves outside the 'limits of acceptable change' this may indicate a change in ecological character that could lead to a reduction or loss of the values for which the site was Ramsar listed. In most cases, change is considered in a negative context, leading to a reduction in the values for which a site was listed".

The objective of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan (2018) is to "maintain, and where necessary improve, the ecological character of the Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site and support wise and sustainable use."

Accordingly, the plan defines Limits of Acceptable Change (LAC) for two CPS being *hydrology* and *freshwater vegetation* at Reedy Lake that provide a clear guide for assessing any change in its ecological character.

5.7.1 Hydrology

The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan (2018) defines a Limit of Acceptable Change (LAC) for *hydrology* at Reedy Lake as follows:

"Reedy Lake to be wet for no longer than 10 continuous years, or dry for more than five."

For the period 2016-2022 during which water levels (to mAHD) have been available for Reedy Lake from gauge 233603 it is clear from the plot of water levels in **Error! Reference source not found.** that this LAC h as been met.

Although the definition for wet and dry is not provided by the Ramsar Management Plan, *wet* is assumed to mean Reedy Lake not fully drawing down in summer, as has been the case since 2020, with water levels fluctuating within the higher end of the range of 0.6-0.8mAHD; and *dry* is considered to mean Reedy Lake having reached full draw down to 0.1-0.3mAHD or below (with evaporation of remaining standing water).

5.7.2 Freshwater vegetation

The Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar Site Management Plan (2018) defines a Limit of Acceptable Change (LAC) for *freshwater vegetation* at Reedy Lake as follows:

> *"**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."*

For each time step across the Landsat and Sentinel-2 time series, the proportional cover (%) of each vegetation class identified in the LAC relative to the total area of Reedy Lake were calculated and are presented in the results section of this report. All results showed that the proportion of open water, sedges/rushes, tall reeds, and lignum remained well within the 70% threshold of the LAC.

5.7.3 Summary

From the evidence derived in this project, there is an observed natural range of variability in hydrology and freshwater vegetation that continually falls within the respective LAC. From this it is sufficient to say that the ecological character of Reedy Lake is being maintained in accordance with the Ramsar requirements.

5.8 Potential future climate and associated changes in vegetation

The Victoria's Future Climate Tool[2] was used to explore the potential future climate for Reedy Lake. The tool provides data on several climate variables. For Reedy Lake, projected seasonal changes in maximum temperatures and rainfall were of interest as these variables are important influences on water levels in Reedy Lake and on the length and suitability of the growing season (Haslam 1975; Soetaert et al. 2004; in Rogers and Ralph, 2010).

The projections indicate increases in maximum temperatures across all seasons and timeframes; however, the changes in precipitation are varied and depend on the projection, season, and timeframe. Annual rainfall is projected to decline. Overall, Reedy Lake is likely to experience slightly warmer and drier conditions, with seasonal variations. These will continue to promote favourable conditions for a diverse vegetation community.

[2] https://vicfutureclimatetool.indraweb.io/project

Table 5-1 – projected % change in precipitation

Season	2030 RCP4.5	2030 RCP8.5	2050 RCP4.5	2050 RCP8.5	2070 RCP4.5	2070 RCP8.5	2090 RCP4.5	2090 RCP8.5
Annual	-0.83	-1.61	-2.54	-4.45	-4.84	-4.64	0.59	5.20
Summer	8.69	17.57	10.95	1.79	11.81	15.53	24.72	26.14
Autumn	2.04	-0.85	10.92	0.86	-2.88	-2.58	0.48	4.27
Winter	-6.22	-0.37	-3.7	-7.22	-2.87	-5.95	-0.9	-7.16
Spring	10.15	-0.56	2.38	14.67	-0.34	4.39	-5.13	7.03

Table 5-2 – projected °C change in maximum temperatures

Season	2030 RCP4.5	2030 RCP8.5	2050 RCP4.5	2050 RCP8.5	2070 RCP4.5	2070 RCP8.5	2090 RCP4.5	2090 RCP8.5
Annual	1.22	1.51	1.91	2.57	2.19	3.72	3.09	4.94
Summer	1.83	1.86	2.46	2.95	2.55	4.09	3.21	5.27
Autumn	1.16	1.40	1.76	2.50	2.55	3.77	3.22	4.91
Winter	0.78	0.99	1.23	1.68	1.88	2.81	2.52	3.86
Spring	1.50	1.93	2.28	3.18	2.56	4.30	3.44	5.72

5.9 Appraisal of the impact and limitations of the recommended watering regime

Considering the information on observed changes and trends in vegetation extents and the potential influence of water depths and salinities (in particular), on these extents; and considering the likely climate future for Reedy Lake, the currently recommended watering regime was appraised. Because Lignum and sedges/rushes are associated with the wetland perimeter or higher and are tolerant of (indeed favour) high salinities, the greatest effect of the watering regime is on maintaining the balance between Phragmites, Typha and Open Water vegetation types in the wetland below elevations of 0.8mAHD.

5.9.1 Impact of the watering regime

Reducing the depth and duration of wetland flooding and ensuring subsequent draw down of the wetland water level enables shallow saline groundwater to have an increased influence within the soil profile, making the conditions less favourable for reeds. Indeed, Ecological Associates (2007) propose that exposing reeds to existing saline groundwater over the course of one or more growing seasons is likely to be an effective approach to control their extent.

From the results of this study, it was evident that the watering regime was beginning to have an impact on the extents of Phragmites and Typha between 2016 and 2019 when draw down in water levels was being achieved. It is likely that during these draw-down periods, soil salinity in the wetland bed would have increased.

Ecological Associates (2014) state because there is an observed lag (Ecological Associates, 2007) between lake levels rising and falling and groundwater levels rising and falling, there is the potential for both gaining (groundwater discharging to the lake) and losing (lake leaking to groundwater) conditions, depending on the climate, river levels and possibly interaction with vegetation.

Lakebed sediments are permeable and would allow low to moderate amounts of discharge of groundwater when lake water levels are low, and conversely local recharge of groundwater when lake levels are high.

Roberts and Marston (2000; in Rogers and Ralph, 2010) state that periodic or seasonal inundation and fluctuations in water depth appear to provide ideal conditions for the growth of Typha and Phragmites. Thus, the efficacy of the watering regime at Reedy Lake appears to hinge on the duration of dry periods created by water level draw down and the soil salinities that are present during those periods. Seasonal drying in excess of four months and soil salinities in excess of 200 mS/cm in the upper 0.3 to 1.0m of the soil profile, appear to be required to have a combined negative impact on the viability of the rhizomes of Typha and Phragmites.

Ecological Associates (2014) state that the groundwater conductivity data strengthens the proposition that the extent of Typha and Phragmites might be reduced by managing water levels to promote soil salinisation. If the lake were operated at lower levels a greater area of the wetland exposed to the shallow water table and soil salinities may rise to a level that reduces Phragmites growth. Factors to consider are the soil salinity in wetlands can vary vertically in the root zone and can be different in the soil and surface water. Soil salinity usually varies over time and plants may only grow in periods of low salinity, being dormant at other times.

The EM38 survey by Ecological Associates (2014) provides indicative Apparent Electrical Conductivity (ECa) values for the tolerable soil salt concentrations of different vegetation types at Reedy Lake:

• Typha ECa less than 100 mS/cm

• Phragmites ECa less than 200 mS/cm

• Bolboschoenus caldwellii ECa 200 to 500 mS/cm

• Samphire ECa 400 to 600 mS/cm

• Bare ground / salt scald ECa >600 mS/cm

Ecological Associates (2014) state that in terms or restoring open water habitat to the lake the data indicate that Typha is the principal species of management concern. Summer inundation provides optimal growing conditions for Typha and should be avoided (Cook et al. 2014). Phragmites distribution is limited more by competition than water availability (Haslam, 1970; in Rogers and Ralph, 2010), although sub optimal growth for Phragmites occurs when stands are flooded for less than 6 months in each year.

Cook et al. 2014 advise to avoid regularity. Environmental watering should not follow a strict and regular timeline. As the Australian climate is inherently variable it is important that watering does not occur at the same time, but instead is delivered in various seasons and to various depths and durations. Autumn and winter watering should be more frequent than spring watering to reduce the amount of time the wetlands are inundated during the optimal growth period of Typha and Phragmites.

Between 2016 and 2019 the watering regime was very regular. The above advice from Cook et al. (2014) should be considered in adjusting the timing of watering at Reedy Lake over time to create irregularities.

Water Regime and Vigour

	Typha	*Phragmites*
Frequency	Annual; up to every 2-3 years	Annual; up to every 2-3 years
Depth	Not critical Grows vigorously in 30 to 150 cm	Not critical Grows well in 10 to 100 cm
Duration	From 8 to 12 months Grows well in less (6 months) if timed July-December	From 8 to 12 months Grows well in less (6 months) if timed August-January
Timing (wet)	Start Autumn-Winter	Spring-Autumn
Timing (dry)	Late Summer-Autumn	~~Autumn-early Winter
Tolerances	Re-establishes its canopy quite well after 2 years dry. Can regrow from 5 years dry but is much less vigorous. Drawdown (dry soil) lasting 3 years will reduce vigour.	Re-establishes its canopy quite well after 2 (even 3 ?) years dry. Can regrow from 7 years dry but is much less vigorous. Drawdown (dry soil) of 4 years (maybe 3 ?) will reduce vigour.
Elimination	Elimination difficult to achieve. Requires consecutive years dry (more than 5, as much as 7).	Elimination not practicable. Stems die and breakdown, but rhizomes last several years

Figure 5-4 – recommended water regime to reduce Typha and Phragmites vigour in orange text (source: Roberts et al., 2014)

5.9.2 Limitations of the watering regime

Due to the shallow bathymetry of Reedy Lake, the maximum possible elevation for inundation is 1.0-1.1mAHD. As such it is not possible to use the watering regime to deeply flood Typha and Phragmites to the 1-1.25m depths and durations required to stress the plants. Such flooding would need to be sustained for several months across 2-3 successive growing seasons (Spring to Autumn inclusive) to begin to have an effect. This is not achievable, nor desirable at Reedy Lake, because of the need to balance other objectives.

Instead, the only option is periodically drawing down the wetland to create the conditions required to cause the rhizomes of both species to intermittently die-off and discourage vigorous aboveground growth that would re-charge the rhizomes. The strategy at Reedy Lake is not to eliminate Phragmites and Typha rather to induce enough variation in conditions to ensure they remain in dynamic equilibrium with other wetland vegetation.

To highlight the difficulties with more aggressive attempts to manage Tall Reed, the length of dry periods required to significantly reduce the vigour of both species would need to be more than five years. This is because the rhizomes of Typha typically last for ~6 years and those of Phragmites ~10-15 years. As a result, Phragmites stands have overall greater drought resistance. This highlights the need for management regimes that strike a balance between Phragmites and Typha presence along with other vegetation types.

To affect the optimal growing conditions, drying needs to occur during Autumn and Winter for Typha and Spring-Summer-Autumn for Phragmites. Given this, to affect both species in this manner requires overlapping dry periods that extend for the full calendar year. Again, this is not achievable or desirable to Reedy Lake, because of the need to balance other objectives. An unfavourable water regime for these species is therefore one with shorter duration of flooding and/or longer dry intervals, and less frequency of flooding, than for favourable. Reducing vigour after sustained favourable conditions (which recharges the rhizomes) will require a few years of unfavourable conditions. Again, such conditions can be created at Reedy Lake by ensuring the wetting-drying regime is sustained and optimised to respond to changes in vegetation extents being retrospectively observed in the monitoring data, into the future. Because of the lag between action and response, vegetation changes detected a few years after implementation of the watering regime, are able to inform future refinement to the regime.

Through the operation of the inlet and outlet channel water level controls (penstock gates) water levels in Reedy Lake can be varied between 0.3 and 0.8m AHD in accordance with the desired watering regime. Operational limitations relate to the low gradient and freshwater environment of the inlet and outlet channels which cause siltation and colonisation by reeds, which act to block the channels requiring periodic maintenance to clear the channels. The minimal difference in water levels between the Barwon River and Reedy Lake and between Reedy Lake and Lake Connewarre is also a factor.

Climate variation already exerts a strong influence on water levels in Reedy Lake beyond our ability to control them. There are hydrological limitations to achieving the desired watering regime which were evident during the period 2019 to 2022, with the advent of several La Nina years and higher water levels in Reedy Lake, where summer draw down was unable to be achieved. It is likely that under future climatic conditions, the frequency of more intense rainfall events will increase resulting in slightly more frequent high flow events in the Barwon River which may spill more frequently into Reedy Lake. Higher summer water levels in the Barwon River downstream of Reedy Lake may also reduce the ability to draw water levels down to those required to institute the required drying periods.

Projected sea level rise into Lake Connewarre may have an impact on Reedy Lake in terms of inundation by tidal surface water towards the end of the century, however it would have an earlier impact on groundwater levels and salinities. Further investigation of the sea level rise implications for Reedy Lake would be valuable, building on the initial assessment of Lower Barwon Wetlands Connectivity by Water Technology from 2014, especially using the higher resolution LiDAR (CCMA, 2017) that is now available.

5.9.3 Summary of the impact of the water regime on vegetation

Water level fluctuation controls inundation extents, depths, frequencies, and durations. Water accesses different parts of the wetland and creates different depths when it reaches different levels. This influences where different vegetation types prefer to colonise the wetland surface based on water depths relative to wetland surface elevation and their lifecycle characteristics.

Wetting freshens the soil and drying increases its salinity. Drying is critical at Reedy Lake to maintain the diversity of vegetation types per the LAC by creating unfavourable soil salinity conditions for Phragmites and Typha to dominate and favourable conditions for the diversity of brackish wetland vegetation including sedges/rushes and coastal saltmarsh, to flourish.

Shallow groundwater is playing a key role in sustaining Phragmites and in salinisation of wetland soil. The effect of the water regime upon vegetation involves this interaction with groundwater.

The dynamics of the variables at Reedy Lake are summarised in Figure 5-5.

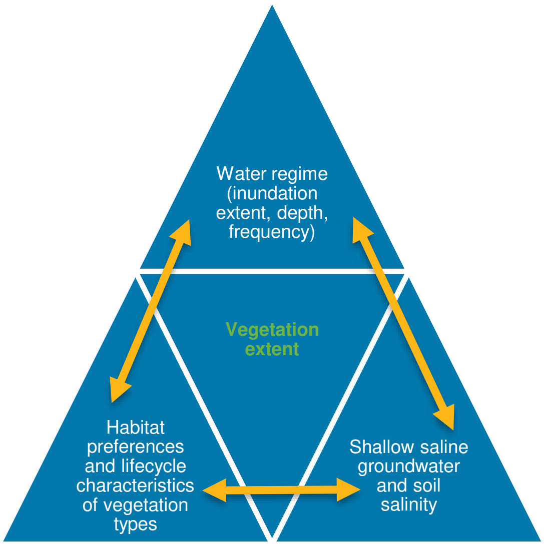


Figure 5-5 – interplay of environmental variables at Reedy Lake

5.9.4 Summary of impact and limitations of the water regime on future vegetation

It is difficult to predict the future response of changes in vegetation extents at Reedy Lake to likely future climate and environmental variables, especially given the observed degree of seasonal and annual variation in extents, largely in relation to cycles of wetting and drying. The future vegetation community composition at Reedy Lake is likely to be influenced largely by climate driven variation in water levels, associated salinities, and the resulting pattern of wetting and drying. During El Nino and 'normal' years the drying part of the regime will predominate and will favour saline tolerant vegetation communities, especially those that have root access to shallow groundwater. During La Nina years, increased freshwater inundation should be expected.

Further detailed information on the vulnerability of Victorian wetlands to projected climate change is available in a State Government report[3] from 2013. Further investigation of the climate change implications specifically for Reedy Lake is required.

[3] Department of Sustainability and Environment (2013). Indicative Assessment of Climate Change Vulnerability for Wetlands in Victoria. Department of Sustainability and Environment, East Melbourne, Victoria.

6 CONCLUSIONS

6.1 Use of remote sensing methods to map vegetation extent and change over time

In conjunction with information on key environmental variables, this study has demonstrated:

- the efficacy of using remote sensing methods to develop a consistent time series of change in vegetation community extent over nearly 40 years, from 1983 to 2022. 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.

- that wetland surface elevations influence the location and extent of key vegetation communities by creating preferable habitat conditions; and the response of vegetation communities to wetting by inundation and/or rainfall and drying.

6.2 Ability to assess wetland ecological character and Limit of Acceptable Change

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.

The Limit of Acceptable Change is:

“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 study has shown that:

- Reedy Lake has been within the Limit of Acceptable Change (LAC) since its listing as a Ramsar site in 1983. None of the vegetation types identified in the LAC has exceeded the 70% limit.

- The ecological character of Reedy Lake is being maintained over time, as indicated by:
    - The observed seasonal, annual, and long-term variation in the extents of key vegetation types within ranges with apparent upper and lower bounds.
    - The apparent influence of the watering regime in 2016-2019 in the observed contraction in Phragmites and Typha association within the wetland (below elevations of 0.8mAHD).

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*.

7 RECOMMENDATIONS

This section highlights several recommendations that have emerged because of this study. These recommendations are deliberately focused on refining the use of a remote sensing methodology to map vegetation extents into the future, based on what was learned from completing this study.

7.1 Spatial and spectral resolution of the satellite imagery being used in the analysis.

This study demonstrated the utility of freely available 'analysis ready' satellite imagery in mapping vegetation extents and retrospectively deriving changes in those extents over time. As part of an ongoing monitoring program using remote sensing methods and satellite imagery the following is recommended

7.1.1 Spatial resolution

- Use 10m (100m^2) Sentinel-2 imagery over 30m (900m^2) Landsat imagery.
- Trial the use of 0.5m Worldview-3 imagery and see how the classification results compare to Sentinel-2.

Sentinel-2 imagery performed very well for classification of Phragmites, Typha, Bolboschoenus and large contiguous areas of Lignum. To increase the accuracy and precision of mapping less contiguous patches of Lignum, especially when surrounded by dense beds of sedges/rushes/grasses (e.g., Bolboschoenus and Distichlis) satellite imagery with a higher spatial resolution than 10m is recommended.

7.1.2 Spectral resolution

For Sentinel-2 and Worldview-3 imagery, the following bands are required:

- Visible bands: red, green blue
- Infrared bands: red-edge, near-infrared, shortwave infrared

These bands are available from both Sentinel-2 and Worldview-3. They are required for both the classification and in subsequent spectral indices analysis.

7.1.3 Imagery acquisition and costs

It is recommended to continue using freely available Sentinel-2 analysis ready imagery from Geoscience Australia; plus, trial the use of appropriately corrected satellite imagery from the Worldview 3 satellite platform. This imagery is not free. To receive archive pricing (by using imagery older than 90 days in archive) it is recommended to schedule future vegetation mapping as retrospective exercises that cover the previous two years. This means that four images would be obtained, one in each of the summer and winter seasons in each year, to provide for seasonal and annual comparison.

Archive pricing for 0.5m 8-band multispectral imagery is between $10-20USD per km^2 with a minimum order of 25km^2 and 2km width. Reedy Lake has an approximate area of 8.76km2. Given the minimum order requirements the based cost for one image would be $250-500USD. The total two-year cost for four images would then be $1000-2000. The Area of Interest (AOI) would be larger than required so could include Hospital Swamp, Baensch's Wetland and Sparrovale wetland, intervening areas and surrounds to enable vegetation mapping to be completed for these areas at the same time.

7.2 Classification algorithm and training samples being used in the analysis.

7.2.1 Classification algorithm

This study used a Maximum Likelihood classification algorithm. The algorithm performed well, and it is recommended that future classifications use the same algorithm.

7.2.2 Training sample selection

Reedy Lake has a spatially complex assemblage of diverse vegetation types. As determined in this study, these vegetation types can vary significantly in their extent seasonally and over time. Careful selection of training samples from several locations across the wetland is required to ensure that the spectral characteristics of the different vegetation types are accurately captured.

7.3 Using spectral indices as part of the analysis.

The preliminary results obtained in this study for NDVI and NDVIre showed promise as potential indicators of plant vigour, especially for Phragmites, Typha and Bolboschoenus. These vegetation types have chlorophyll rich leaf surface areas that are readily detected in the analysis and show distinct seasonal changes in the vegetation indices between summer (high levels of greenness) compared to winter, with seasonal die-back. It is recommended that further investigation be performed using remotely sensed imagery over the period 2016 to 2022 to derive a retrospective time-series of NDVIre for these three key vegetation types. Lignum, with its woodier form has proved more challenging to detect in the indices. Further work at potentially higher spatial resolution is required to resolve the use of vegetation indices for this vegetation type.

7.4 Monitoring frequency

Retrospective classification of satellite imagery to map vegetation types is recommended, ideally every two-years, to detect changes in vegetation extents due to the lag time between watering actions and the subsequent changes in vegetation extent and to provide data that can reliably inform upcoming seasonal watering plans. Annual monitoring could be undertaken, but interpretation of the results would be limited until a greater length of record was available because monitoring annually will not allow for trends to be detected in the analysis at that time.

7.5 Other recommendations

Several additional recommendations to fill knowledge gaps in relation to the watering regime are:

- Establish a soil salinity monitoring program for Reedy Lake
- Investigate the implications of projected sea level rise for the hydrodynamics of Reedy Lake
- Investigate the likely climate change implications for the vegetation at Reedy Lake
- Investigate the use of remotely sensed vegetation indices (e.g., NDVIre) to monitor vegetation health remotely in conjunction with a field-based monitoring program to ground truth the results.

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APPENDIX A
REEDY LAKE EVC MAP 2022


500 250 0 500 Meters
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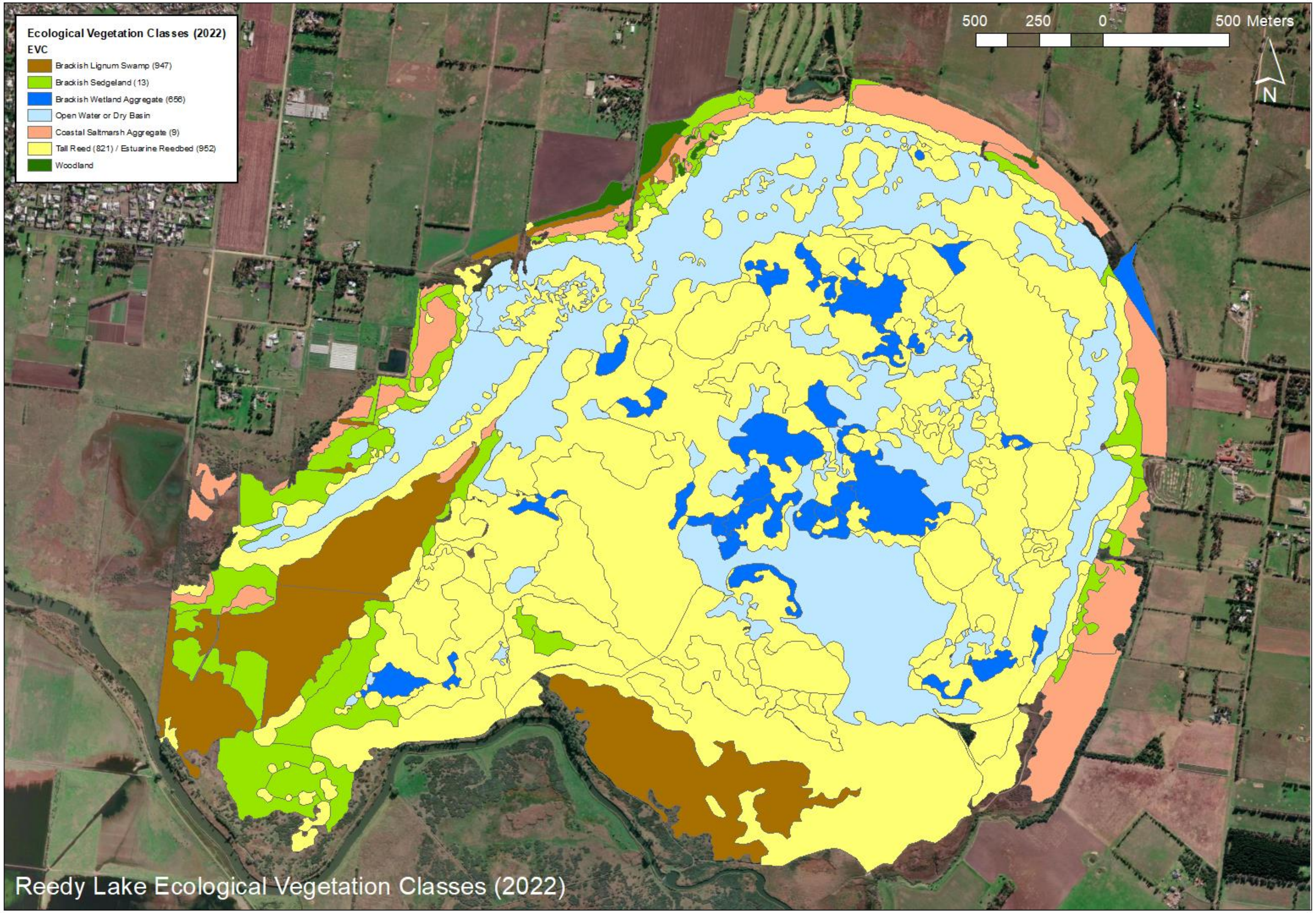
Reedy Lake High Resolution Aerial Image (2022)


Ecological Vegetation Classes (2022)
EVC
Brackish Lignum Swamp (947)
Brackish Sedgeland (13)
Brackish Wetland Aggregate (656)
Open Water or Dry Basin
Coastal Saltmarsh Aggregate (9)
Tall Reed (821) / Estuarine Reedbed (952)
Woodland
500 250 0 500 Meters
N
Reedy Lake Ecological Vegetation Classes (2022)

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Melbourne

15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800

Sydney

Suite 3, Level 1, 20 Wentworth Street
Parramatta NSW 2150
Telephone (02) 9354 0300

Brisbane

Level 5, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1460

Adelaide

1/198 Greenhill Road
Eastwood SA 5063
Telephone (08) 8378 8000

Perth

Ground Floor, 430 Roberts Road
Subiaco WA 6008
Telephone (08) 6555 0105

New Zealand

7/3 Empire Street
Cambridge New Zealand 3434
Telephone +64 27 777 0989

Wangaratta

First Floor, 40 Rowan Street
Wangaratta VIC 3677
Telephone (03) 5721 2650

Geelong

51 Little Fyans Street
Geelong VIC 3220
Telephone (03) 8526 0800

Wimmera

597 Joel South Road
Stawell VIC 3380
Telephone 0438 510 240

Gold Coast

Suite 37, Level 4, 194 Varsity Parade
Varsity Lakes QLD 4227
Telephone (07) 5676 7602

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