TOOTANELLUP WETLAND SUITE

Further Investigations of Boggy Lake, Tootanellup Lagoon and the intermediate wetland

Report prepared for Green Skills Inc., Denmark WA by:

Steve and Geraldine Janicke 2023

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Acknowledgements

The authors would like to thank Basil Schur of Green Skills Inc for his support for these investigations.

The Green Skills' program involving a Climate Change related assessment of the Tootanellup wetlands is supported by South Coast Natural Resource Management Inc., through funding from the Australian Government's National Landcare Programme as well as Janicke Environmental Assessments. Gondwana Link Ltd, Birdlife Western Australia, the Denmark Bird Group and the Koorabup Trust. It also formed part of Green Skills' and BirdLife WA's Festival of Birds & Biodiversity 2022 program supported by Lotterywest and Birdlife WA. Green Skills also acknowledges the technical and scientific information and advice provided on wetlands by Ruhi Ferdowsian and Don McFarlane.

For bibliographical purposes this report should be cited as:

Janicke S. and Janicke, G. (2023) *Tootanellup Wetland Suite; Further Investigation of Boggy Lake and Tootanellup Lagoon and the intermediate wetland.* Report prepared for Green Skills Inc., Denmark WA.

Cover photo collage: Steve Janicke

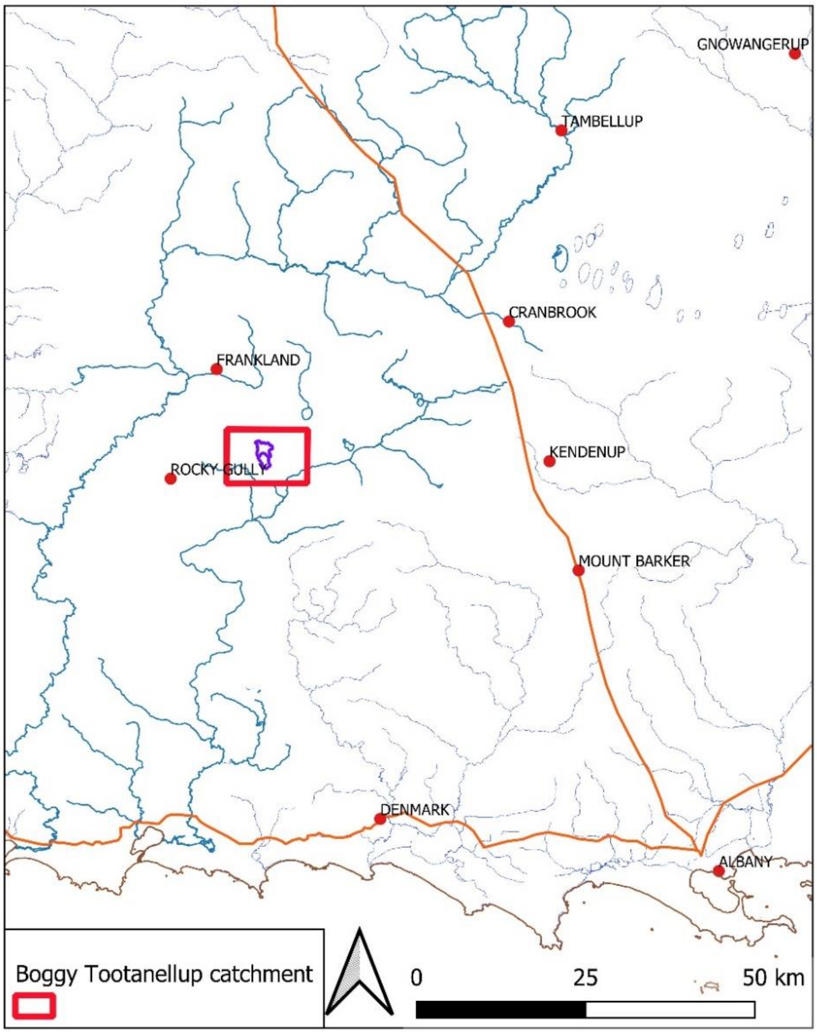
All photos are by Steve and Geraldine Janicke or Basil Schur.

This project received funding through the Western Australian Government's State Natural Resource Management Program, and the Koorabup Trust with additional assistance provided by Janicke Consultants and Green Skills . The support of Gondwana Link and the Gillamii Centre is also acknowledged.

Contents

Introduction

In October 2020 Green Skills Inc. purchased Lot 2249 Rocky Gully Road, which is between Rocky Gully and Frankland River, in the Upper Kent catchment in Western Australia. The 49.5 ha (122 acre) property has approximately 18 ha of remnant bush and 31.5 ha of cleared land. The property is a strategic link between the larger Tootanellup Nature Reserve and a Department of Water and Environmental Regulation (DWER) reserve which encompasses a group of three freshwater wetlands of high conservation value.



The three main wetlands are identified in two ways as follows:

Boggy Lake - wetland A

Middle Lake - wetland B

Tootanellup Lagoon – wetland C

There are several ephemeral wetlands in the DWER reserve, two which have been labelled Wetlands D & E.

Permission had been granted to Green Skills to undertake bird and other environmental surveys at the lakes as well as seed collecting on the adjoining Boggy Lake property. Green Skills is also partnering with BirdLife Western Australia and the Denmark Bird Group to undertake regular surveys at Boggy Lake and adjacent wetlands to ascertain the presence of Australasian Bitterns.

Figure 1: Location of Boggy Lake and Tootanellup suite wetlands relative to regional towns on the south coast of Western Australia.

The Tootanellup wetland suite is surrounded by DWER conservation reserve and farmland with some tenuous connections to other reserves and bush remnants. The wetlands have been and are experiencing the hydrological pressures due to land clearing at both a local and semi-regional scale as well as reduced regional rainfall. However, management of the reserve is limited to dealing with local hydrological pressures. A range of investigative surveys are being undertaken to delineate the hydrological and aquatic ecological character of the wetlands to assist with planning projects to manage these wetlands.

The primary concerns for the three lakes are increasing water salinity, degradation of the aquatic habitat in general and degradation of the vegetation in the surrounding riparian buffer.

These threats to the quality of habitat in the reserves threaten the fauna using the area. The goal of management is to ameliorate degradation processes to ensure the wetlands have sufficient resilience to retain their essential ecological character.

Three approaches to conservation management for the Tootanellup wetland suite of wetlands are,

- Take no actions apart from monitoring condition.
- Undertake remedial revegetation of targeted areas just in case.
- Gain greater insight to better inform management decisions before undertaking actions.

Figure 2: The Tootanellup wetland suite with temporary benchmark locations

Catchment relationship between Boggy Lake and Tootanellup Lagoon.

The following description of the form of the Tootanellup wetland suite consisting of Boggy Lake, Middle Lake and Tootanellup Lagoon, provides the foundation for discussions and speculation regarding the possible hydrological and ecological future of the reserve and what may or may not be achievable in terms of management actions.

Table 1: Wetland location and geometry

Wetland name	Easting	Northing	Length N - S (m)	Length E - W (m)
Boggy Lake	513554	6185500	675	585
Middle	514076	6184565	400	275
Tootanellup Lagoon	514425	6184190	380	290

Table 2: Wetland catchment areas.

FEATURE AREA (Ha)	BOGGY LAKE	MIDDLE LAKE	TOOTANELLUP LAGOON
Wetland	30	9.3	9
Private farmed	174	16	93
Private remnant	60	-	13
Reserve	106	25	74
TOTAL	370	50.3	189

The three larger wetlands are arranged linearly along what appears to be an ancient water course. They are separated by narrow, sandy ridges that restrict surface water flows between them except in extreme events that could increase the water depth to two or more meters. The distance between the adjoining edges of Boggy Lake and Middle Lake is approximately 170 meters and between Middle Lake and Tootanellup Lagoon approximately 120 meters. A distinct swale can be observed sloping down from Middle Lake to Boggy Lake and this indicates there has been surface water flow in the past. When this last occurred is unknown. Tentative estimates of ridge elevations suggest the water depth in Middle Lake would have to exceed 2 meters before surface overflow to Boggy Lake can occur. If the depth of water in Boggy Lake exceeds approximately one meter, then overflow into a broad ephemeral damp land to the west, can occur.

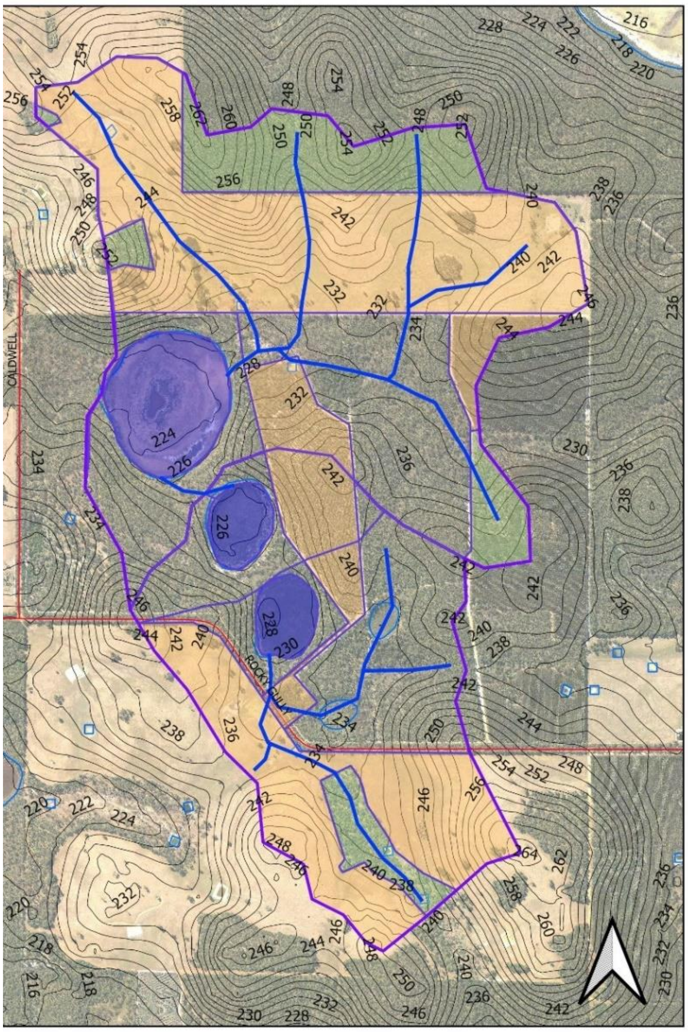
Table 3: Relative bed levels of the three wetlands

	Relative bed levels (m) surveyed 04/12/2022	Relative bed elevation (m)	Contour (AHD) interpretation from aerial images
Boggy Lake	8.4	0	224
Middle Lake	10.2	1.8	226
Tootanellup Lagoon	12.8	4.4	228

Tootanellup lagoon can receive flows from a small catchment to the south. A past connection with Middle Lake is indistinct but was most probably along the northwest shoreline. Middle Lake has no other distinct or potential stream inputs. What is largely unknown is the extent of groundwater interactions with the wetland suite.

The beds of all three wetlands are very slightly bowl shaped and can be considered essentially level. Boggy Lake has a central and slightly deeper basin approximately 0.3 – 0.4 meters deeper than the wider bed area. The basin occupies an area of roughly 1.2ha which is only 4% of the total bed area of the lake. This basin was a pond that contains some water and was accessed on the 24 February 2023 when the broader area of the lake was dry. The absence of obvious spoil around the perimeter suggested that the basin had not been purposefully excavated and is a natural feature.

It is possible however, that it may have been ‘scraped’ out in the very early settlement days, as this was a common practice to try and ensure the availability of stock water during dry conditions.



Boggy Lake, Tootanellup wetlands
Catchment areas (Ha)

Feature	Boggy Lake	Middle Lake	Tootanellup Lagoon
Lake area	30	9.3	9.0
Private farmed	173.6	16.1	92.7
Private remnant	59.8		13.4
Reserve	106.1	50.2	74.1
Total area	369.4	50.2	189.1

Boggy Lake and Tootanellup Lagoon
Stream lines (kms)

Boggy Lake	Middle Lake	Tootanellup Lagoon
6.37		3.22

0 0.25 0.5 0.75 1 km

Boggy Lake flow lines
Boggy Tootanellup catchment
Catchment
Lake
Private
Remnant
Reserve

Janicke En

Figure 3: Catchment boundaries, areas and stream lines for Boggy Lake, Middle Lake and Tootanellup Lagoon.

Lake Vegetation

Middle Lake and Tootanellup Lagoon are almost completely covered in Jointed Twigrush (*Machaerina [Baumea] articulata*) with very little open water areas. There are a few patches of Sheath Twigrush (*Machaerina [Baumea] vaginalis*) and Bare Twigrush (*Machaerina [Baumea] juncea*) on slightly raised areas of the lakebed. Bare Twigrush also forms a fringing band around the wetlands at the highwater level.

Boggy Lake is divided almost 50:50 between open water and bands of dense Jointed Twigrush (*Machaerina [Baumea] articulata*) predominantly around the periphery, as well as scattered patches around the central pond. It is possible that the entire bed was once covered in Jointed Twig Rush as are Middle Lake and Tootanellup Lagoon at present. As with the two smaller lakes, patches of Sheath Twigrush and Bare Twigrush occur on slightly raised areas.

Two patches of Bullrush or Narrowleaf Cumbungi, (*Typha domingensis*) were found near the southern and north-eastern edges. Narrowleaf Cumbungi can tolerate water salinity up to 6 ppt[1]. Increasing salinity within the wetland would limit it's spread.

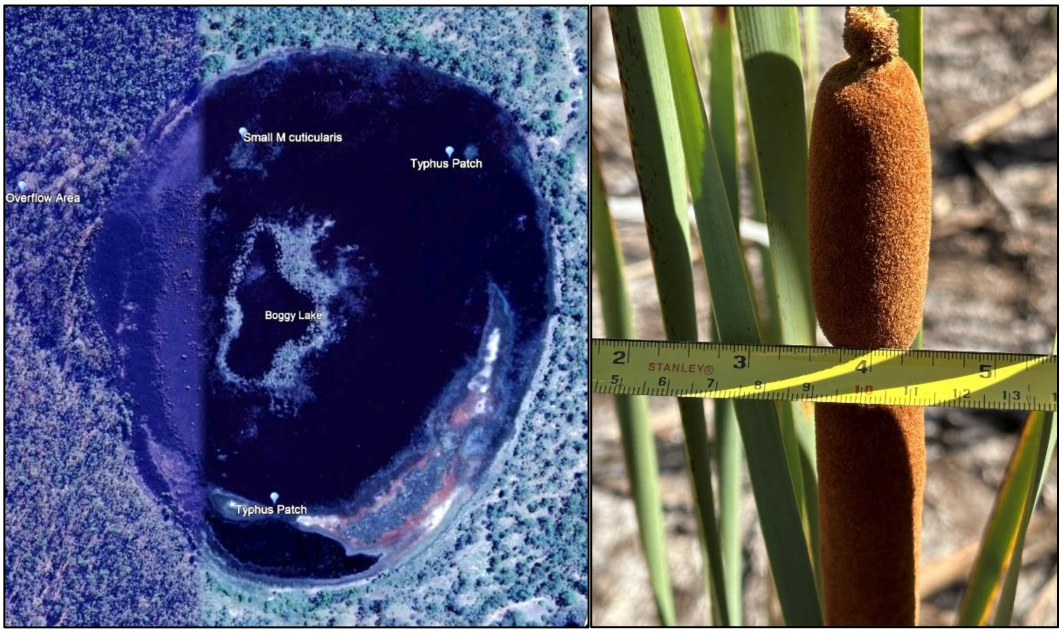


Figure 4: Location of Narrowleaf Cumbungi (Typha) and tape measure against leaves and flower spike.

Small samphire plants were also observed thinly scattered around the eastern edge. Seeds may have washed in from the saline groundwater patch within the creek environs.

The lakebed topsoil is composed of black peaty material to a depth of about 250mm sitting over dense black-to green-grey clay. The peaty material is typically formed from sedges, mainly Jointed Twigrush[2] and this implies that in the past the whole lakebed had been covered with Jointed Twigrush. The loss of sedge cover and uneven distribution in the central lake area poses the question, why?

Jointed Twigrush can tolerate prolonged inundation up to 1 meter deep and can tolerate water levels dropping below the surface in summer[3]. The rhizome roots extend to approximately 20cm deep and the peat provides moist conditions for the roots when the level falls below the peat surface[4]. It is a rapid grower in good circumstances. It is also reported to tolerate brackish water from 1000 to 3000 mg/L TDS (i.e., up to an electrical conductivity [EC] of 4.5mS/cm). However, it has been observed, by the

[1] Glenn, Thompson, Frye, Riley, Baumgartner, "*Effects of salinity on growth and evapotranspiration of Typha domingensis Pers*.," Aquatic Botany, Volume 52, Issues 1–2, 1995, Pages 75-91, ISSN 0304-3770,

[2] A guide to managing and restoring wetlands in Western Australia: Chapter 2: Understanding wetlands, Wetland vegetation and flora of SW, Department of Environment and Conservation.

[3] Water and Rivers Commission 2000, Using rushes and sedges in revegetation of wetland areas in the south west of WA, WRC, River Restoration Report No. RR 8

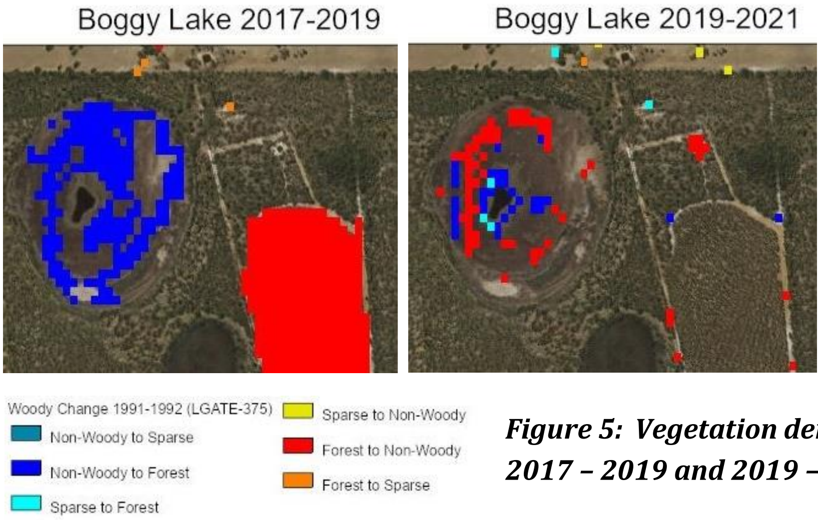
[4] Carbon products from peat project Lake Muir Nature Reserve: Report and recommendations of the EPA, Bulletin 440, June 1990.

authors growing, in Lake Nunijup, albeit not very healthily, in salinities between 8 to 10 ppt when inundated.

Vegetation change

Land Monitor provides mid-scale monitoring of salinity and vegetation across Western Australia using satellite imagery. Appendix 4 shows aerial imagery with vegetation changes around Boggy Lake from 1974 to 2021.

Care needs to be taken when interpreting the imagery as it uses multi-spectral indices to estimate changes in density of forest and non-woody vegetation and these can be affected by other factors. For example, higher water levels in the lake can reduce the apparent stem density of the sedges which may be misconstrued as a decrease in cover. Between 1974 to 1980 Land Monitor imagery implies that there was a complete reduction of vegetation in Boggy Lake. However, it is difficult to claim this was the period when the Twigrush cover was removed. The imagery legend implies that between 2017 – 2019, the lakebed vegetation changed from non-woody to forest which is not correct.



Either the water became eutrophic and there was a greater reflection of green off the water or some other factor was being interpreted as increase in vegetation. The removal of the plantation timber is reflected accurately. Between 2019-2021 the red areas possibly indicate reduced health of Jointed Twig Rush, and the blue – increased health.

Figure 5: Vegetation density changes in Boggy Lake between 2017 – 2019 and 2019 – 2021

An examination of rainfall records for nearby locations Rocky Gully town, Frankland and Bangalup (20 kms west) was made (See Appendix 3). The rainfall records from Bangalup were most consistent and have been used in this discussion. There has been a 20% drop in rainfall from the 1920s to 2022. The annual rainfall in 2022 was 660 mm and by January 2023 Boggy Lake had dried out. An annual rainfall of 660mm or less was used to look for the number of years in which the rainfall was potentially low enough for Boggy Lake to dry out over the following summer. Table 4 suggests the frequency of low rainfall years and therefore potentially dry lakebed events has more than doubled in recent years and this would adversely impact the health and recovery growth of Jointed Twigrush.

Table 4: The number of years annual rainfall was potentially low enough for Boggy Lake to dry out

Years	1920-1960, 40 years	1960 – 2000 40 years	2000 – 2022 22 years
Number of times annua rainfall was below 660mm and Boggy Lake potentially dried out.	6	11	12

There is a proviso regarding this supposition; namely the dense sedge cover over Tootanellup Lagoon and Middle Lake reduced evaporation and was observed to still hold water over the summer of 2023. In that case the lower frequency of 660 mm rainfall years in the first half of the twentieth century may not necessarily have led to Boggy Lake drying out. The synergy between reduced rainfall, reduced sedge cover, along with slowly increasing water salinity, may be collectively defining a new aquatic regime.

Figure 6: The dry bed of Boggy Lake (24/2/2023) exposed scattered clumps of decomposing Jointed Twig Rush (roughly 1 per square meter) that once must have covered most of the now open water areas. Insert: a close up of the remnants of fibrous material that was once the base of a Jointed Twig Rush clump.

Water quality

Water quality investigations commenced in October 2021 to get a better understanding of the wetland condition and dynamics. The results are shown in Table 5. Seasonal variations in lake water levels defines what is known as the *hydro-pattern* of the wetlands. This defines the peaks and troughs which might be expected as a matter of course over periods of a decade or more. The hydro-pattern may be generally consistent from year to year or trending towards some other point of equilibrium. 2021 was a wet year in the area and during the October 2021 sampling event, surface water was able to be collected at the perimeter of the Jointed Twigrush fields of all three wetlands. Tootanellup Lagoon and Middle Lake waters were quite fresh, and this was reflected in the aquatic macroinvertebrate populations. Boggy Lake was brackish and subsequently edging towards saline, but commensurate with salt concentration due to evaporation. By January 2023, Boggy Lake had largely dried except for a small and shallow central pond.

There had been little if any rainfall in the area during the previous two months. In February the central pond was accessed, and a water sample was obtained. The electrical conductivity was 40.9 mS/cm (seawater is 53 mS/cm) and the pH was 7.5. Given the shallowness of the pond (~ 0.1 m), the high salinity could reasonably be attributed to salt concentration by evaporation.

The fact that Boggy Lake had dried out (apart from the small pond), but both Tootanellup Lagoon and Middle Lake retained shallow fresh surface water in January 2023, suggested that the dense Jointed Twigrush cover acts to significantly reduce evaporation. This can be expected given the effect of shading and the reduction of wind speed to nearly zero at the water surface, even during periods of strong northwest to easterly summer winds. It may also be inferred that transpiration from the sedges is the lesser source of water loss and losses through the bed of the lakes are likewise, small.

Figure 7: By January 2023, Boggy Lake had largely dried except for a small central pond.

The central areas of Tootanellup Lagoon and Middle Lake are not easily accessible due to the dense stands of Jointed (and spiky) Twigrush extending across the full width of the basins. There appears to be slightly deepening gradients and the central parts may be 0.2–0.3 meters below the level of the foreshore.

In January 2023 the edge of the water in Tootanellup lagoon had retreated to about 30 – 40 meters from the perimeter of the Jointed Twigrush and in Middle Lake it was over 50 meters from the perimeter. Some small open area patches were observed further into the wetlands, and these may relate to slightly raised areas of the bed which favoured Sheath and Bare Twigrushes.

Simple water monitoring tactics

Small environmental management projects with corresponding small and unpredictable budgets require monitoring tools which match those characteristics. Sophisticated waterway monitoring programs usually require specialist equipment which means expertise and expensive equipment. This level of investigation aims to clarify environmental processes with a high degree of confidence in the conclusions. One common limitation of local studies is the uncertainty of ensuring ongoing funding. Nevertheless, basic data collected consistently over time can build up to provide a valuable and useful description of the waterway of interest, in this case wetlands. This type of monitoring is for the purpose of tracking changes in real time and assessing the effectiveness of management actions. This does not mean that more specific research cannot be included.

The location and accessibility into the Tootanellup wetlands lends itself to the following relatively low cost water monitoring approach.

- Opportunistic seasonal water monitoring of all three wetlands. The key parameters to monitor are; Water levels, electrical conductivity (salinity), pH, and temperature.
- It is desirable to continue to monitor the salty inputs to Boggy Lake from the northeast catchment area during winter periods and from significant storm events (winter and summer).
- Rainfall (to be correlated with nearby weather stations). A rain gauge at the conservation block would be useful in this respect to lake recharge inputs to be quantified more accurately.
- If feasible, the establishment of several shallow monitoring bores for assessing sub-surface water salinity (not necessarily a semi-regional water table) in key locations.

Table 5: Water quality measurement for the wetland suite

Date	Wetland name	Conductivity mS/cm (25C)	Salinity calc (ppt)	pH	Turbidity (NTU)	Temp °C	Depth water at site (m)	Tannins	Site
24/10/21	Boggy Lake	4.5	2.26	6.5	30	25.5	0.8	slight	BM1
10/2/22	Boggy Lake	12.5	6.4	7.3	50	30	0.2	Strong	Nth edge
19/6/22	Boggy Lake inflow (~1 L/s)	10.2	5.7	-	-	-	-	Nil	Confluence
22/1/23	Boggy Lake (subsurface)	7.9	-	6.1	-	-	-0.4	NA	Nth edge
24/2/23	Boggy Lake central pond	40.9		7.5			0.05	Slight	Shallow
24/10/21	Tootanellup Lagoon	1.35	0.67	5.9	30	19	0.3	Slight	SE edge
10/2/22	Tootanellup Lagoon	2.65	1.32	6.1	30	23	0.2	Strong	SE edge
22/1/23	Tootanellup Lagoon	3.8	-	5.9	<10	19	0.05	slight	SE edge
24/10/21	Middle Lake	0.38	0.19	6.3	50	26	0.5	strong	Sth edge
22/1/23	Middle Lake	1.91	-	6.0	<10	21	0.05	slight	Sth edge
24/10/21	Ephemeral playa	0.32	0.162	6.1	30	23.8	0.2	Slight	
24/10/21	Ephemeral playa	1.48	0.74	5.9	5	27	0.2	tannins	
24/10/21	Ephemeral playa	0.45	0.22	6.8	50	24	0.3	slight	
22/1/23	Farm soak	22.4	-	8.6	-	-	-	-	nth boundary

Water quality measurements were made in-situ using Horriba Compact Conductivity and pH Meters (LAQUAtwin-EC-33 and pH33). Turbidity was determined using a Turbidity tube and temperature using a glass thermometer.

Depth to watertable

Figure 8 provides broad estimates of depth to water table in the Middle Kent River catchment and includes the Tootanellup wetlands (Source: DeSilva et al, 2006 Salinity Situation Statement: Kent River, DOW, WRT 33 [5]). It can be seen that the depth to water table in the reserve is estimated at less than 2 meters. This would need verification or otherwise. In this report, groundwater salinity near the wetlands is estimated as less than 7000 mg/L TDS.

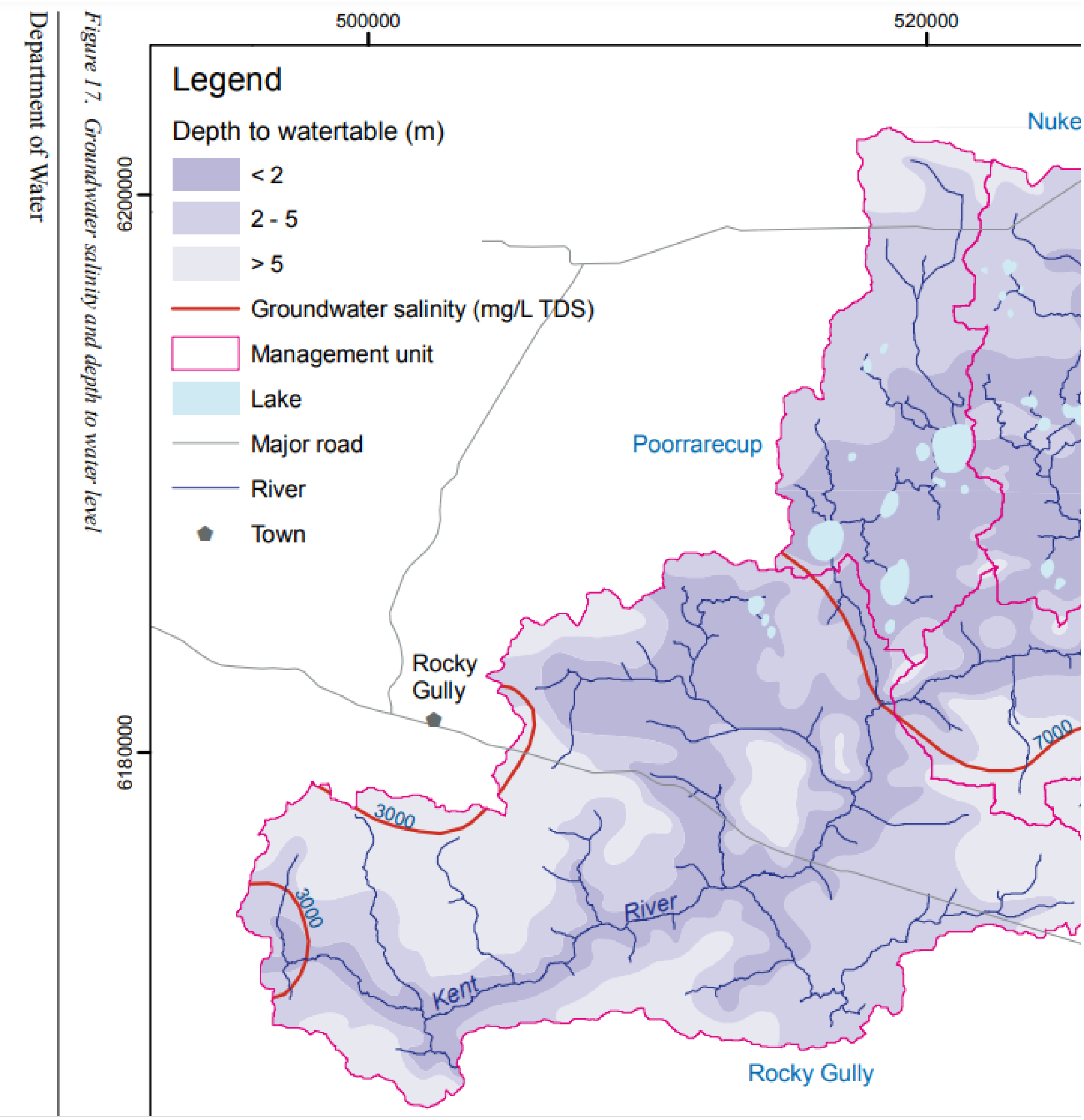


Figure 8: Groundwater salinity and depth to water level

[5] De Silva, J, Bari, MA, Dixon, RNM, Coppolina, ML, Boniecka, LH & Ward, BH 2006, Salinity Situation Statement: Kent River, Department of Water, Water Resource Technical Series No. WRT 33, 129p.

Surrounding areas of influence

The private land immediately east of the wetlands has an area of 36ha of which 29.5 ha has been cleared of Blue Gums. These are known to have a strong influence on local groundwater levels. According to hydrogeologist Ruhi Ferdowsian, this area may play a significant role in influencing the water condition in the wetlands.

The other area of influence is the catchment to the north and east of Boggy Lake. This has an area of approximately 350 ha and consists of four first order streamlines which converge to drain into Boggy Lake via a narrowing swale adjacent to the shoreline of the lake and at the northern foot of the eastern lunette. The swale is covered in dense *Machaerina (Baumea) juncea*, large paperbarks and Yates. Between the lake and the northern reserve boundary groundwater appears to be impacting surface soil conditions and surface ponding was observed on 19/06/2022. Low surface flow was observed entering Boggy Lake and the flow rate was estimated at not more than one litre per second. The conductivity was 10.2 mS/cm indicating the salinity was slightly more than the estimated values for groundwater in the semi-regional area. A trickle flow was also observed on a subsequent visit. The relative contributions of these two areas to the long term water condition in the wetlands is uncertain, however the water quality data collected to date indicates that saline surface flows do occur.

Shear zone - a potential influence

The GeoView WA interactive mapping tool shows an interpreted bedrock map (Figure 9) which indicates there is a geological shear zone trending NW to SE and intersecting the northeast corner of the wetland reserve. This coincides with an observation of saline groundwater being expressed in shallow surface puddles in the area between the shear zone and the edge of Boggy Lake. The distance between the shear zone and the lake is about 400 meters.

Overheu et al, comments in the Cranbrook-Toolbrunup: Catchment Appraisal Report 2001, that 'n*umerous shear zones and faults occur in both the Archaean rocks and the meta-sediments. These features have dictated the position of the creek and affect surface and groundwater flows.*'

Bari et al note that, '*These zones act as conduits or barriers to groundwater movement*'.

Ferdowsian comments regarding the Upper Denmark catchment that, '*most of the salt seeps are associated with the intersection of creeks and shear zones. This is probably due to the conduit/barrier mechanism of the shear zones.*'

The presence of the shear zone in the northeast quadrant of the reserve, the saline seep and its influence on Boggy Lake appears to be a significant target area for reducing ground water inputs. The area warrants further investigation.

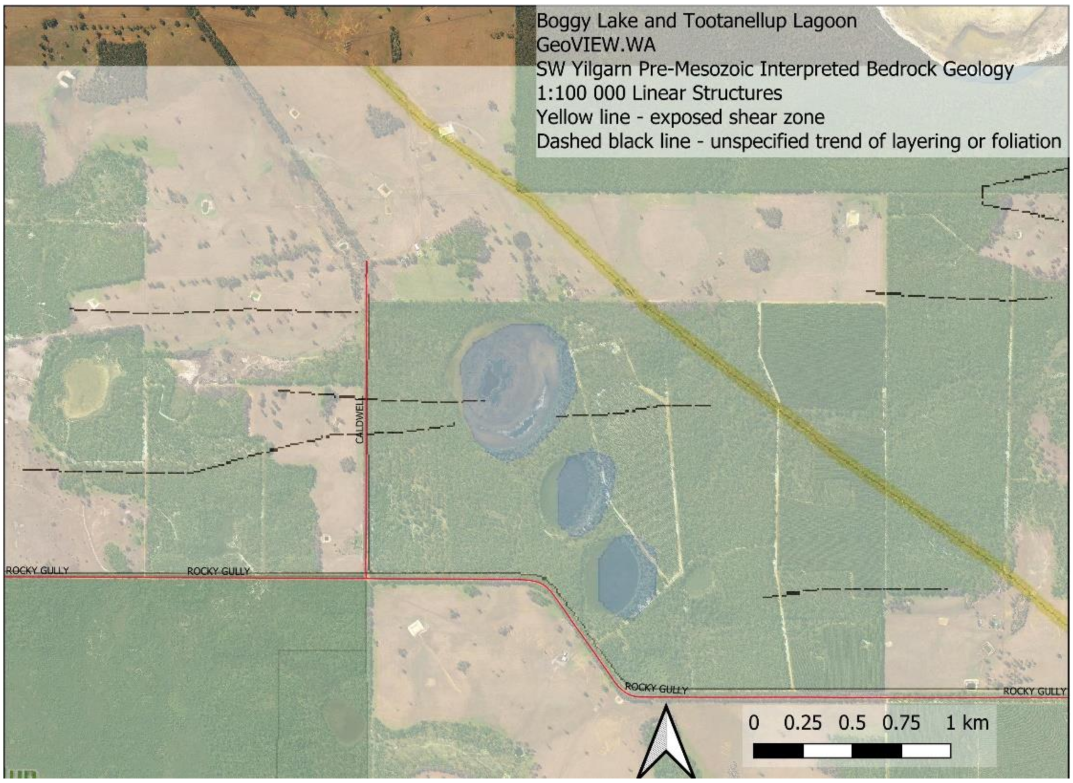


Figure 9: Geological view of shear zone (yellow line) and layering trend.
Source: GeoView (https://geoview.dmp.wa.gov.au/geoview/?Viewer=GeoView)

Land monitor salinity online mapping

Land monitor salinity mapping from satellite imagery.

When compared with ground truth mapping by DPIRD hydrologists, the 2018 mapping did not map 40.0% of the salt affected land and incorrectly mapped 3.2% as salt affected.

- Land Monitor Salinity 1998
- Land Monitor Salinity 2018

Figure 10: Land monitor salinity mapping from satellite imagery. Source: NRInfo (natural resource information) soil-landscape mapping. (https://dpird.maps.arcgis.com/apps/webappviewer/index.)

NRInfo online soil landscape mapping

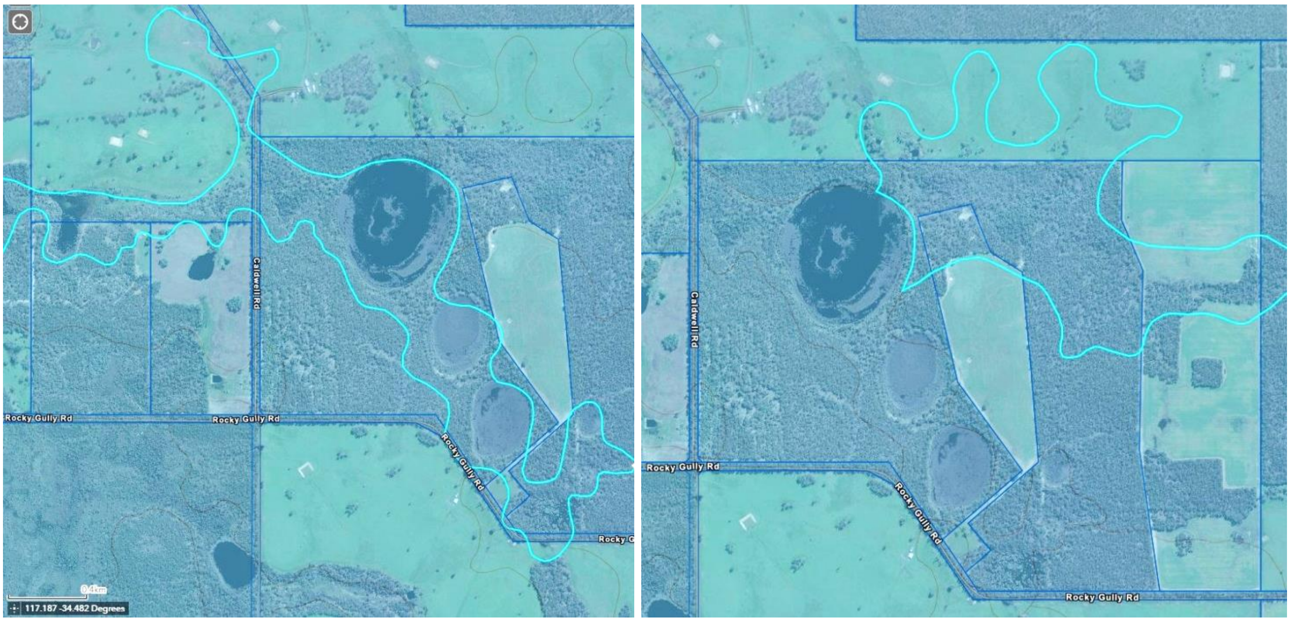


Figure 11: Left: Camballup wet phase map unit. Right: Perillup Plain subsystem map unit. Adjacent map units are THE Mallawillup subsystem. Source of above imagery: NRInfo (natural resource information) soil-landscape mapping. (https://dpird.maps.arcgis.com/apps/webappviewer/index.)

Table 6: Frankland land resources survey soil mapping

Land Qualities -	Map Unit Name	Summary Map Unit Description
Salinity at Surface 10% of map unit has a moderate to extreme risk	Camballup wet phase	Areas of permanent and ephemeral lakes and swamps with lunettes. Wet soil and semi-wet soil with saline wet soil and duplex sandy gravel
Salinity at Surface 5% of map unit has a moderate to extreme risk	Perillup Plain subsystem	Gently undulating plain with some swamps. Duplex sandy gravels, Grey deep sandy duplexes with Wet and Semi-wet soils
2% of map unit has a moderate to extreme risk	Mallawillup subsystem	Undulating rises with broad flat swampy depressions. Soils are formed in colluvium and weathered granite. Gravelly soils are common

Source: NRInfo (natural resource information) soil-landscape mapping. (https://dpird.maps.arcgis.com/apps/webappviewer/index.)

Understanding the hydrogeology of the wetlands

The following discussion revisits observations and concepts presented by Ruhi Ferdowsian and Dr Don McFarlane regarding the hydrogeology of the Tootanellup wetland suite. Recent water observations and data collected by Steve and Geraldine Janicke have then been added to help qualify what these imply about the system.

Responding to comments by hydrogeologist Ruhi Fredowsian (*italics*).

> ***The valleys and flats are infilled depressions containing Tertiary sediments. Very likely, the regolith in the valleys have coarse material at depth. A semi-regional aquifer may be flowing in the more conductive coarse material and the low hills have shallow local aquifers that flow from hilly areas towards the valleys and feed the deeper semi-regional aquifer.***

The depth profile of the sediments deep beneath the wetlands (greater than 2m) is unknown and can only be determined accurately by drilling exploration bores. Current investigations are limited to surface observations. For this reason, the interaction between any semi-regional aquifer and the lake waters is speculative. Employing sophisticated ground penetrating technology may yield some insight in a non-invasive manner.

Gamma ray surveys provide a glimpse of the overlying geological structure of the landscape with granite and gravels generally producing stronger Thorium radiation counts than quartz sands and silts. Surface geology can also reveal features at depth. The airborne map of Gamma ray intensity over the wetland suite as shown in Figure 12 is relatively uniform and provides little evidence of any anomalies or near surface granite or laterite along the centre line of the wetlands. Interestingly the former plantation timber area to the east shows a higher signal strength and may reflect an influence of vegetation on Gamma signal strength. Several exploratory bore holes in key locations may be sufficient to shed light on the nature of the semi-regional and local groundwater structure around the wetland suite.

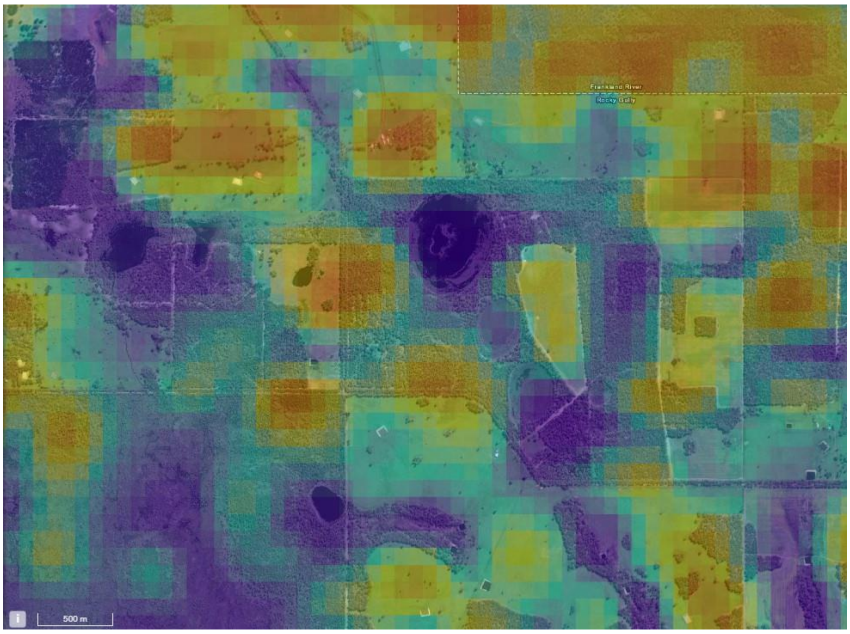


Figure 12: Radiometric 2015, unfiltered Thorium ppm. Boggy lake is slightly above centre of image. Source: Geoscience Australia (https://portal.ga.gov.au/)

Janicke Environmental Assessments

> ***<u>Very likely,</u>* the wetlands are perching over the semi-regional aquifer, but they are not affected by its salinity. The main contributor to the salinity of the wetlands are the local aquifers close to and around the wetlands. This means that high rate of recharge in the cleared areas around the wetlands *<u>may</u>* cause/increase salinity in the wetlands. At the moment freshwater is perching over the wetland including the lakes. The salinity of these lakes will increase during the dry period.**

Figure 13 below indicates there is opportunity for movement of groundwater into the wetland suite from all sides, but the areas to the northeast and east are expected to be dominant although the relative contribution along specific subterranean pathways is unknown.

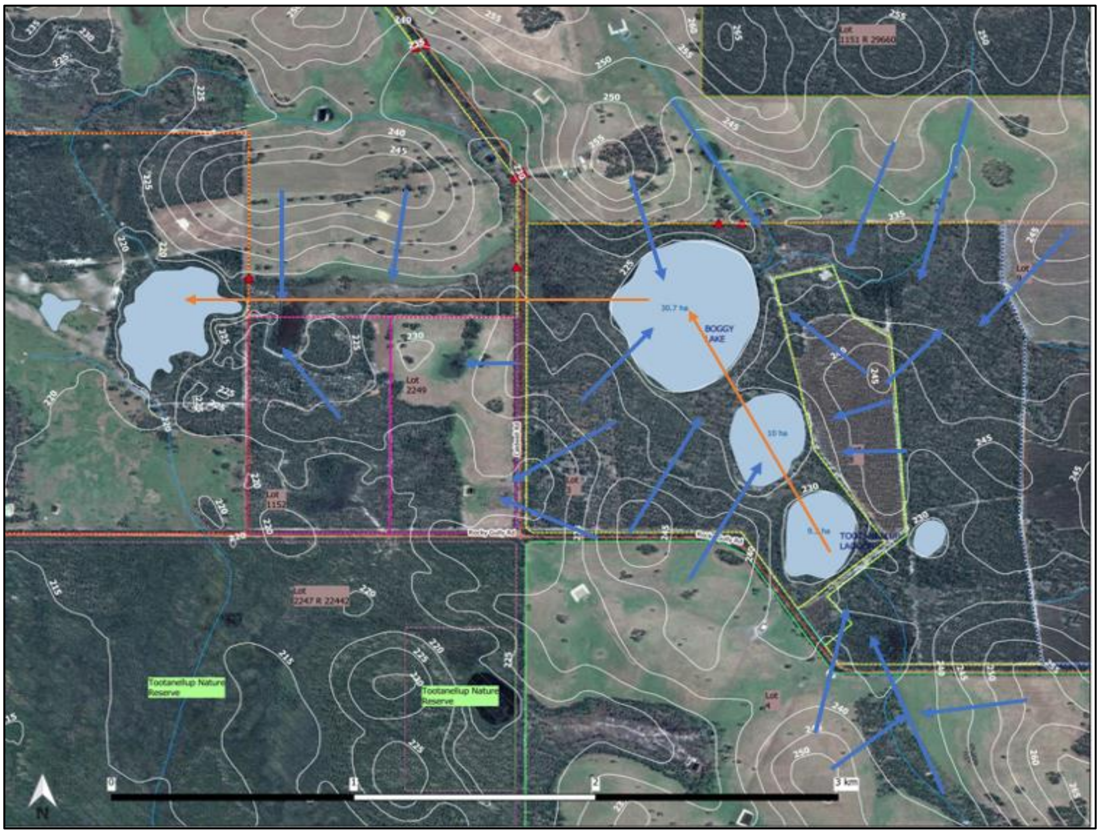


Figure 13: Boggy Lake and adjacent wetlands. The blue arrows show the flow directions and their possible discharge zones.

The bed of Boggy Lake was examined to determine the composition of the upper soil horizon sediments. By late January 2023 there was no surface water, but the lakebed was damp and spongy with the 'bogginess' increasing out from the shoreline. The top layer consists of an organic layer about 0.2 metres thick. Water quickly flowed into the base of a hole suggesting the material is quite porous. The sediment below this consisted of a grey/black, organic rich clay. The electrical conductivity of the subsurface water was 7.9 mS/cm (seawater is approximately 53 mS/cm). By way of comparison, a year earlier in February 2022 the surface water conductivity was 12.5 mS/cm and in June 2022 the conductivity of a slight surface flow into the lake from the north-eastern creek was 10.2 mS/cm. This suggests the higher salinities of surface waters could largely be attributed to evaporation.

Two further visits to Boggy Lake were made during February 2023 and a metal rod was used to probe the sediments in various locations. The rod was easily pushed into the sediments and the point of resistance increased in depth away from the shoreline from a few centimetres up to 1.5 m at roughly 50 meters from the shoreline where the probe end appeared only slightly damp. The top soil profile was again inspected at several locations to check if there was subsurface water available for salinity testing

Table 7: Shallow bed soil profiles February 2023

Easting	Northing	Depth (m)	Comment
513709	6185071	0.5	Dry peaty layer to 0.25m then black to dark grey heavy sticky clay
513759	6185130	0.6	Dry peaty layer to 0.25m then grey moist sticky clay.
514008	6185448	0.8	White sand to 0.4m followed by light grey-brown sandy clay to 0.7m then grey green heavy sandy clay.
513897	6185624	0.6	Dry peaty layer to 0.25m followed by grey sandy clay to 0.5m then heavy grey green clay.
513719	6185621	0.5	Hole dug in January, Dry peaty layer damp clay to 0.3 m then dark grey heavy clay.

The bed soil profile appears to be relatively uniform across the entire basin. The exception being where the catchment creek enters the lake. There, a layer of porous white sand, about 350 mm thick beneath the surface peat layer suggested sediment has washed down from the catchment in the distant past to form a delta, possibly during one large flood event or due to a sequence of smaller events. Another possibility is that the sand originates from the leading edge of the nearby lunette. The sand layer sits on top of sandy clay and would provide a permeable subsurface path for groundwater coming from the north east catchment area.

These observations support the above assessment made by Ruhi.

> ***The flow paths indicate that the biggest threats to the wetlands are the cleared area to the north and the recently cleared area to the east. In two to three years' time, the two recently cleared areas may increase the salinity of Boggy Lake. The biggest threat is from the area immediately to the east of the lake.***
>
> ***The cleared area to the south also has some impact. Wetland B (i.e., Middle Lake) also may be impacted by groundwater and recharge from recently cleared area to its east.***

The extent of groundwater influence from the cleared area along the eastern boundary of Tootanellup Lagoon and Middle Lake is currently unknown, however if the groundwater is saline then the freshness of the waters and the nature of the aquatic macro-invertebrate populations suggest inputs have not been significant. The two wetlands provide some indications of what conditions in Boggy Lake may have been like prior to clearing for agriculture.

A shallow swale allows surface flows to enter Tootanellup Lagoon from Rocky Gully Road and the farmland to the south. Water quality changes in the Lagoon can provide clues about local hydrogeological processes from the south and ongoing monitoring of salinity and pH is recommended. Salinity measurements of surface flows during or after significant storm events can help clarify the extent of the influence of the southern catchment.

In the absence of the natural vegetation, the lakes would be or would become saline. The salinity of the lakes and wetland may increase in the future. Boggy Lake may experience high salinity (> 3000mg/L). Salinity of the other lakes and wetlands may remain slightly higher than the present levels.

This assessment reflects the findings elsewhere in the region that vegetation predominantly has a local effect on groundwater levels. The impacts of removal of the plantation trees to the east may better be determined by monitoring Middle Lake which has no significant surface channels entering it.

Tootanellup Lagoon and Middle Lake can also act as reference wetlands for conditions in Boggy Lake

I think if we can intercept the shallow groundwater, we can save the lake.

The surface drainage catchment for Boggy Lake extends approximately 2 Km northward and has an overall area of 234 ha with 74% cleared and 26% uncleared land. Revegetating cleared land is currently seen as the best way to manage groundwater and surface flows into waterways.

The question posed was*: What is involved in deciding on which are the priority areas in the Boggy Lake catchment that need to be focussed on for revegetation or other catchment treatments?*

Since farmers are unlikely to want to revegetate their entire farm to maximise protection of the wetlands, the only other option is a tactical approach. In other words, are their 'hotspots' that are not particularly useful for agriculture but can be revegetated to help protect the wetlands and hopefully moderate if not reverse any unfavourable trends. The existence of a shear zone in the northeast sector of the reserve lends weight to this being an important 'hotspot' and a target area.

There are two mechanisms for preventing or at least ameliorating salinisation of the wetlands, first ensuring local groundwater levels and hence inputs, are reduced. Secondly, by maximising fresh stormwater inputs. For these reasons, revegetation presents something of a conundrum since increasing perennial vegetation cover can indeed lower local water tables, but also intercepts rainfall and reduces surface runoff and hence infiltration of fresh water into the soil.

The relative groundwater inputs into the lakes from the catchment to the north and east is unknown. However, water was observed pooling on the flats immediately downstream of the northeast boundary of Boggy Lake and this appeared to be a groundwater expression.

Responding to comments from Dr Don McFarlane in November 2021 (*italics*):

Increasing lake salinities could come from one or a combination of three processes:
1. Saline runoff, if the catchments feeding the lakes are salt affected
2. Concentration of salts by evaporation over the summer- autumn period
3. Rising saline groundwater

Current observations, although frugal, support the notion that all three processes are important for understanding the hydro-pattern of Boggy Lake. However, the salinity contribution due to these various sources is uncertain. Continuing monitoring of water salinity values and local rainfall data during coming years will help to clarify the various contributions. This need not be intensive monitoring and the aim is to pick up seasonal variations and the impact of major storm events.

> ***As for revegetation, it could help if processes 1 and 3 are dominant. But if the lakes are recharged by rain falling on the surrounding dunal system and winter seepage into the lakes, this will exacerbate process 2. Even returning the surrounding areas to pre-European cover will reduce recharge of fresh water in a drying climate. It helps in dry years to have sparse vegetation on these dunes. This may seem wrong when you want to restore the original vegetation.***
>
> ***But we don't have the original climate and it will get much drier and hotter, so we need to adapt. The current vegetation is not equilibrated with the new climate.***

Process 1 implies that surface water salinity measurements will be useful to assess the salt contribution due to runoff. As mentioned above, the conductivity values during and after significant storm flow events in conjunction with water level changes in the lake, should provide some reasonable estimates of the quantities of salt entering Boggy Lake via this process.

Seasonal baseline data should ideally be gathered before any revegetation works are undertaken if monitoring is to be of any use in evaluating the effectiveness of such actions. In the rush to 'solve a perceived problem', this requirement is often overlooked.

> ***Ironically, when there is little salt storage in the soil profile, dryland agriculture enables fresh water to recharge and helps groundwater fed wetlands.***

The amount and distribution of salt stored in the areas to the north and east is unknown but not negligible given the few salinity values obtained from Boggy Lake. However, the freshness of Middle Lake and Tootanellup Lagoon waters implies that groundwater feeding them has not been a significant input.

The bed of Middle Lake is roughly 2 meters higher than that of Boggy Lake and the bed of Tootanellup Lagoon is nearly 4.5 meters higher than Boggy Lake. This suggest that groundwater from the eastern areas may preferentially trend towards Boggy Lake and/or passes deeper below the bed of the smaller wetlands. If salinities increase noticeably in Tootanellup Lagoon and Middle Lake, it might be inferred that rising groundwater is actively occurring across the entire reserve. This highlights the importance of gathering baseline data if salinity trends are to be assessed in future or management success confirmed.

> ***I (Don) am unsure which of the above 3 processes are dominant in your catchment. Ideally bores would help identify the level and salinity of groundwater in perched and regional aquifers.***

Apart from being an expensive exercise, installing monitoring bores within the reserve bushland is not advisable due to potential damage by the movement and operation of machinery. However, the seepage area adjacent to the north eastern reserve boundary has little understory and a monitoring bore in that location could provide useful data about groundwater inputs from the northern catchment of Boggy Lake. Likewise, a bore or two along the eastern reserve boundary may shed light on the relative groundwater influence from the former plantation area and would complement surface water measurements in Tootanellup Lagoon and Middle Lake.

In the absence of direct groundwater data, surface water measurements act as a surrogate for monitoring general trends, but this introduces a speculative element which puts a question mark against the assumptions discussed here.

> ***If you can calculate lake water storage changes, monitoring salt concentrations will show whether the salt increase can be attributed to evaporation by itself, or if there needs to be an external source of salt (runoff or groundwater discharge).***
>
> ***The lake salinity will rise more slowly if it is by evaporation compared with a rising saline water table under the lake. If it is concentrated by evaporation, halving of the water in storage will double salinity assuming there is negligible outflow. So, you may only need to measure groundwater salinities every year of two and see that it is steady. Stream salinities need more***
>
> ***While concentrations are important (mg/L), if there isn't much discharge from the lakes then the amount of salt (tonnes/year) is important (concentration x volume).***
>
> ***This is often the case for nutrients as well. Ideally you should measure lake levels and convert these to lake volume using a bathymetry map. This may require someone with surveying skills as the current digital terrain models only measure to the nearest metre, assuming you can see the bottom.***

On 24 September 2022, areas of Boggy Lake were accessed by canoe and the bed was determined to be relatively flat with the water depth typically 250 mm at the time. More detailed bathymetry could be easily obtained when water depth is 400 mm or more and this would enable a more accurate calculation of the volume of water in the lake for various depths.

In December 2022 a temporary benchmark (BM1) was established on the northwest side of Boggy Lake and arbitrarily assigned an elevation of 10.00 m. The bed elevation relative to this was calculated to be approximately 8.3 m. Benchmarks were also established for Middle Lake and Tootanellup Lagoon. All three benchmarks were linked to determine the relative bed elevations between the wetlands.

Table 8: Benchmark location details.

Wetland	Easting	Northing	Relative benchmark elevation
BM1 - Boggy Lake	0513583	6185564	10.00 m
BM2 – Middle Lake	514169	6184574	13.11 m
BM3 - Tootanellup Lagoon	514227	6184499	13.99 m

Note: The UTM eastings and northings apply to zone H50

An optical level was used to determine the relative water levels in all three wetlands and to establish elevation benchmarks, BM2 at Middle Lake and BM3 at Tootanellup Lagoon. It was noted that the ground based water levels at the edge of the wetlands agreed quite well with estimates from the interpolated contour lines using GIS.

The volume of water in the wetlands, coupled with salinity measurements, would allow the salt loads and relative effects of evaporation and inputs from the catchment to be calculated. Measuring flow volumes and actual salt loads coming from surface runoff in the catchment is problematic. Normally, this would require the construction of a gauging weir, but this would be difficult given the flat and diffuse nature of the creek line. However, Boggy Lake has no surface flow outlet at moderate to high water levels therefore it is suggested that measurements of water levels in the lake coupled with local rainfall and salinity data would be a simpler (and cheaper) approach to gauge surface inflows. Salt loads could be reasonably estimated using data from before, during and after specific storm events.

A back of the envelope calculation

Area of Boggy Lake = 30 ha = 300,000 sqm

Catchment area = 350 ha = 3,500,000 sqm

Consider a moderately intense rainfall event of 30 mm (0.03 m) over a 24 hour period

Assuming the runoff percentage is 5% this equates to 1.5 mm (0.0015 m) of the rainfall amount

Discharge into Boggy Lake = 3,500,000 x 0.0015 = 5250 cubic meters

Increase in depth of lake = 0.0175 m = 17.5 mm (which is quite measurable)

> ***The Blue Gums (eastern area) will have dried the regolith under them but may not have affected much further away from the plantation. This is why Richard George has stopped recommending selective revegetation as a whole-of-catchment solution to dryland salinity caused by process 3 above. A lot of water movement is vertical and what happened locally is very important.***

As indicated investigating the groundwater connection with the areas to the north and east would require the installation of at least three monitoring bores.

> ***Bore holes need only be shallow because you need to know if the regional water table is within 5 m of the lakebed. And perched aquifers will be sitting on clay within the top few metres.***

Surface probing has indicated a dense clay layer in Boggy Lake is at a depth of approximately 300 to 400 mm and during summer can dry out to at least twice that depth but remains soft enough to easily push a probe to depths greater than a meter. For this reason, endeavouring to drill a hole to five meters depth in the lake bed using heavy machinery, is problematic. However, the ground around the periphery appears much firmer and a small drilling unit may be a feasible option in those areas during summer. To fully understand the groundwater system below and around the lake, a substantial, and therefore costly array of piezometers is usually required, however a few strategically placed bores can help clarify specific processes.

> ***Often perching of lake water is greatest when lake levels are low (thick peat, clay or sapropel in the centre of the lake) but the banks are much more permeable. So, there may be seepage outflow when lake levels are high. The fact that the lake is fresh means that there must have been salt flushing in the past.***

Likewise, investigating the groundwater connection between the lakes would require at least one bore at each isthmus. These areas are open and have likely been grazed and access for a small drill rig would be feasible without creating too much disturbance. We suggest that investigating any subsurface connection between the lakes is less important than clarifying the extent of influence from the north and east.

> ***The lake needs runoff or seepage of fresh water to maintain levels. The drying climate is reducing runoff and recharge by 3% for every 1% reduction in rainfall. Perennial***

vegetation reduces runoff and recharge. Rainfall currently can now come in short showers, interspersed with wind and sun. Canopy interception of these showers can be 40-80% before root uptake intercept the soil water. So, revegetation can exacerbate drying. If recharge is occurring through the lake banks, revegetating them will make things worse.

Question: If the rising salinity in Boggy Lake is caused entirely or mainly by Concentration of salts by evaporation over the summer- autumn period, would you be advocating for measures to actually increase run-off to Boggy Lake from the cleared areas of the catchment?

To help answer this question will require a better understanding of the salinity of surface flows entering Boggy Lake from the north-eastern catchment and Tootanellup Lagoon from the southern catchment.

Question: What do you think of Ruhi's preliminary statement that "The main contributor to the salinity of the wetlands are the local aquifers close to and around the wetlands. This means that high rate of recharge in the cleared areas around the wetlands may cause/increase salinity in the wetlands. "

Don: I agree. We used to think that recharge was through distant sandy upland areas requiring a catchment solution and multiple farmers' efforts. We now realise that it is more likely to be close to the problem areas. But I am not sure that the regional water table is close to the surface without looking at bore records or salt-affected land.

Do you know what water regime you want for the lakes – seasonal depths and salinities? You may need a combined engineering – perennial vegetation solution. If you had shallow drains capable to bringing fresh water into the lake even in dry years, and a sluice gate to allow water to exit and flush salts, this would be ideal for adaptive management. And perennial plants where the regional water table is close to the surface.

These options require considerable investigation especially in view of a drying climate and any associated increase in substantial summer storm events. It is our view that there is insufficient data to model the ground water and surface water processes in the wetland suite to justify modifying any surface features. One exception may be to consider the function of the already modified roadside drains along Rocky Gully Road on the southern boundary of Tootanellup Lagoon.

Implications of the structural assessment

The above assessments draw on observations, experience in the wider catchment area and upon established hydrogeological principles. The use of the words may, likely, and could, reflect the paucity of quantitative data about how groundwater processes are contributing to the state of the wetland suite. Obtaining sufficient data to clarify subsurface processes can be a time consuming and costly exercise involving the establishment of arrays of piezometers and regular collection of data from these to adequately capture seasonal and annual variations and long term trends. Surface water quality data provides a surrogate glimpse into what is happening beneath and around the wetlands, but as with groundwater, consistent data collection and observations over periods of years are required to confidently understand the hydrological drivers which determine the ecological character of the wetlands.

The initial inferences posed questions relevant to any proposed management activity, particularly the issue of revegetating cleared areas immediately east and or north of the wetlands. Of particular interest is whether enhancing or revegetating these areas would be sufficient to ameliorate the risk of a continuing upward trend in the salinity of the wetlands. As with many management strategies, there can be downsides, as well as upsides to on-ground actions. While actions may produce the desired result they also may not. For example, while revegetation of adjacent cleared areas or parts thereof may reduce the salinisation potential, it may also further reduce water levels by limiting freshwater surface runoff.

Nevertheless, observations to date, although frugal, point to the significance of the shear zone intersecting the reserve in the north-east quadrant. This is potentially a priority area for action to reduce ground water inputs into Boggy Lake.

Further insight into the shallow aquifer connection between the lakes and the adjacent cleared areas would be useful prior to initiating on-ground works.

Likewise, the nature of any subsurface connectivity, or otherwise, between Boggy Lake and a semi-regional aquifer beneath the bed of the lakes, suggests there is some value in further investigations. However, this will mean considering the establishment of monitoring bores which in turn require the means for these to be monitored seasonally over a number of years.

The collection of surface water quality data (notably salinity and pH) can shed some light on the hydrogeological processes taking place and this may be sufficient. However due to the temporal and spatial variability of water condition, such monitoring must inevitably span many years to create a suitable baseline data set.

In addition to threats to the ecological integrity of the wetlands, arising from local land management activities, past, present and future, there is the issue of regional hydrological changes due to climate change as well as local changes to agricultural practices. This supports the suggestion that the collection of water quality data is best continued in the long term and should be done consistently. As suggested previously, this need not be an onerous task, but it is important to remember that historical data can only be collected once.

For these reasons there is a strong case for not 'rushing into revegetation projects until adequate baseline data has been collected. A five year monitoring period would be a minimum.

Conversely, there is a case for undertaking immediate revegetation works apart from water monitoring considerations. This is regarding enhancing local habitat in degraded areas of the reserve and improving the quality of terrestrial connectivity with nearby remnant bush areas.

Appendices

Appendix 1: The timeline for the various investigations is as follows:

24 October 2021: A preliminary survey of Boggy Lake and the adjacent wetlands on the DWER reserve was conducted with the help of Basil Schur and several citizen science volunteers. The survey included:

- Water quality parameters (salinity, pH, temperature, turbidity). The other water bodies or wetlands encountered were also be measured.
- Macroinvertebrate sweep of six wetlands preserved with specimens in 75% ethanol and identified to the lowest taxonomic level possible.
- Riparian assessment with respect to and wetland condition.

10 February 2022: A wetland BioBlitz was undertaken with the aim of documenting the biodiversity of the site and to assess what risks the wetlands may be under from salinity etc and to consider possible management action. This included:

- Water quality parameters (salinity, pH, temperature, turbidity) for Boggy Lake and Tootanellup Lagoon
- Macroinvertebrate sweep of the two wetlands with specimens preserved in 75% ethanol and identified to the lowest taxonomic level possible.
- Sharing data and understanding of the wetlands with the Great Southern TAFE students and other volunteers.
- Mapping *Macrozamia riedliei* (Zamia cycad), potential Cockatoo nesting tree locations, recording of biota on iNaturalist and monitoring of marsupial nest boxes on the Green Skills Tootanellup property.

The three wetlands were circumnavigated to determine whether there were any significant sources of surface runoff into the lakes and to investigate what historical surface flow connections may have existed between the wetlands. An active streamline was identified on the eastern side of Boggy Lake.

24 October 2022: A relative height datum was established at Boggy Lake and the central area of the lake was accessed by kayak to determine the general depth at the time and calibrated to the datum. Water was monitored for electrical conductivity at two sites in the lake and at two sites on the eastern drainage line that had been identified in February 2022.

24 February 2023: Boggy Lake

Tracks observed: Cat and fox prints, large bird and webbed duck prints.

Baumea looking very healthy 2.5m tall

Lake bed soil profile assessed.

Appendix 2: Salinity categories

There are different ways of categorising water salinity: fresh, brackish, saline and hypersaline depending on the focus or reason for making the categories. Table X quantifies the ranges for each of the general classifications using various common measurement units.

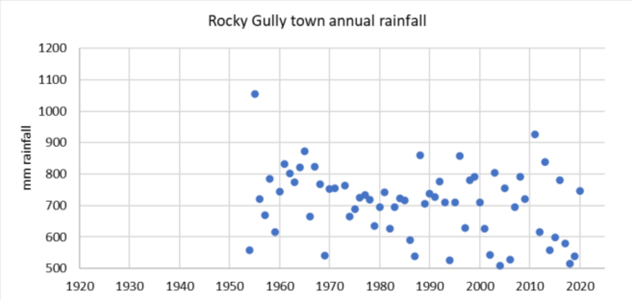
Table 9: Mayer et al (2005) Classification based on agricultural/industrial usage of water.

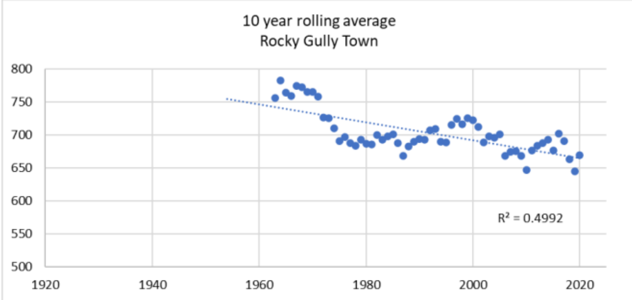
Salinity status	Electrical conductivity (mS/cm)	Salinity (mg/L)	Salinity (ppt)	Description and use
Fresh	0.8	< 500	0.5	Drinking and all irrigation
Marginal	0.8 - 2	500 –1 000	0.5 - 1	Most irrigation, adverse effects on ecosystems become apparent
Brackish	2 - 4	1 000 – 2 000	1 - 2	Irrigation certain crops only; useful for most stock
Saline	4-17	2 000 – 10 000	2 - 10	Useful for most livestock
Highly saline	17 - 52	10 000–35 000	10 - 35	Very saline groundwater, limited use for certain livestock
Brine		>35 000	>35	Seawater: some mining and industrial uses exist
	Classifications from Mayer, XM, Ruprecht, JK & Bari, MA 2005, Stream salinity status and trends in south-west Western Australia, Department of Environment, Salinity and land use impacts series, Report No. SLUI 38			

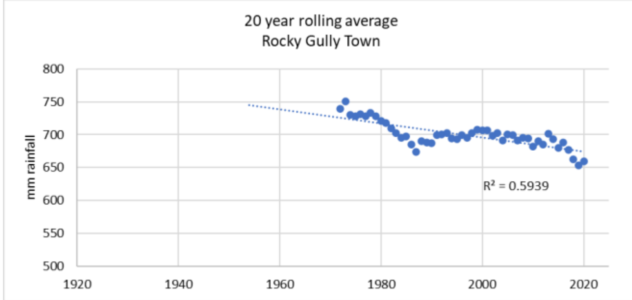
Table 10: Wetland salinity categories based on macroinvertebrate tolerance (Pinder et al, 2005).

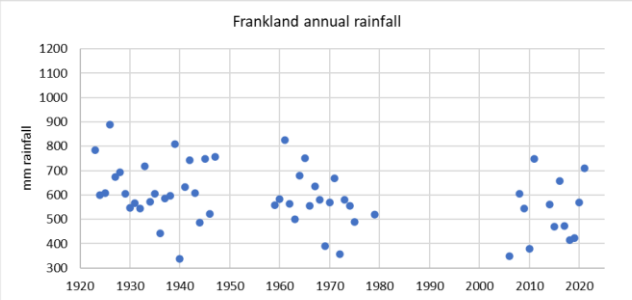
• <3 ppt, freshwater	Note: seawater is approximately 35 ppt (52ms/cm).
• 3 to 12 ppt, sub-saline or brackish	
• 12 to 35 ppt, saline	
• >35 ppt, hypersaline.	

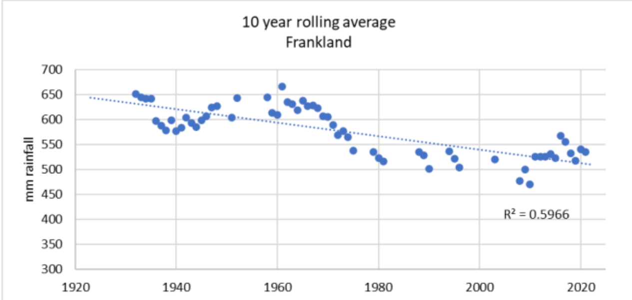
Appendix 3: Rainfall records for nearby locations

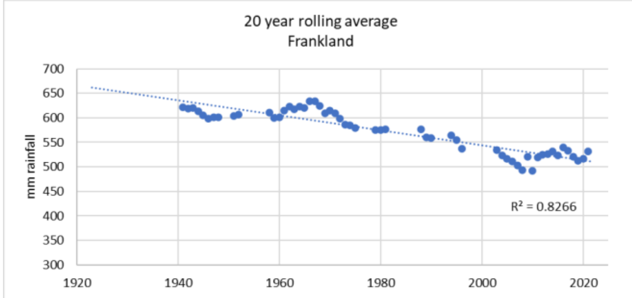


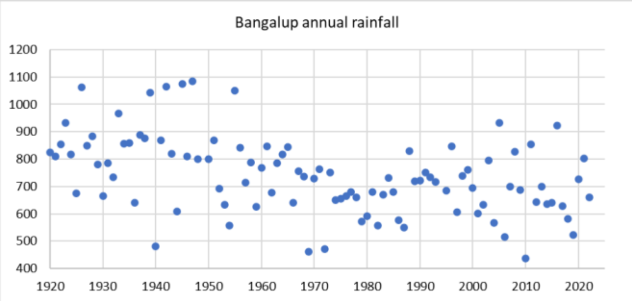


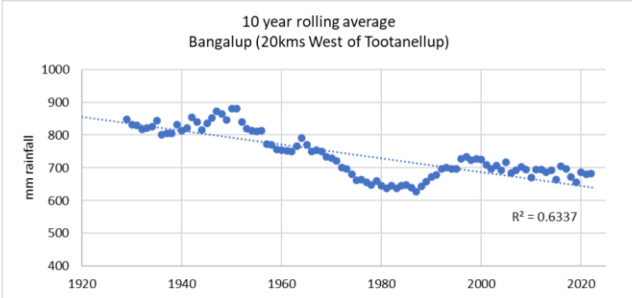


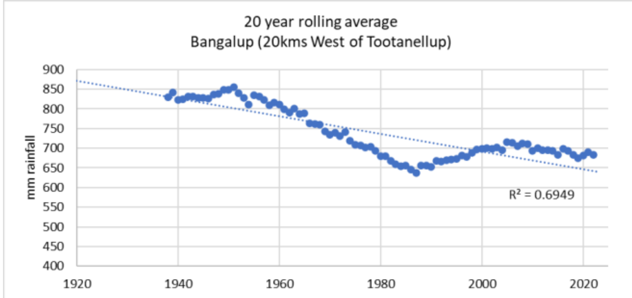




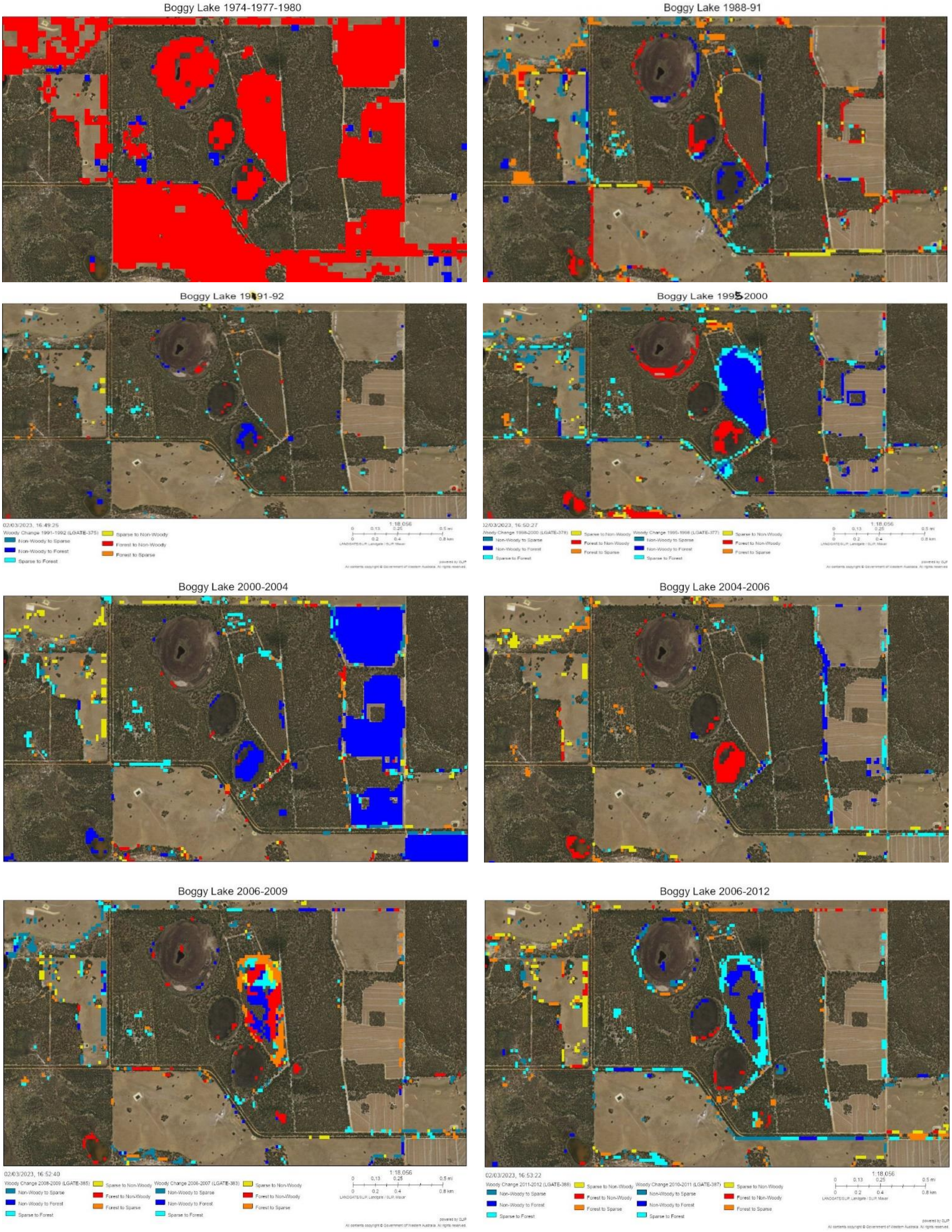






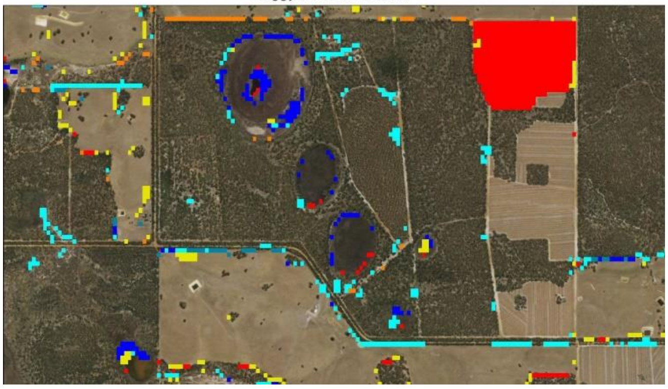


Appendix 4: Satellite interpreted vegetation changes around Boggy Lake

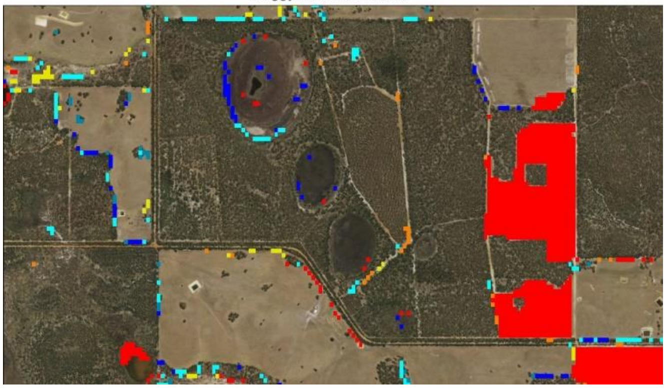


Janicke Environmental Assessments

Boggy Lake 2012-2014

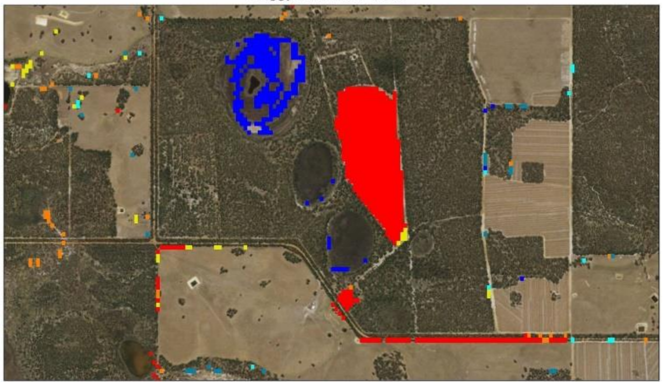


Boggy Lake 2014-2016

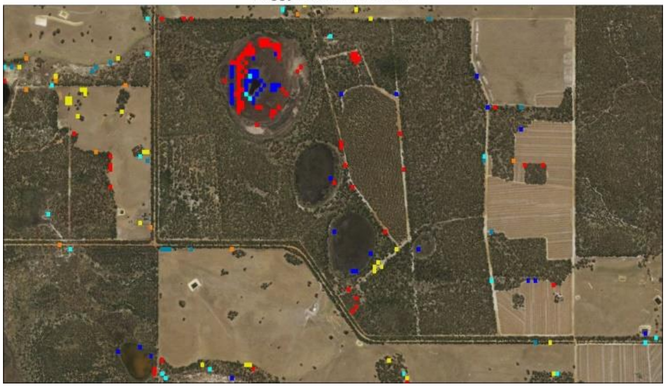


Boggy Lake 2016-2017

Boggy Lake 2017-2019



Boggy Lake 2019-2021



Land Monitor provides mid-scale monitoring of salinity and vegetation across Western Australia using satellite imagery.

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Appendix 5 Water quality meter calibrations and control checks

Instruments: Horiba Scientific LAQUAtwin–EC-33, LAQUAtwin-pH-33

Date: 24SEP22

<u>Calibrations</u>

EC @ 0800, Std 12.88 mS/cm - reading 12.7 mS/cm

pH @ 0800 Std 7.0 - reading 6.9, Std 4.1 - reading 4.02

<u>Control check</u>

EC @ 1130, Std 12.88 mS/cm – reading 12.95 mS/cm

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Glossary of terms

Benchmark (BM): A reference datum for measuring relative surface and water level elevations.

Hydro-pattern: The variability of water depth both seasonally, annually and in response to various storm events.

Lunette: A crescent shaped sandy ridge on the leeward side of a lake under the influence of the prevailing winds during their formation.

First order stream: The smallest distinct natural perennial channel and vale that carries annual rainfall runoff.

Calibration: The setting of readings on an instrument to correspond to known target (standard) values of the parameter it is desired to measure.

Control check: Using a standard sample with a known value to check whether an instrument is reading values accurately.