Annual Report 2020

Salty Lagoon Post-Closure Monitoring Program (Years 6 – 10)

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Executive Summary

GeoLINK and Aquatic Science and Management have been engaged by Richmond Valley Council (RVC) to implement the Salty Lagoon Post Closure Monitoring Program (PCM). This report (Annual Report 2020) summarises the results of the monitoring undertaken between July 2019 and June 2020. Key findings are summarised below.

A long period of drought followed by a short period of substantial rainfall were key factors influencing the Salty Lagoon environment during the reporting period. Prolonged dry conditions persisted between June and December 2019. This was followed by a wetter January to June 2020 period, starting with three significant rainfall events in January and February 2020. Residual effects from saline water inflow from Salty Creek into Salty Lagoon during the 2018/19 reporting period were also evident.

Water Quality (Monitored at Salty Lagoon and Salty Creek)

- Water level: The water level in Salty Lagoon remained full for the second half of the reporting period after low levels persisted during dry weather. One water quality monitoring site was dry in December 2019 after prolonged drought conditions.
- Conductivity: Conductivity fluctuated throughout the reporting period due to a combination of high salinity levels at the start of the reporting period and heavy rainfall in the latter half of the reporting period. No movement of saline water from Salty Creek into Salty Lagoon was recorded.
- Dissolved oxygen (DO): During this reporting period the DO concentration measured at the Salty Lagoon permanent water quality monitoring station (PWQMS) dropped below 1 mg/L on a moderate number of occasions (approximately 18%). However, the DO concentration was 6 mg/L or less on approximately 54% of occasions. These figures are comparable with most of the results from the MPPC.
- pH: The pH measurements at the Salty Lagoon PWQMS have been stable but relatively high throughout this monitoring period.
- Temperature: Over the reporting period temperature fluctuated according to both daily and seasonal patterns. There is a relationship between water level in Salty Lagoon and the magnitude of temperature variation.
- Turbidity: During the current monitoring period turbidity measurements were relatively stable. Recorded increases were in response to rainfall runoff and microalgal growth.
- Nitrogen: During the current reporting period the concentrations of total nitrogen (TN) were relatively high. The median concentrations at three sites exceeded the guiding values but statistical analyses do not indicate an increasing trend for the PCM. TN concentrations increased during an extended dry period but also in response to heavy rainfall. This indicates that nitrogen stored in the sediment in Salty Lagoon is a major source of nitrogen in the system and that the combination of drought, bushfires and heavy rainfall led to delivery of a large nitrogen load. Organic forms of nitrogen dominated and there was no indication that the release of treated effluent upstream increased nitrogen concentrations.
- Phosphorus: Variation in phosphorus concentrations at the sites in Salty Lagoon did not conform precisely to a specific pattern. Site S2 is the site most influenced historically by discharged effluent from the Evans Head Sewage Treatment Plant (STP) and is most often the site with the highest phosphorus concentration. This trend was reversed when heavy rainfall followed a period of drought and bushfires. As with MPPC monitoring TN and total phosphorus (TP) concentrations appear to have varied independently during this reporting period. For most of the results, the greater proportion of the TP present was present as orthophosphate. This has important implications for the growth of algal material, which requires phosphorus to be present in the bioavailable form of orthophosphate.

- Chlorophyll-a: Chlorophyll-a concentrations were relatively high on occasions during this reporting period. The median chlorophyll-a concentrations at three sites exceeded the guiding value. The highest chlorophyll-a concentrations measured were recorded after an extended period of drought and were not associated with the highest total nutrient concentrations or bioavailable nutrient concentrations.
- Blue green algae: Blue green algae were not detected during this monitoring period.
- Faecal indicator organisms: With the exception of a few spikes the enterococcus and faecal coliform concentrations were low at all sites during the reporting period. The major contributors to the observed variation in the concentration of faecal indicator organisms are runoff from the catchment and the presence of waterfowl. The results do not suggest that discharge from the Evans Head Sewage Treatment Plant (STP) or leaks from the Evans Head sewerage system are influencing the concentrations of faecal indicator organisms.

Aquatic Vegetation/ Weeds

- No significant introduced species of aquatic weeds have been recorded in the current monitoring period, though one native species sometimes considered a nuisance plant was recorded and one non-native species commonly found in the local environment was recorded.
- The risk of weed invasion into Salty Lagoon remains.

Erosion

The erosive head-cut migrating towards Salty Lagoon from Salty Creek advanced significantly during this monitoring period. This remains a considerable risk to the positive changes recorded in the Salty Lagoon environment since the closure of the artificial channel. Remediation of the head-cut is being planned by NSW National Parks and Wildlife Service (NPWS).

Overall System Health

The overall health of the Salty Lagoon ecosystem has improved since closure of the artificial channel. No evidence of the current Evans Head Sewage Treatment Plant discharge adversely impacting the Salty Lagoon system has been observed.

Ongoing Monitoring and Management

Additional monitoring activities (i.e. vegetation monitoring and provisional macroinvertebrate, fish, waterbird and frog monitoring) scheduled for the final year of the PCM program (2021/2020) are no longer recommended. These additional monitoring activities are unlikely to make observations additional to those previously observed during the MPPC program (GeoLINK 2017b) due to prolonged brackish conditions at Salty Lagoon.

The recommendations of Salty Lagoon Post MPPC Monitoring Recommendations (GeoLINK 2017a) remain valid. Based on the PCM findings to date, ecological monitoring at Salty Lagoon post the PCM program is not warranted as the health of the system has overall improved since closure of the artificial channel. Ongoing Evans Head STP discharge and head-cut monitoring is recommended until it is confirmed that water flow between Salty Lagoon and Salty Creek is controlled and the erosion/head-cut risk is low.

1. Introduction

1.1 Background

GeoLINK and Aquatic Science and Management (ASM) have been engaged by Richmond Valley Council (RVC) to implement *the Salty Lagoon Post Closure Monitoring Program* (PCM; GeoLINK 2017a). Prior to this current engagement, RVC implemented the *Salty Lagoon Ecosystem Response Monitoring Program* (ERMP – Worley Parsons) and the Salty Lagoon Monitoring Program: Pre/Post Channel Closure (MPPC – Hydrosphere 2010a).

In brief, the ERMP sought to monitor the ecological health of the system for a two-year period, and to collect data across a range of disciplines to allow for further planning to be undertaken in accordance with the broader aims of the rehabilitation strategy. The study site for the ERMP was more extensive than that being monitored under the MPPC or the current engagement and included sampling sites along the entire length of the drainage channel from the Evans Head Sewage Treatment Plant (STP) to Salty Lagoon, and areas of adjoining bushland to the north of this facility. This work was completed in March 2010 (Hydrosphere 2010b) and included the following components:

- Water quality and hydrology
- Diatoms
- Macroinvertebrates
- Fish
- Frogs and waterbirds
- Flora and vegetation mapping
- Weeds.

The MPPC sought to monitor the ecological health of the system before and after a trial closure of the artificial channel that once connected Salty Lagoon and Salty Creek. The study site for the MPPC was the same as the current engagement. The MPPC spanned between March 2011 and June 2017, and included the following components:

- Water quality and hydrology
- Macroinvertebrates
- Fish
- Frogs and waterbirds
- Flora and vegetation mapping
- Aquatic Weeds.

The current PCM program continues from the MPPC monitoring with a reduced frequency of site visits and a reduced overall suite of monitoring components (GeoLINK 2017a). It commenced in July 2017 and is scheduled to conclude in June 2022.

1.2 Objectives

The objectives of the post closure monitoring program are summarised as follows:

1. Monitor the health of the Salty Lagoon ecosystem and confirm that the current Evans Head STP discharge is not adversely impacting water quality and ecology at Salty Lagoon.
2. Monitor water quality and ecological attributes of the MPPC where predicted trends have not been confirmed and risks to the ecosystem remain.
3. Observe medium to long-term changes in the Salty Lagoon system in response to channel closure.

This report (*Annual Report 2020)* summarises the results of the monitoring undertaken between July 2019 and June 2020 as part of the PCM program.

2. Water Quality

2.1 Introduction

Adequate water quality has been identified as a key factor influencing the ecosystem processes in Salty Lagoon. Issues with water quality such as high nutrient concentrations and rapid changes in conductivity and dissolved oxygen (DO) have been identified in previous monitoring. Poor water quality in the past has led to fish kills, indicating ecosystem collapse (Hydrosphere 2009). The Salty Lagoon water quality monitoring program provides the key information for understanding the Salty Lagoon ecosystem.

Ongoing monitoring of water quality in Salty Lagoon has changed for the post closure monitoring period. However, there is still a multi-faceted approach to water quality sampling involving permanent water quality monitors, discrete sampling of surface waters and an additional response protocol. The range of parameters covered by each of these approaches to water quality monitoring is described in **Table 2.1**.

Table 2.1 Approaches to Water Quality Monitoring and Parameters Measured for the MPPC

Approach	*Sampling Type*	*Parameters*
Permanent water quality monitoring stations (PWQMS)	Physico-chemical	Temperature, conductivity, dissolved oxygen (DO), pH, turbidity, water level
Monthly discrete sampling and adaptive management response sampling	Physico-chemical	Temperature, conductivity, dissolved oxygen (DO), pH, turbidity, secchi depth, redox potential
	Chemical	Total nitrogen, ammonia, nitrate, nitrite, total kjeldahl nitrogen, total phosphorus, orthophosphate
	Biological	Chlorophyll-a, blue green algae, faecal coliforms, enterococci

2.2 Methods

2.2.1 Permanent Water Quality Monitoring Stations

There are two permanent water quality monitoring stations (PWQMS) in place measuring water level, temperature, pH, conductivity, turbidity and DO concentration. Each PWQMS is fitted with an YSI EXO3 sonde and a HOBO U50 water level data logger. Data is collected at 30-minute intervals, logged and accessed during bi-monthly site inspections. The water level data is corrected prior to reporting using the surveyed levels of the measuring boards at each of the permanent water quality monitoring stations and a barometric pressure logger deployed at Salty Lagoon (S1). The individual probes on each EXO3 sonde are removed from the PWQMS, calibrated and serviced after a four-month deployment.

2.2.2 Routine Discrete Sampling

Discrete water quality samples were taken from surface water (approx. 0.2 m depth) at four sites in Salty Lagoon (S1-S4) and a single site (S5) in Salty Creek on a bi-monthly basis. An additional quality assurance (QA) replicate sample was collected from a randomly chosen site each monitoring event. The specific locations of all sites sampled are presented in **Table 2.2** and displayed in **Illustration 2.1**. Sampling was undertaken bi-monthly (every second month) commencing at the end of August 2019 for the reporting period (six events in total).

Table 2.2 Locations of Water Quality Sample Sites in Salty Lagoon and Salty Creek (WGS84)

Site	*S1*	*S2*	*S3*	*S4*	*S5*
Easting	0542064	0541799	0542037	0541738	0542187
Northing	6782801	6782669	6783013	6783033	6783665
Site description	Salty Lagoon PWQMS	SE of drainage channel	NE area of lagoon	NW area of lagoon	Salty Creek PWQMS

Physico-chemical water quality parameters in discrete surface water samples were measured with an HORIBA U-52 hand held water quality meter. Depth profiling of physicochemical parameters was undertaken at one metre intervals at sites where the water depth was sufficient to allow it. Depth profiling is undertaken to improve the understanding of stratification of the water column at times when the water level is high. The results of depth profiling are reported in bi-monthly ecosystem health reports and will not be repeated here.

Discrete samples were collected in jars for analysis of chemical and biological parameters at the Coffs Harbour Laboratory (CHL). Sterile jars were used for bacteriological analysis and brown glass jars were used for analysis of chlorophyll-a and blue green algal (BGA) content. Samples were placed upon ice in an Esky and delivered to CHL within 24 hours of collection.

2.2.3 Adaptive Management WQ Sampling

The MPPC Salty Lagoon Response Protocol was reviewed and updated in October 2017 to guide adaptive management as part of the post closure monitoring program (GeoLINK 2017b). The new protocol involves assessing the collected water quality data and environmental variables such as the status of the entrance to Salty Creek, the status of the head-cut between Salty Creek and Salty Lagoon and seasonal rainfall fluctuations to prepare a risk level.

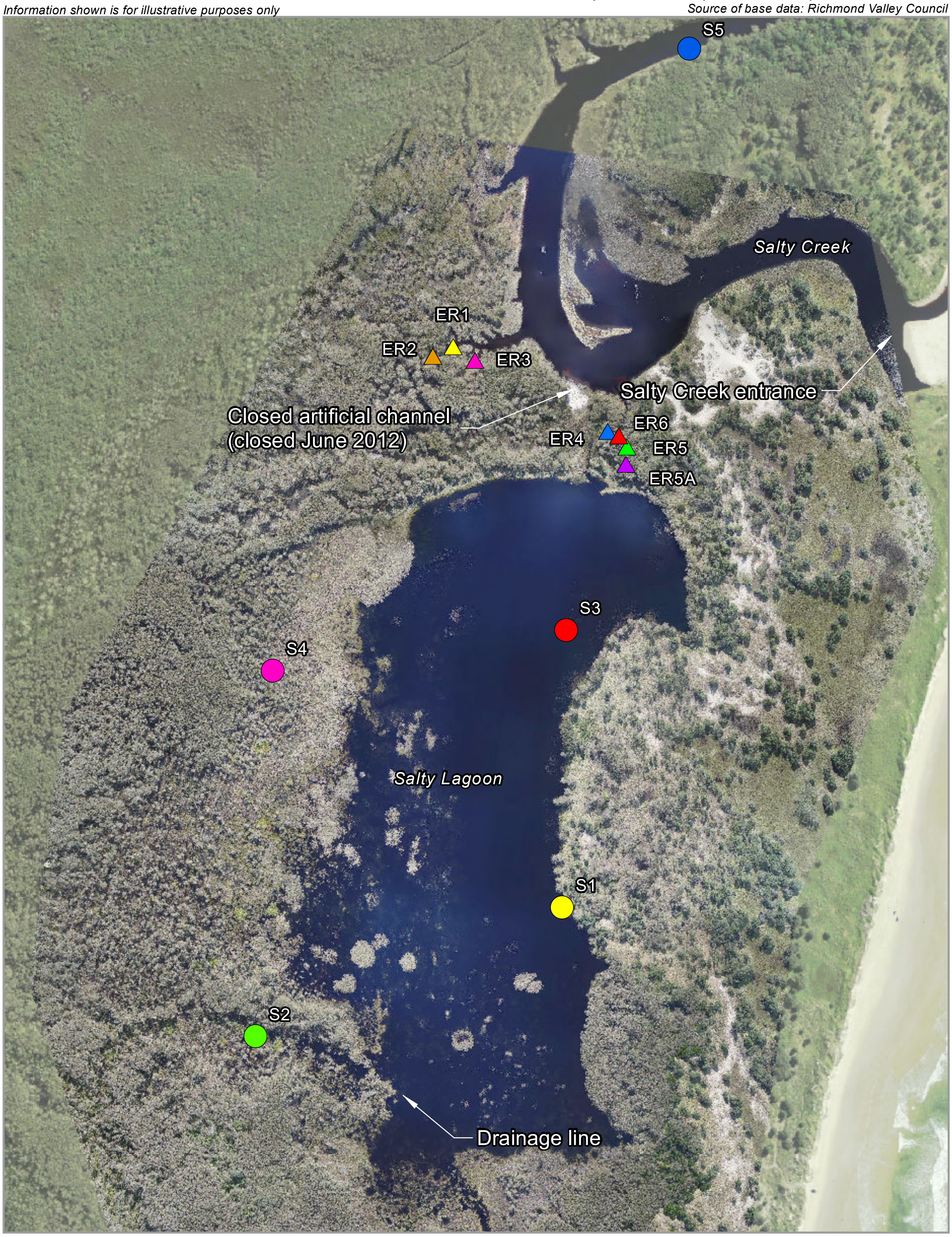
Adaptive management water quality sampling is only implemented when the Salty Lagoon system is in a 'high risk' status, a site inspection is undertaken, and an environmental incident is noted.

During this reporting period a risk rating of 'uncertain' was assigned from January 2020 until the end of the reporting period, due to a perceived risk associated with the status of the eroding head-cut. On two occasions, a 'high' risk status associated with heavy rainfall resulted in two adaptive management site inspections. No environmental incidents were noted and no adaptive management water quality sampling resulted from either visit.

Drawn by: DSA Checked by: AB Reviewed by: AB Date: 24/08/2020

Source of base data: Richmond Valley Council

Information shown is for illustrative purposes only



LEGEND

Water Quality Site

- S1
- S2
- S3
- S4
- S5

Erosion Monitoring Site

- ER1
- ER2
- ER3
- ER4
- ER5
- ER5A
- ER6

0 120

Location of Water Quality and Erosion Monitoring Sites

2.2.4 Guiding Values

Guiding values for the MPPC monitoring program were revised in September 2012 using water quality data collected between April 2011 and September 2012 as part of the MPPC project. They were developed separately for Salty Lagoon and Salty Creek, from surface water data collected at all sites and incorporated all parameters measured as part of the MPPC.

The guiding values were set at the 80th percentile value of the collected data set for Salty Lagoon and Salty Creek with the following exceptions:

- The guiding values for DO were set at the 20th percentile value.
- A guiding value range was developed for pH, conductivity and temperature in Salty Creek due to the varying influences of sea water and freshwater runoff. The outlying points for the guiding value ranges were set at the 10th and 90th percentile values.

The guiding values were developed to assist with the contextualisation of results, rather than as a measure of the health of the waterway. However, guiding values also provide a yardstick, around which the adaptive management of Salty Lagoon can be discussed.

These guiding values are being used as part of the current post closure monitoring program for all water quality parameters being sampled; and are presented in **Table 2.3**.

Table 2.3 Guiding Values for all Water Quality Parameters

Measure		*Guiding Value*	
		Salty Lagoon	*Salty Creek*
Chemical	Total nitrogen (mg/L)	1.60	1.64
	Ammonia (mg/L)	0.05	0.11
	Nitrate (mg/L)	0.01	0.01
	Nitrite (mg/L)	0.01	0.01
	Total kjeldahl nitrogen (mg/L)	1.60	1.64
	Total phosphorus (mg/L)	0.14	0.04
	Orthophosphate (mg/L)	0.11	0.01
Biological	Chlorophyll-a (µg/L)	5	3
	Faecal coliforms (CFU/100mL)	135	150
	Enterococci (CFU/100mL)	170	40
	Blue green algae (cells/mL)	0	0
Physical	Dissolved oxygen (mg/L)	4.09	5.52
	Turbidity (NTU)	13.0	11.0
	pH	6.9	4.3 – 6.8
	Conductivity (mS/cm)	8.0	0.3 – 21.5
	Temperature (˚C)	25.9	13.1 – 28.8

2.3 Results and Discussion

2.3.1 Rainfall

Rainfall, or lack thereof, is a key factor influencing water quality in Salty Lagoon and Salty Creek. Monthly rainfall conditions for the reporting period are displayed in **Figure 2.1**. Daily rainfall for the reporting period is displayed in **Figure 2.2** and **Figure 2.3**. Overall, the monitoring period was characterised by below average rainfall, with the exception of heavy rainfall in February 2020. Total rainfall for this monitoring period was 1322 mm. The annual average rainfall for the Evans Head BOM station is 1454.4 mm. The period between July 2019 and January 2020 could be described as drought conditions. Almost a third of the total rainfall for this reporting period fell in three large events in January and February 2020. There were six daily rainfall totals of greater than 50 mm during this reporting period.

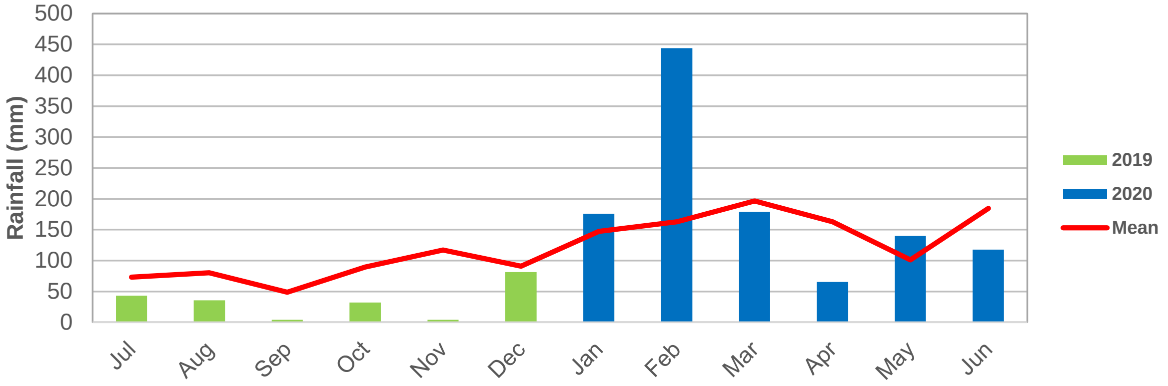


Figure 2.1 Monthly rainfall at the Evans Head BOM weather station for the reporting period displayed against average monthly rainfall (BOM 2020)

2.3.2 Permanent Water Quality Monitoring Stations

2.3.2.1 Data Quality and Consistency

Following the installation of the YSI EXO3 water quality monitoring systems in October 2017 the data quality and consistency improved significantly. However, for the period between July 2019 and June 2020 there are some gaps in the data from the PWQMS. These are either:

- Short-term (between 30 minutes and two hours) gaps in the data set associated with changing deployed probes for serviced and calibrated probes.
- A gap in the Salty Creek pH, temperature, conductivity, DO and turbidity measurements between 29 August and 4 September 2019 due to battery failure.
- A gap in the Salty Creek DO measurements from 8 September until 7 November 2019 due to probe error.
- A large gap in the Salty Lagoon pH, temperature, conductivity, DO and turbidity measurements in June 2020 where no data was collected due to battery failure.

Significant gaps in the data are highlighted in **Figures 2.2** and **2.3**. Over the monitoring period from 1 July 2019 to 30 June 2020 the missed data points from the Salty Lagoon PWQMS were as follows:

- <0.03% temperature and water level data points
- 1326 (8.2%) missed conductivity, turbidity and DO data points due to battery failure
- 1468 (9.1%) missed pH data points due to battery failure and sonde error.

Over the monitoring period from 1 July 2019 to 30 June 2020 the missed data points from the Salty Creek PWQMS were as follows:

- 250 (1.4%) missed temperature, conductivity and turbidity data points due to battery failure
- 4473 (34.1%) missed pH data points due to battery failure and probe error
- 3112 (21.5%) missed DO data points due to battery failure and probe error.

As part of routine maintenance, the logged results are compared in the field with data collected from a handheld water quality probe every month. In general, the results correlate very well. The correlation has improved further since the deployment of the YSI EXO3 equipment.

2.3.2.2 Key Points Arising from the Salty Lagoon Data Set

The results from the Salty Lagoon PWQMS are presented in **Figure 2.2** and are discussed below.

Water Level

The water level was high in Salty Lagoon at the beginning of the reporting period but decreased steadily in response to dry conditions and evaporation between August 2019 and January 2020. Heavy rainfall in January and February 2020 resulted in some of the highest levels ever recorded in Salty Lagoon on 9 February 2020 before bank-full conditions returned and persisted until the end of the reporting period. Water levels in December 2019 were so low that there was no water to sample at site S4. The water level chart in **Figure 2.2** indicates that the maximum water level reached in Salty Lagoon for the reporting period was 2.41 m AHD (Australian Height Datum), after heavy rainfall on 9 February 2020. The lowest water level recorded was 1.24 m AHD after very hot conditions on 10 January 2020. There was no evidence of salt water ingress from Salty Creek during this reporting period. In addition to the long-term variations in water level, daily variations in the water level of up to five centimetres were measured during the hottest days of summer. It is thought that contraction and expansion of the water body in response to daily temperature variations contributed to this variation.

Conductivity

Conductivity is a measure of the saltiness of the water. The key driving factors causing fluctuations in the conductivity of the water recorded in Salty Lagoon during this reporting period were the high conductivity at the start of the reporting period, evaporation and rainfall. Evaporation causes a gradual increase in conductivity measurements as salts become more concentrated. Rainfall has the opposite effect but typically operates over shorter timeframes.

The conductivity measurements presented in **Figure 2.2** show that the dry conditions between August 2019 and January 2020 facilitated evaporation and a subsequent increase in the conductivity to levels almost as high as seawater, with a maximum conductivity of 50.4 mS/cm measured on 11 January 2020, an increase of over 200% from the measurement of 16.5 mS/cm on 11 August 2020. The maximum measurement of 50.4 mS/cm was the highest conductivity recorded in Salty Lagoon since closure of the artificial channel in July 2012. These extreme measurements are indicative of the impact drought conditions had on water quality generally during this reporting period.

Heavy rainfall in January and February 2020 resulted in a return to brackish conditions and ongoing low to moderate rainfall led to a return to freshwater conditions (conductivity < 1.5 mS/cm) by the start of June 2020. There was no evidence of saline water inflow from Salty Creek into Salty Lagoon.

Dissolved Oxygen

Historically, variation in the DO concentrations measured in Salty Lagoon relate to the following features (GeoLINK 2017b):

- Diffusion: The surface of the water is exposed to the air and dissolves oxygen constantly through diffusion. For this reason, DO concentrations tend to be higher in surface waters.
- Microalgal concentrations: Microalgae produce oxygen during the day through photosynthesis and consume it at night through respiration. Nutrient availability has an impact on DO concentrations indirectly through supporting microalgal concentrations.
- Light availability: This influences the photosynthetic activity of microalgae throughout the water column and attached to the benthos. Turbidity, therefore, is a key regulator of DO concentrations.
- Wind and flow driven mixing: Mixing of the water column serves to bring well oxygenated water from the surface into lower parts of the water column. The stronger the wind or flow, the deeper the mixing. North and south winds have the greatest effect on Salty Lagoon due to the north-south orientation.
- Water level: The depth of the water determines the impact of wind driven mixing and the availability of light at the bottom of the water column.
- Salinity: There have been sharp reductions in DO concentration associated with saline water ingress in previous years, possibly due to the impact upon microalgal concentrations and the increased likelihood of stratification.

During this reporting period the major features of DO variation were:

- Diurnal fluctuations
- More stable DO concentrations during brackish and freshwater conditions and high water levels
- More variable DO concentrations during times of higher salinity and lower water levels
- Greater daily fluctuations during the summer months, when water levels became lower.

During this reporting period the DO concentration measured at the Salty Lagoon PWQMS dropped below 1 mg/L on a moderate number of occasions. In the current reporting period, the DO concentration was 6 mg/L or less for approximately 54% of measurements and 1 mg/L or less for approximately 18% of measurements. This is a higher rate of occurrence of hypoxic conditions at the Salty Lagoon PWQMS relative to the previous two annual reporting periods. The extreme conditions associated with drought and flood described in the previous two subsections are likely to have been the cause of this change.

pH

The pH measurements at the Salty Lagoon PWQMS were variable during this reporting period, in response to the same changes that drove the variation in water level, conductivity and DO concentrations. The data indicates that the pH in Salty Lagoon varied over the long-term mostly in response to evaporation and rainfall conditions and in the short-term mostly in response to oxygen availability and/or sunlight. Daily variations in response to DO concentrations and light availability were larger when saline, low water level conditions dominated. The variation between maximum and minimum pH concentrations was relatively high during this reporting period, with a minimum pH of 6.5 and a maximum of 10.2.

Temperature

Over this reporting period temperature fluctuated according to both daily and seasonal patterns. There is also a relationship between water level in Salty Lagoon and the magnitude of daily temperature variation. When water levels are low, temperature variation tends to be greater.

Water temperature indirectly and directly impacts upon other parameters. For example, at higher temperatures water has a lower oxygen carrying capacity and higher temperatures encourage microalgal growth and activity and can therefore contribute to algal blooms.

The difference between maximum and minimum temperatures was large during this reporting period with a maximum measured temperature of 36.04°C and a minimum of 11.44°C. During the hottest days of summer and coinciding with the lowest water levels measured during this reporting period, maximum daily temperature fluctuations of over 10°C were measured.

Turbidity

Turbidity measurements fluctuate in response to various other factors such as wind driven sediment suspension and microalgal growth. During the current monitoring period turbidity measurements were relatively stable and remained below 5 NTU for more than 90% of measurements. The periods of higher turbidity measurements were not associated with the heaviest rainfall or lowest water levels, indicating that they may have resulted from higher microalgal concentrations rather than increased suspended sediment.

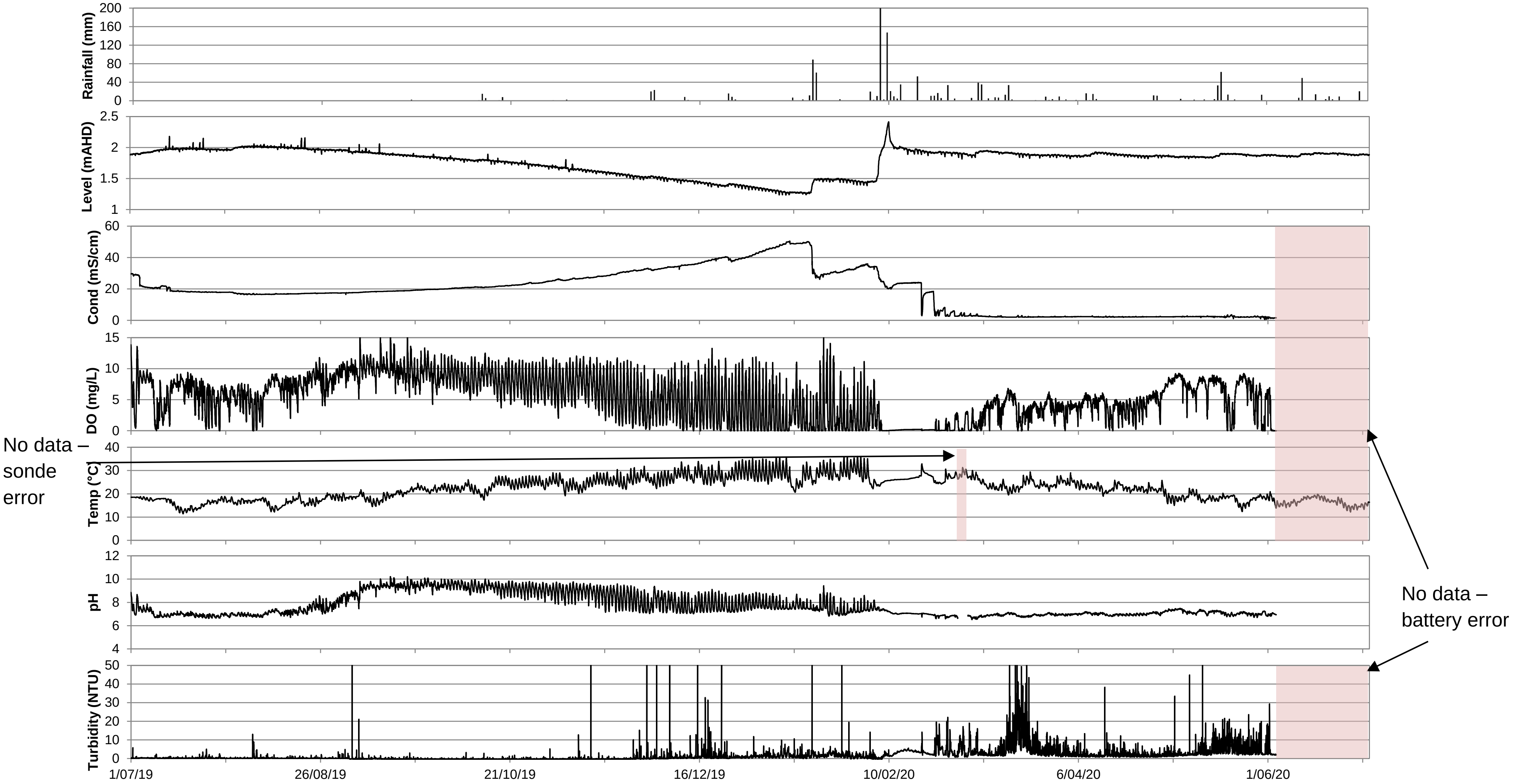


Figure 2.2 Data from the Salty Lagoon PWQMS for the 2019/20 reporting period

2.3.2.3 Key Points Arising from the Salty Creek Data Set

The Salty Creek PWQMS is important in the context of managing Salty Lagoon as it provides information about how water quality in Salty Creek can impact upon Salty Lagoon. The results from the Salty Creek PWQMS are presented in **Figure 2.3** and discussed below.

Water Level

The most important factor affecting the water level in Salty Creek is the status of its entrance. The collected data indicates that the entrance to Salty Creek opened at least five times in the current reporting period, compared with a minimum of two and a maximum of seventeen times in the annual reporting periods of the MPPC. The level of Salty Creek increased sharply on four occasions during this reporting period as a result of seawater ingress during large swell and storm surge conditions, and on three occasions in response to heavy rainfall. The entrance to Salty Creek tends to close during the large swell events, which result in sand delivery to the beach and an increased height of the entrance berm. One such event in late February 2019 led to very high water levels and a closed entrance. The entrance remained closed from that point until the heavy rainfall on 9 and 10 February 2020, when the entrance opened approximately 250 m south of where it had previously been. Prior to the entrance opening in February 2020, water levels in Salty Creek had slowly reduced as a result of drought conditions between August 2019 and February 2020.

Conductivity

The conductivity measurements from the Salty Creek PWQMS fluctuated widely in response to the dynamic state of the entrance, seawater ingress, medium and heavy rainfall events, and dry conditions. However, the water in Salty creek was saline for most of the monitoring period and brackish or fresh only for short periods following heavy rainfall. The median conductivity measurement was 30.7 mS/cm, approximately 60% the value of seawater. During the drought conditions experienced between August 2019 and February 2020 the conductivity increased steadily, almost doubling. This indicates the significance of evaporation in understanding water quality during that period.

Dissolved Oxygen

DO concentrations measured at the Salty Creek PWQMS fluctuated widely throughout the year. A variety of factors influence the DO concentrations in Salty Creek. The general patterns of variation were as follows:

- An extended period of very low DO concentrations occurred while high water levels and saline conditions persisted between July and October 2019.
- DO concentrations in Salty Creek fluctuated diurnally for a significant proportion of the reporting period. During this reporting period diurnal fluctuations were most prominent when there were stable saline conditions and low water levels.
- The water column in Salty Creek is often stratified with respect to DO concentration, although this is not apparent from the logged information.

The DO concentration measured at the Salty Creek PWQMS was 6 mg/L or less for approximately 99% of the measurements and 1mg/L or less for approximately 76% of the measurements. For the third consecutive reporting period these figures indicate that low DO concentrations were more prevalent than during the years of the MPPC.

pH

The pH measurements from the Salty Creek PWQMS fluctuated during this reporting period but were more stable than previous years. The pH variations observed were closely associated with conductivity and the state of the entrance. Runoff from the catchment is naturally acidic, resulting in lower pH measurements in Salty Creek following heavy rainfall. Such conditions only occurred after the heaviest rainfall event in February 2020. Seawater ingress has the opposite effect, leading to alkaline pH measurements. The pH in Salty Creek was greater than seven for a large proportion of the current reporting period and averaged 6.89.

Temperature and Turbidity

Temperature measurements in Salty Creek fluctuated on a daily and seasonal basis. Daily fluctuations in temperature are strongest when water levels are low. Turbidity measurements from the Salty Creek PWQMS were generally low, with the median recorded value from the PWQMS of 3.35 NTU. Periods of greater turbidity generally occurred during seawater ingress events and after heavy rainfall.

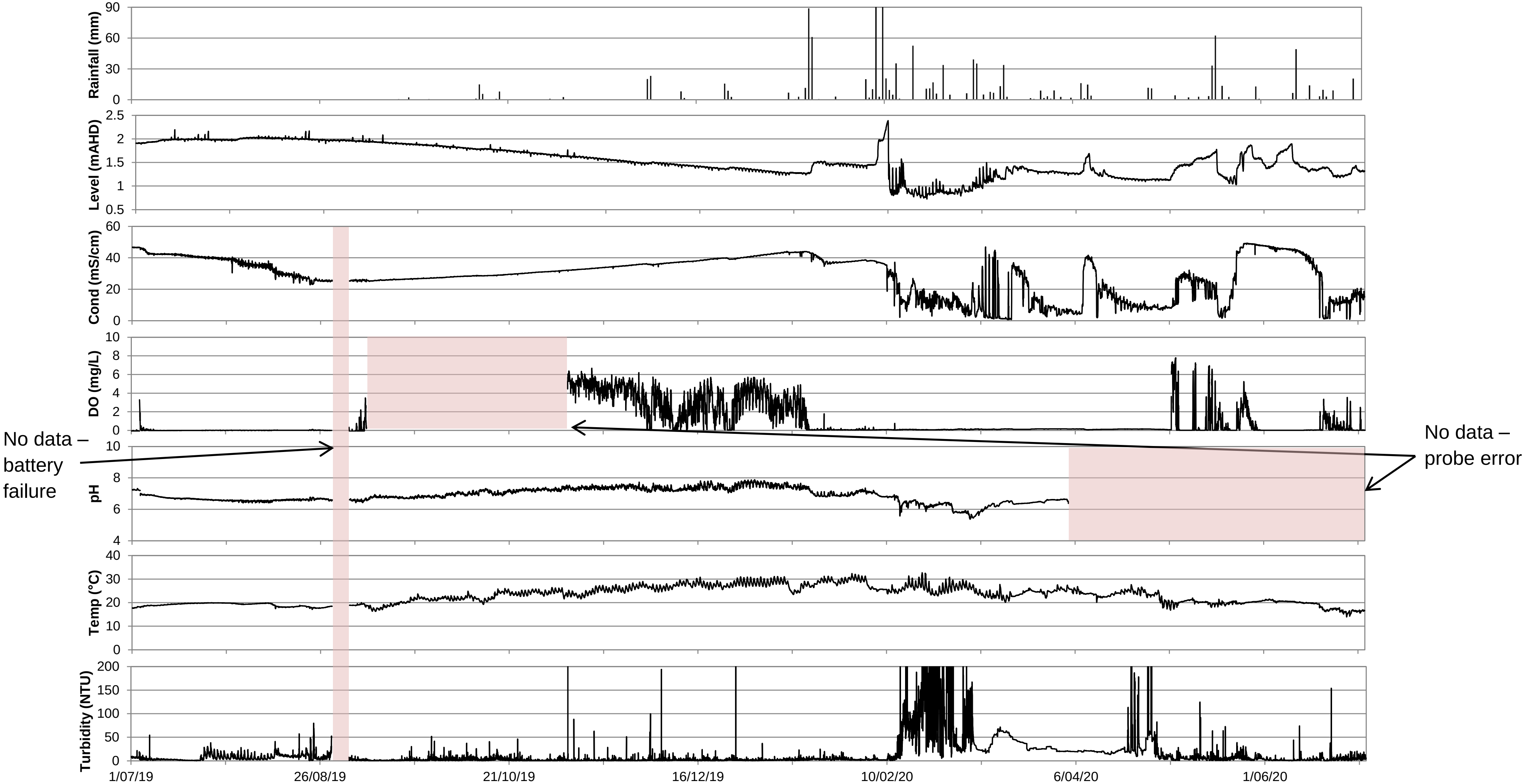


Figure 2.3 Data from the Salty Creek PWQMS for the 2019/20 reporting period

2.3.3 Discrete Water Quality Samples

This section describes the results of discrete water quality samples collected during normal bi-monthly water quality monitoring. A summary of median results for all samples from all sites is presented in **Table 2.4**. Most of the median results complied with guiding values.

Table 2.4 Median Results of Discrete Samples from Surface Waters at all Sites Between 1 July 2019 and 30 June 2020

Indicator	*Salty Lagoon*					*Salty Creek*	
	Guiding Value	*S1*	*S2*	*S3*	*S4*	*Guiding Value*	*S5*
Nitrite nitrogen (mg/L)	**1.6**	0.010	0.010	0.010	0.010	**1.64**	0.010
Nitrate nitrogen (mg/L)	**0.01**	0.010	0.010	0.010	0.010	**0.01**	0.010
Oxidized nitrogen (mg/L)	**-**	0.010	0.010	0.010	0.010	**-**	0.010
Ammonia nitrogen (mg/L)	**0.05**	0.010	0.012	0.010	0.010	**0.11**	0.012
Total kjeldahl nitrogen (mg/L)	**1.6**	**1.64**	**1.61**	**1.65**	1.57	**1.63**	1.15
Total nitrogen (mg/L)	**1.6**	**1.64**	**1.61**	**1.65**	1.57	**1.63**	1.16
Total phosphorus (mg/L)	**0.14**	0.095	0.060	0.095	0.030	**0.04**	0.030
Orthophosphate (mg/L)	**0.11**	0.021	0.030	0.019	0.010	**0.01**	0.010
Chlorophyll-a (µg/L)	**5**	**19**	5	**9**	**12**	**3**	2
Enterococcus (CFU/100mL)	**170**	31	**177**	23	105	**40**	16
Faecal coliforms (CFU/100mL)	**135**	12	36	11	5	**150**	31
Blue green algae (cells/L)	**0**	0	0	0	0	**0**	0
Temp (˚C)	**25.9**	20.21	19.76	21.28	16.36	**13.1-28.8**	23.63
pH	**6.9**	**7.07**	6.23	**7.60**	5.47	**4.3-6.8**	**6.88**
ORP (mV)	**-**	129	177	135	213	**-**	210
Cond (mS/cm)	**8.0**	**10.11**	**8.11**	**10.09**	2.31	**0.3-21.5**	16.08
Turbidity (NTU)	**13**	3.9	1.9	3.1	2.3	**11**	2.2
DO (mg/L)	**4.09**	5.69	**1.77**	8.14	**2.94**	**5.52**	5.75
DO (% sat)	**-**	68.6	19.0	87.3	32.5	**-**	77.8
TDS (ppt)	**-**	6.32	5.04	6.31	1.48	**-**	10.04
Salinity (ppt)	**-**	5.85	4.65	5.85	1.20	**-**	9.55

Note: ***red text:*** *not compliant with MPPC guiding values (GeoLINK 2012).*
Results below detection limits analysed as the detection limit.

In addition to the analysis of summary results against guiding values the discrete water quality data collected since the beginning of the post-channel-closure monitoring has been analysed for trends using the Mann-Kendall test. The Mann-Kendall test provides a Kendall score (S) and tau statistic (tau) that indicate the direction of trend, in addition to a variance value (VarS) and p-value (p) that indicate the statistical significance of the trend. The results of the Mann-Kendall test were analysed by applying a decision matrix to define the trends as either 'Increasing', 'Decreasing', 'Possible Increasing', 'Possible Decreasing', 'No Trend' or 'Stable' using a method derived from Newell *et al*., (2007).

The decision matrix is presented in **Table 2.5**. The results of the Mann Kendall test are presented in **Sections 2.3.3.1** to **2.3.3.5**. along with discrete water quality monitoring results from individual sites.

Table 2.5 Mann-Kendall Test decision matrix

Mann Kendall Score (S) and tau	*Statistical significance (p)*	*Trend*
>0	<0.05	Increasing
>0	0.05 - 0.10	Possible Increasing
>0	>0.1	No Trend
≤0	>0.75	No Trend
≤0	0.1 - 0.75	Stable
<0	0.05 – 0.10	Possible Decreasing
<0	<0.05	Decreasing

2.3.3.1 Nitrogen

Nitrogen is an element that is essential to life. In waterways it plays an important role in supporting food webs. However, problems arise from excessive nitrogen concentrations in water. Nitrogen is frequently monitored as an indicator of water quality and its capacity to support a healthy aquatic ecosystem. Nitrogen is present in water in several forms. It can be dissolved or particulate and can be present in organic molecules that are unavailable for biological uptake or inorganic molecules that are bioavailable. For the MPPC and post closure monitoring, nitrogen is measured as total nitrogen (TN), and the dissolved inorganic nitrogen (DIN) forms; ammonia, nitrate and nitrite.

Some of the factors that have been found to influence nitrogen concentrations in Salty Lagoon and Salty Creek include seawater ingress, historical pollution, evaporation and rainfall runoff (GeoLINK 2017b).

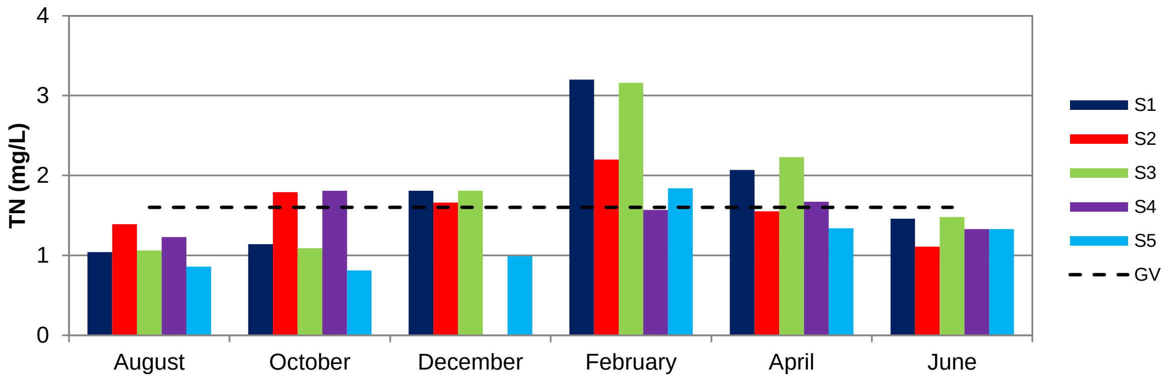


Figure 2.4 Time series of TN concentrations at all sites for the current reporting period

During the current reporting period the concentrations of TN were variable but within the ranges measured during the MPPC project (**Figure 2.4**). During this reporting period a relatively large number of TN measurements did not comply with the guiding values and the median TN concentrations at Sites S1, S2 and S3 did not comply with guiding values.

The highest TN concentrations during this reporting period were measured at sites S1 and S3 in February 2020 after six months of drought conditions were broken by very heavy and sustained rainfall. While rainfall often results in lower nutrient concentrations in Salty Lagoon it is likely that the specific combination of long-term drought, bush fires in the surrounding area and very heavy rainfall delivered nutrients to the system in higher than normal concentrations.

Aside from infrequent spikes in the concentration of nitrite, nitrate and ammonia, average DIN concentrations were relatively low at all sites for this reporting period (**Figure 2.5**) and the median DIN concentrations for this reporting period all complied with guiding values (**Table 2.4**). There was no obvious trend notable in the variation observed. DIN concentrations at S1 and S3 were very high in February 2020 along with other nutrient concentrations.

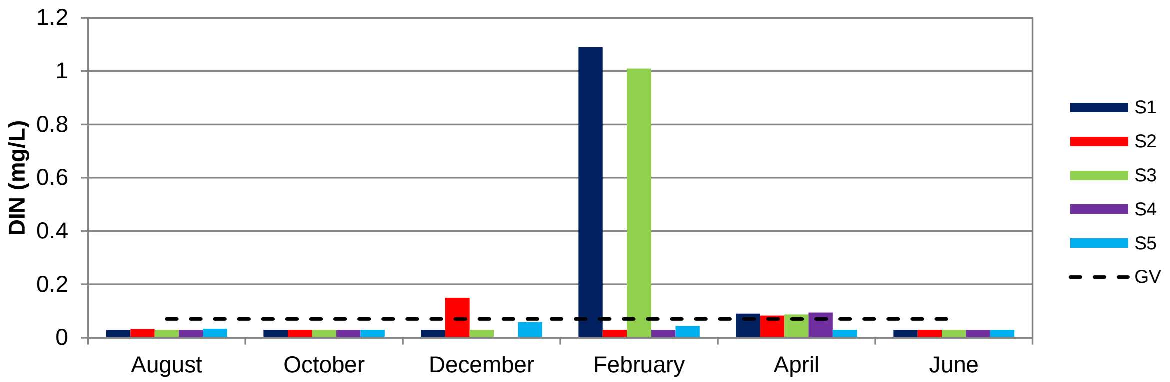


Figure 2.5 Time series of DIN concentrations at all sites for the current reporting period

Application of the Mann-Kendall test to the TN and DIN results since the beginning of the PCM did not find any upwards trends in concentration (**Table 2.6**). All of the results indicated either stable concentrations or no detectable trend.

Table 2.6 Mann-Kendall Test results for TN and DIN concentrations since October 2017

Parameter	Statistic	S1	S2	S3	S4	S5
DIN	S	-21	24	-30	-7	13
	Variance (S)	561.00	376.67	557.33	373.00	424.33
	Tau	-0.16	0.25	-0.24	-0.07	0.12
	p	0.40	0.24	0.22	0.76	0.56
	Trend	**Stable**	**No Trend**	**Stable**	**No Trend**	**No Trend**
TN	S	24	3	25	-14	-10
	Variance (S)	589.33	588.33	588.33	584.67	589.33
	Tau	0.18	0.02	0.18	-0.10	-0.07
	p	0.34	0.93	0.32	0.59	0.71
	Trend	**No Trend**	**No Trend**	**No Trend**	**Stable**	**Stable**

2.3.3.2 Phosphorus

Phosphorus is also essential to life and, like nitrogen, plays a role in supporting aquatic food webs and can be detrimental to aquatic ecosystems at excessive concentrations. Phosphorus exists in a variety of forms in water, either as bioavailable phosphorus (orthophosphate) or organic molecules containing phosphorus unavailable for biological uptake.

Median TP and orthophosphate concentrations complied with guiding values at all sites during this reporting period. There was not a clear pattern to the variation in phosphorus concentrations (refer to **Figure 2.6** and **Figure 2.7)**. However, the data does allow for some general observations:

- Site S2 is the site most influenced by historical and current discharged effluent from the Evans Head STP and is most often the site with the highest total phosphorus and orthophosphate concentrations. However, following very heavy rainfall in January and February 2020, phosphorus concentrations at S2 were relatively low in April and June 2020.
- Phosphorus was only detected in Salty Creek in two samples during this reporting period.
- The highest concentrations of phosphorus were measured at S2 after drought conditions between August and December 2019 and at S1, S2 and S3 following very heavy and sustained rainfall in January and February 2020. These two observations relate to different environmental conditions, the first being the impact of sustained evaporation and the second being the impacts of flooding rainfall after a period of drought and bushfire.

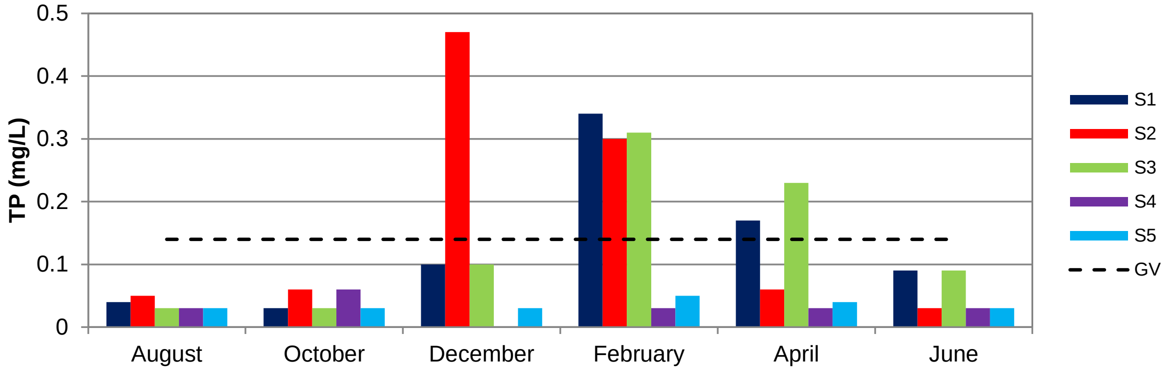


Figure 2.6 Time series of TP concentrations at all sites for the current reporting period

Orthophosphate concentrations were closely related to the total phosphorus concentrations, particularly in the samples where total phosphorus concentrations were very high, during the summer months (**Figure 2.7**).

Application of the Mann-Kendall test to the TP and orthophosphate results since the beginning of the PCM did not find any upwards trends in concentration (**Table 2.7**). All of the results indicated either stable concentrations or no detectable trend, with the exception of the TP concentrations from S5, which indicated a possible increasing trend. This result is highly likely to have resulted from phosphorus rich runoff entering Salty Creek from Salty Lagoon after heavy rainfall in January and February 2020. The total phosphorus concentrations in Salty Creek only exceeded the guiding value on one occasion during this reporting period and all remained within the ranges measured during the MPPC. In this case, the 'possible increasing trend' is not an indication of a potential environmental risk.

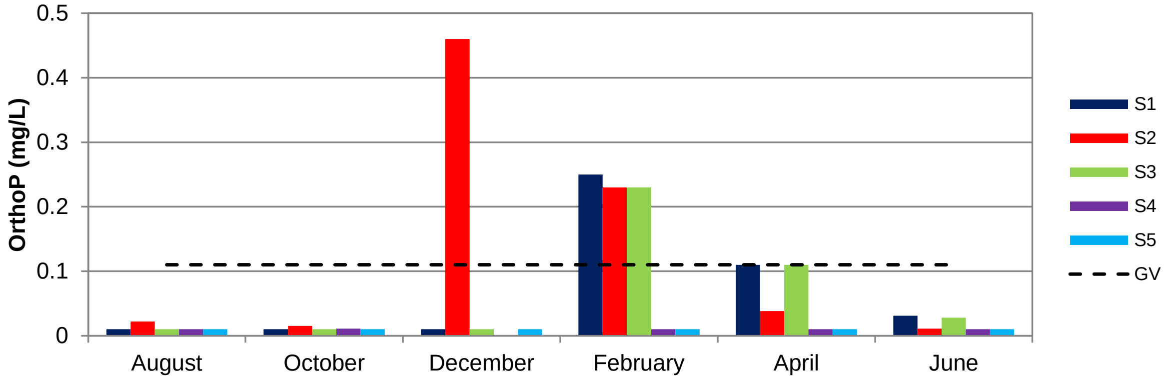


Figure 2.7 Time series of orthophosphate concentrations at all sites for the current reporting period

Table 2.7 Mann-Kendall Test results for TP and orthophosphate concentrations since October 2017

Parameter	*Statistic*	*S1*	*S2*	*S3*	*S4*	*S5*
TP	S	17	-9	13	-8	25
	Variance (S)	583.67	577.00	583.67	460.67	181.00
	Tau	0.13	-0.07	0.10	-0.07	0.39
	p	0.51	0.74	0.62	0.74	0.07
	Trend	**No Trend**	**Stable**	**No Trend**	**Stable**	**Possible Increasing**
Ortho-P	S	8	-3	4	-1	0
	Variance (S)	560.00	588.33	560.00	317.00	0.00
	Tau	0.06	-0.02	0.03	-0.01	-
	p	0.77	0.93	0.90	1.00	-
	Trend	**No Trend**	**No Trend**	**No Trend**	**No Trend**	**Stable**

2.3.3.3 Chlorophyll-a

The concentration of chlorophyll-a is a measurement of microalgae in the water column. Microalgal abundance fluctuates naturally in response to temperature, nutrient concentrations and light availability, but algal blooms are usually considered to be an indication of poor ecosystem health. Chlorophyll-a concentrations in Salty Lagoon did not comply with guiding values in many of the samples collected during this reporting period (**Figure 2.8**) and the median chlorophyll-a concentrations measured at S1, S3 and S4 for this reporting period did not comply with guiding values.

The highest chlorophyll-a concentrations measured were collected in December 2019 while water levels were low and nutrient concentrations were high (**Figure 2.8**). During that time chlorophyll-a concentrations at sites S1 and S3 indicated an algal bloom of large proportions.

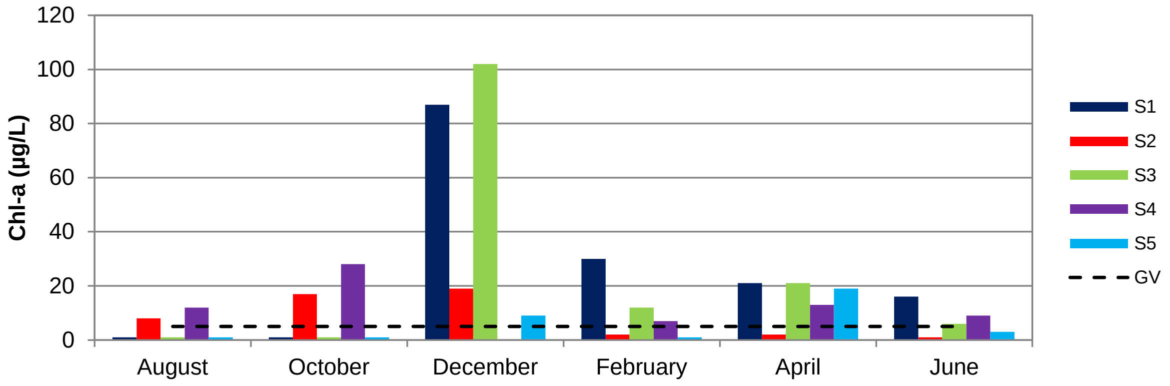


Figure 2.8 Time series of chlorophyll-a concentrations at all sites for the current reporting period

Application of the Mann-Kendall test to the chlorophyll-a concentrations measured since the beginning of the PCM found an 'increasing' trend in the concentration of chlorophyll-a at site S1 and a 'possible' increasing trend at site S5 (**Table 2.8**). The other Mann-Kendall results all indicated no detectable trend. The chlorophyll-a concentration of 87 µg/L measured in December 2019 was the highest recorded at S1 since MPCC monitoring began in 2011. However, the result occurred after sustained drought conditions and is most likely to have resulted from a combination of historical pollution and environmental conditions than from current management. In addition, the chlorophyll-a concentrations measured at S1 after December 2020 reduced steadily (**Figure 2.8**).

Table 2.8 Mann-Kendall Test results for chlorophyll-a concentrations since October 2017

Parameter	***Statistic***	***S1***	***S2***	***S3***	***S4***	***S5***
Chlorophyll-a	S	48	-4	29	26	35
	Variance (S)	524.00	576.00	559.00	576.00	375.67
	Tau	0.40	-0.03	0.23	0.20	0.36
	p	0.04	0.90	0.24	0.30	0.08
	Trend	**Increasing**	**No Trend**	**No Trend**	**No Trend**	**Possible Increasing**

2.3.3.4 Blue Green Algae

Blue green algae are naturally occurring photosynthetic bacteria. Under bloom conditions they can be toxic to humans and aquatic fauna and can cause other problems related to deoxygenation of the water column and reduced light penetration. Blue green algae were not detected in any samples during this reporting period, despite the significant algal blooms indicated by high chlorophyll-a concentrations on some occasions.

2.3.3.5 Faecal Indicator Organisms

Enterococcus and faecal coliforms are bacteria that can be measured as an indication of faecal pollution of waterways. Both enterococcus and faecal coliforms can be sourced from humans or animals and sometimes from rotting vegetation. Faecal indicator organisms are most commonly measured to assess the risks associated with recreational activity in and on waterways. At Salty Lagoon faecal indicator organisms are measured as an indication of faecal pollution represented by the disposal of treated effluent from the Evans Head STP.

There was a high degree of variation among the faecal indicator organism results collected during this reporting period (refer to **Figures 2.9** and **2.10**). The highest enterococcus concentrations were measured at site S2 but the highest faecal coliform concentrations were measured at S4 and S5. All of the median enterococcus and faecal coliform concentrations complied with the guiding values for the project with the exception of the median enterococcus concentration from S2.

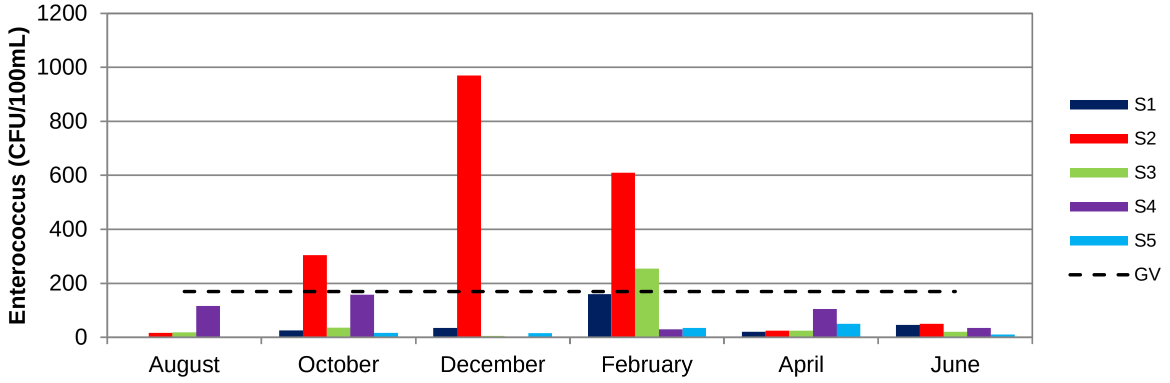


Figure 2.9 Time series of enterococcus concentrations at all sites for the current reporting period

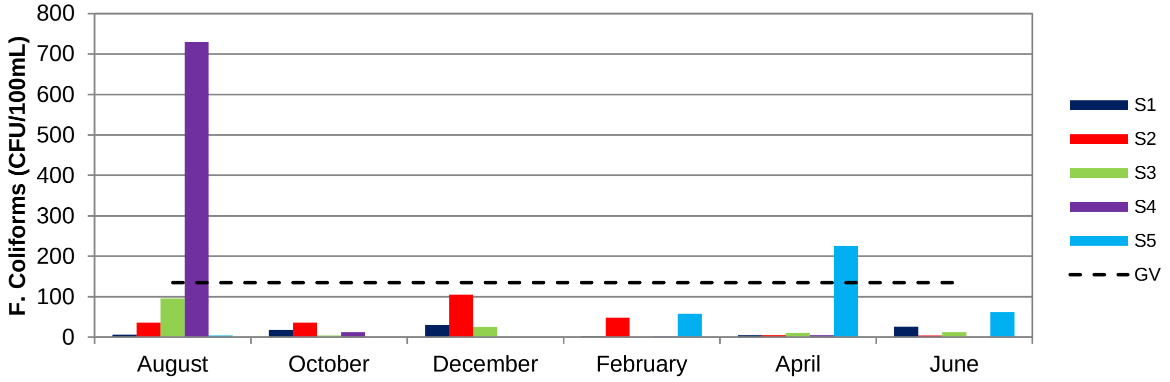


Figure 2.10 Time series of faecal coliform concentrations at all sites for the current reporting period

The major contributors to the observed variation in the concentration of faecal indicator organisms are runoff from the catchment and the presence of waterfowl. The sources of faecal pollution in Salty Lagoon are most likely to be terrestrial fauna and avifauna utilising the lagoon and its immediate catchment. The results do not suggest that discharge from the Evans Head STP or leaks from the Evans Head sewerage system are influencing the concentrations of faecal indicator organisms. Faecal coliform concentrations in discharge from the Evans Head STP are routinely lower than those measured in Salty Lagoon (GeoLINK 2017b). Annual results from the Evans Head STP are presented in **Section 2.3.4**.

Application of the Mann-Kendall test to the chlorophyll-a concentrations measured since the beginning of the PCM did not find any upwards trends in concentration (**Table 2.9**). All of the results indicated either stable concentrations, no detectable trend or possible decreasing concentrations.

Table 2.9 **Mann-Kendall Test results for enterococcus and faecal coliform concentrations since October 2017**

Parameter	Statistic	S1	S2	S3	S4	S5
Enterococcus	S	26	11	29	-34	-30
	Variance (S)	584.67	588.33	583.67	584.67	587.33
	Tau	0.19	0.08	0.22	-0.25	-0.22
	p	0.30	0.68	0.25	0.17	0.23
	Trend	**No Trend**	**No Trend**	**No Trend**	**Stable**	**Stable**
Faecal Coliforms	S	-18	-48	-21	-16	-36
	Variance (S)	587.33	587.33	586.33	582.67	580.67
	Tau	-0.13	-0.36	-0.16	-0.12	-0.27
	p	0.48	0.05	0.41	0.53	0.15
	Trend	**Stable**	**Possible Decreasing**	**Stable**	**Stable**	**Stable**

2.3.4 STP Discharge Monitoring

As part of licensing conditions, the Evans Head STP is required to monitor discharge quality on a fortnightly basis. A suite of effluent quality parameters is sampled including faecal coliform, TN and TP concentrations. The data collected from the Evans Head STP is used to contextualise results collected during the MPPC and inform any pollution incidents that may occur during the project. Monitoring results from the Evans Head STP are presented in **Figure 2.11**, **Figure 2.12**, **Figure 2.13** and **Figure 2.14**.

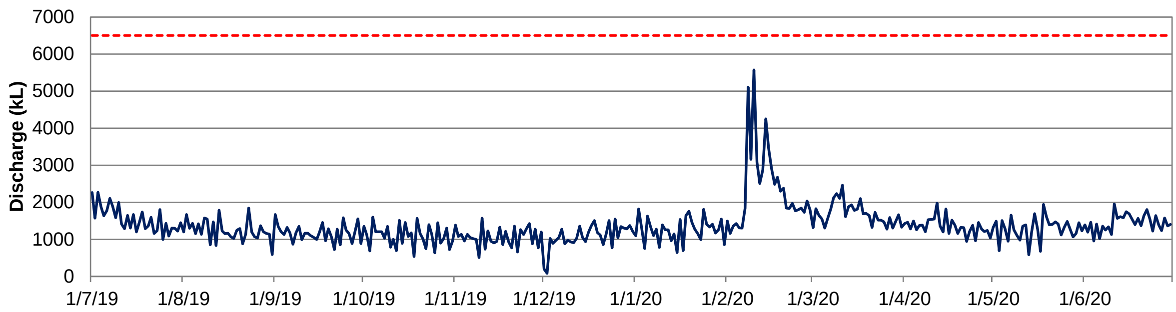


Figure 2.11 **Time series of daily discharge volumes from the Evans Head STP (maximum allowed discharge volume in red)**

The daily discharge volumes from the Evans Head STP did not exceed the licensing limits set by the EPA during this reporting period. The highest discharge volumes were associated with heavy rainfall events. As indicated by the falling water levels in Salty Lagoon during dry periods, the volume of the Evans Head STP discharge is not enough to maintain water levels in Salty Lagoon. Water losses to evaporation and groundwater are larger than the input from the STP.

In general, faecal coliform concentrations in discharged effluent are very low and they complied with the licensing limits on all occasions during this reporting period. The measured concentrations of faecal coliforms in the discharged effluent are typically lower than those measured in samples collected from Salty Lagoon as part of the MPPC project. This, in combination with the fact that faecal coliforms do not persist in the environment for a long period of time, indicates that it is highly unlikely that discharged effluent is contributing significantly to faecal coliform measurements in Salty Lagoon.

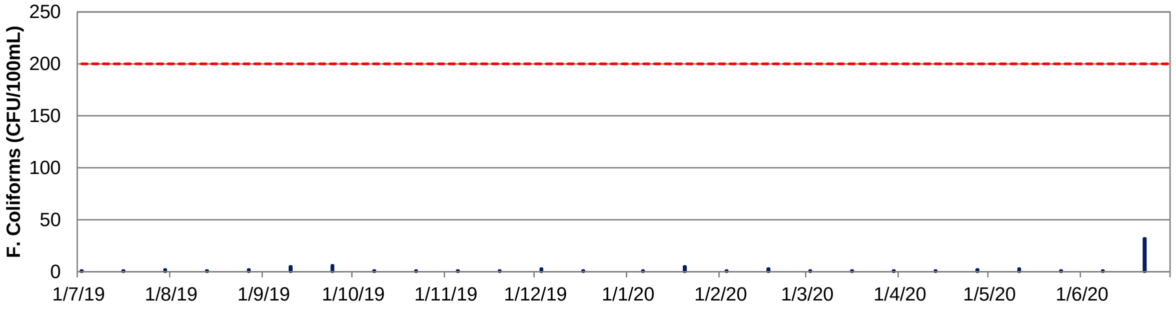


Figure 2.12 Time series of faecal coliform concentrations from the Evans Head STP discharge (90th percentile limit in red)

The TN concentrations in discharged effluent from the Evans Head STP complied with the licensing limits. The 90th percentile limit was exceeded on one occasion during the reporting period.

The concentrations of TN in discharged effluent were generally two to three times higher than those measured at any site within Salty Lagoon during this reporting period. Thus, it appears that the majority of the nitrogen in discharged effluent is processed by the ecosystems occurring along the drainage channel upstream of Salty Lagoon (as described in the ERMP project, Hydrosphere 2010a). It is also likely that dilution with unpolluted water from around the catchment contributes to this effect. It is possible that elevated nitrogen concentrations around Salty Lagoon may be partially maintained in the long term by the input from the Evans Head STP.

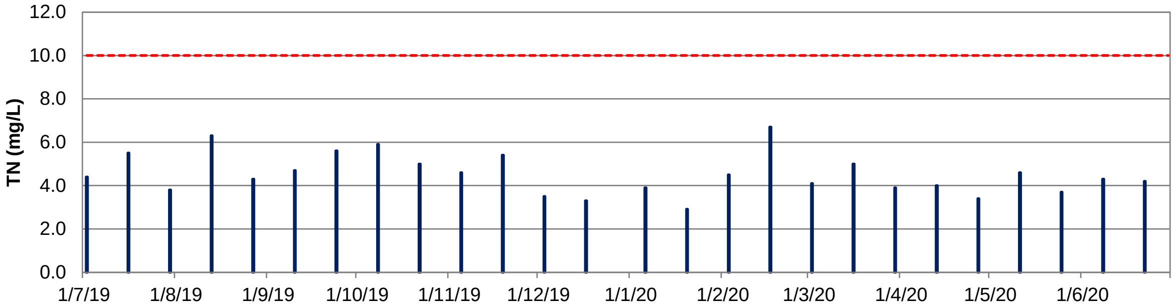


Figure 2.13 **Time series of TN concentration from the Evans Head STP discharge (90th percentile limit in red)**

The TP concentrations in discharged effluent from the Evans Head STP also complied with the licensing limits. The 90th percentile limit was exceeded on two of the 26 occasion during the reporting period.

In contrast to TN concentrations, the concentrations of TP in discharged effluent are generally comparable to those measured at S2, where the drainage channel opens out into Salty Lagoon. Hydrosphere (2010a) found an increasing trend of TP concentration along the drainage channel from the STP to Salty Lagoon and linked it to the release of phosphorus stored in sediments after years of effluent discharge rather than a lack of ecosystem processing of phosphorus released from the STP along the drainage channel. It is likely that this is still the case and that it will continue for some time into the future.

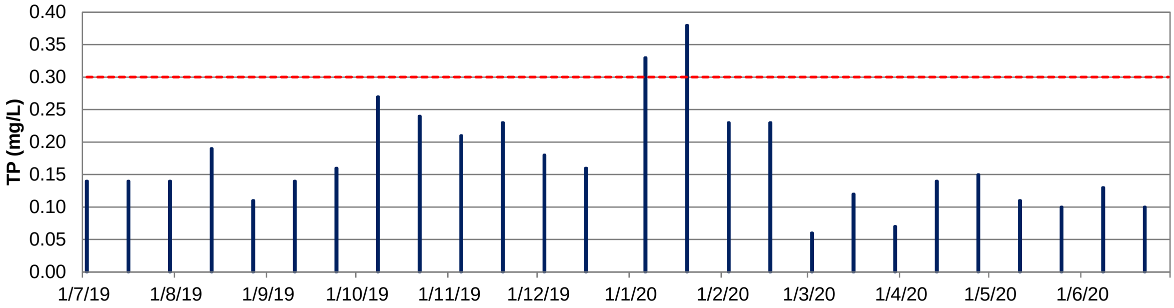


Figure 2.14 Time series of TP concentration from the Evans Head STP discharge (90th percentile limit in red)

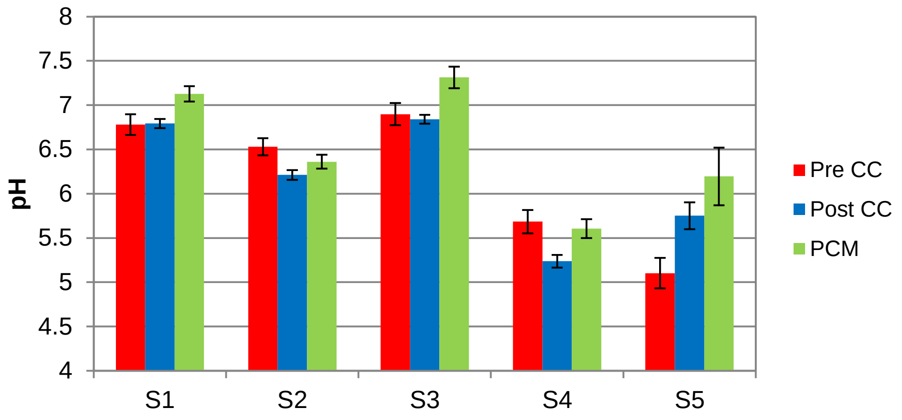
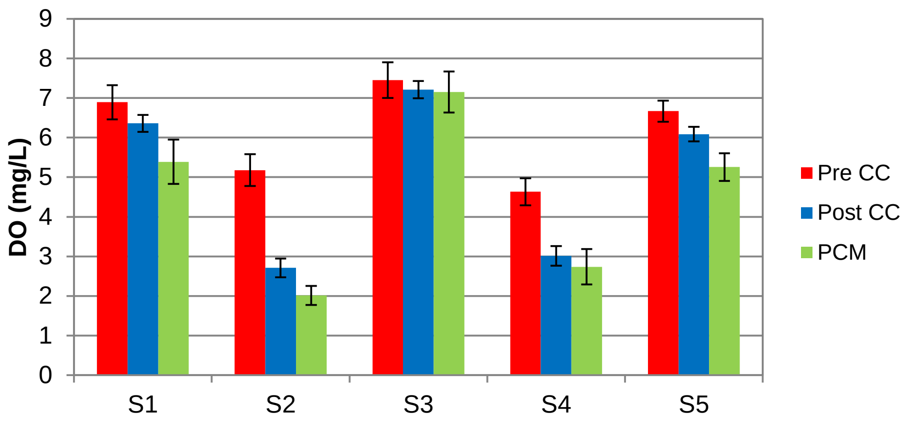
2.3.5 Comparison against Rehabilitation Targets

The primary purpose of the PCM program is to confirm predictions that closure of the artificial channel will result in an overall improvement to the ecological and cultural values of Salty Lagoon. A key objective of the post closure monitoring program is to monitor water quality and the ecological attributes of the system where predicted trends have not been confirmed and risks to the ecosystem health remain. A summary of the predicted major changes to the Salty Lagoon system and the post closuring findings are provided in **Table 2.10**. Collectively the outcomes measured during this reporting period were neutral. Generally, where negative and neutral outcomes have been determined for this reporting period, these conclusions are clearly related to the extreme environmental conditions experienced.

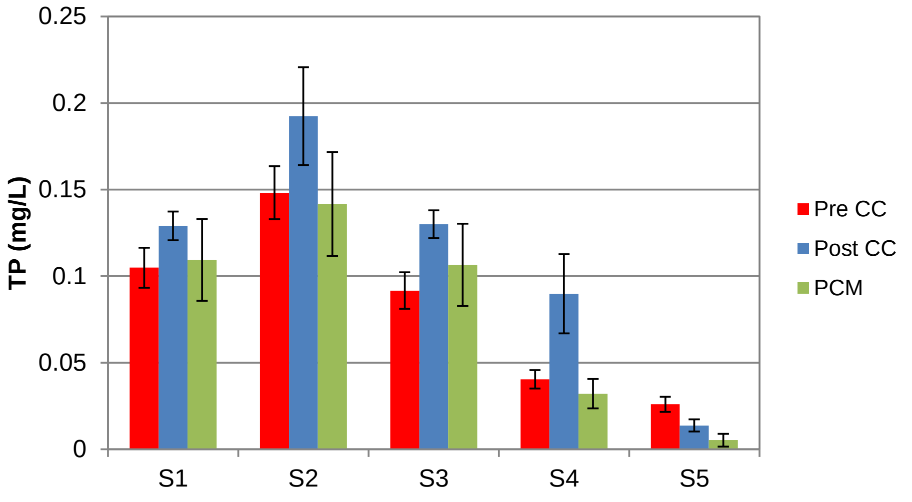
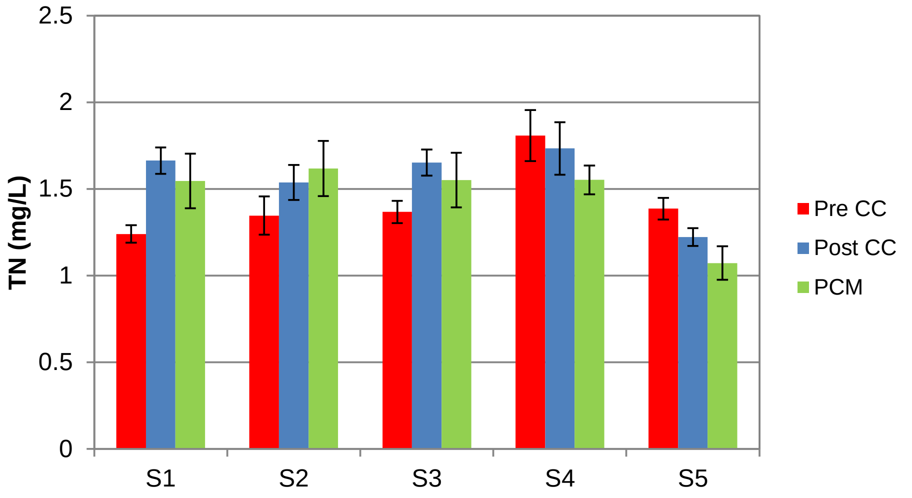
Table 2.10 Predicted Major Changes to the Salty Lagoon System and Outcomes for the 2019-2020 Reporting Period

Predicted Major Changes to System	***Summary of Annual Reporting Period Findings***
More natural hydrology and salinity regime including higher water levels – 1.9 m AHD for approximately 63% of the time.	Neutral outcome for this reporting period: Water levels remained high for a significant proportion of this reporting period with water levels of 1.9 m AHD or greater for 33% of captured data and water levels of 1.8 m AHD or greater for 67% of the captured data. High water levels occurred for a higher proportion of this reporting period than for the previous reporting period. High salinity was a feature of this reporting period with a median conductivity of 18.60 mS/cm measured at the Salty Lagoon PWQMS. Both low water levels and high salinity were a response to 'natural' events, primarily drought conditions. After the heaviest rainfall on 6 February 2020 water levels remained higher than 1.8 m AHD for 99.8% of the remaining measurements collected during this reporting period and the median conductivity was 2.28 mS/cm.
A reduced magnitude and rate of water level variation.	Positive outcome for this reporting period. There were significant changes in water level recorded during this monitoring period but they occurred over long periods of time with the exception of increased water level measurements associated with drought breaking rainfall in January and February 2020.
Less frequent saline water ingress.	Positive outcome for this reporting period. Although saline conditions persisted for much of this reporting period there was no saline ingress. Saline conditions persisted from saline ingress that occurred in the previous reporting period.

Predicted Major Changes to System	*Summary of Annual Reporting Period Findings*
Improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation reduced algal blooms and reduced potential for deoxygenation.	Unclear outcome for this reporting period: It is uncertain if the productivity of the benthic macroalgal assemblage has changed since the closure of the artificial channel. Incidental observations indicate good light penetration to benthic surfaces which could encourage increased benthic productivity. However, algal blooms and deoxygenation events were both recorded during this reporting period. Algal blooms were associated with extreme drought conditions and the deoxygenation event was associated with drought breaking rainfall and an extreme change to salinity measurements. Rapid changes to salinity are often associated with interruption to the benthic microalgal assemblage.
Reduced water column algal biomass.	Negative outcome for this reporting period: Average chlorophyll-a concentrations were relatively high for this reporting period and the median chlorophyll-a concentrations at three sites did not comply with guiding values. The highest chlorophyll-a concentrations were associated with drought conditions.
Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.	Variable outcome for this reporting period: With respect to nutrient and microalgal concentrations the results are mixed. The average TN concentrations are slightly higher than those from the previous annual reporting period at some sites but the average TP concentrations have not increased. Trend analysis using the Mann-Kendall test did not find any trends towards poor water quality, with the exception of the chlorophyll-a concentrations at S1 and S5. Nutrient concentrations at all Salty Lagoon sites either show no detectable trends or are stable since the beginning of the PCM. With respect to turbidity, pH and DO the outcomes have been variable during this reporting period. Again, Mann-Kendall analyses failed to detect trends or indicated stability for these parameters since the beginning of the PCM. Although drought conditions prevailed for much of the current reporting period there were no poor water quality episodes (relative to the conditions observed during the MPPC project). The risk of an environmental incident was either low or uncertain at the time of each of the six bi-monthly reports. The uncertain risk classifications were arrived at in response to variable the potential for worsening head-cut erosion. There were no fish kills or other ecological incidents.
Less temperature variability.	Negative outcome for this reporting period: Due to low water levels experienced during the summer period daily water temperature variation up to and exceeding 10°C was common between December 2019 and February 2020. Maximum daily temperatures of over 35°C were also common during that period.
Reduced average and maximum pH values.	Negative outcome for this reporting period: Prior to channel closure the average logged pH at S1 was 6.88 with a 90^{th} percentile value of 7.42 and a 10^{th} percentile value of 6.34. During this reporting period the average logged pH was 7.72, the 90^{th} percentile value was 9.37 and the 10^{th} percentile value was 6.86. Average pH measurements in discrete samples at the western sites, which were found to have reduced significantly in the post channel closure environment, are only slightly lower than the average pH measurements during the pre-channel closure period at this stage of the PCM (see figure below). The high average pH measurements captured during this reporting period, and for much of the PCM to-date, have been a result of dry conditions and seawater ingress.

<table>
<tr><th>Predicted Major Changes to System</th><th>Summary of Annual Reporting Period Findings</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td>Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.</td><td>Variable outcome for this reporting period: The average DO concentrations in discrete samples from surface waters are significantly lower at this stage of the PCM than in the pre-channel closure state at S1, S2, S4 and S5 (see figure below).


However, the logged DO concentrations generally varied according to a relatively predictable diurnal pattern, and the proportions of logged measurements below 1 mg/L and below 6 mg/L have both continued to be relatively low since the end of the MPPC. Also, the DO crashes that were associated with fish kill events prior to channel closure have not eventuated during this reporting period.</td></tr>
<tr><td>Potential for low DO occurring as a result of high BOD of the marsh sediments and/or increased photo-oxidation of tannins in the warmer months.</td><td>Neutral outcome for this reporting period: This prediction has been realised, although the effects were mostly notable for a short time after heavy rainfall led to re-wetting of marsh sediments (which had been dry) in February 2020. Although the water levels were low in December 2019 and January 2020, and the waters darkly tannin stained, DO production by microalgae led to high DO concentrations during daylight hours, obscuring any impact of tannin photo-oxidation.</td></tr>
</table>

Predicted Major Changes to System	*Summary of Annual Reporting Period Findings*
Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.	Variable outcome for this reporting period: The average TP concentrations for the PCM to date are lower at all sites than the post-channel closure monitoring period but phosphorus concentrations have been highly variable and there are no upward or downward trends apparent since the inception of the PCM program. The mechanisms resulting in reduced phosphorus concentrations are not certain but high concentrations have been associated with extreme weather events. 
Reduced TN concentrations and continued dominance of DON.	Variable outcome for this reporting period: Average TN for the PCM to date are lower at some sites but variability among results is high and there are no statistically significant upward or downward trends at any of the sites in Salty Lagoon. The predicted continued dominance of DON as the major form of nitrogen in samples has continued. 
Reduced probability of wind driven turbidity increases and no draining related turbidity spikes.	Positive outcome for this reporting period: This prediction has been realised.

Predicted Major Changes to System	*Summary of Annual Reporting Period Findings*
Poor water quality episodes around high-risk periods such as low water levels and high temperatures.	Neutral outcome: This predicted risk been realised during the drought that occurred in this reporting period, but it occurred to a lesser extent than in similar conditions during the post-channel closure monitoring. There were temperature spikes and high nutrient concentrations recorded during the period of low water levels and algal blooms resulted. DO concentrations, while subject to strong diurnal variability did not crash altogether, as has been noted in the past.
Reduced severity of Salty Creek drawdown during draining events.	Negative outcome for this reporting period: There were a small number of draining events but the maximum measured drawdown over a period of 1 hour was 63.9 cm on 10 February 2020. This compares with a maximum of 13.7 cm experienced during the pre-channel closure period and 15.4 cm during the first five years of the post-channel closure period.
Less protracted entrance opening of Salty Creek.	Positive outcome for this reporting period: Opening events at the Salty Creek entrance were relatively short during this reporting period.
Potential for aquatic weed growth in early stages with change to freshwater.	Positive outcome for this reporting period: The risk of aquatic weed invasion has not been realised.
Reduced risk of fish kills.	Positive outcome for this reporting period: There have been no fish kill events during this reporting period and the conditions that were related to fish kills in the past have not eventuated.

2.3.6 Emerging Trends and Issues

The erosive head-cut to the east of the old artificial channel continues to present a threat to the project. Ongoing monitoring has observed continued advancement of the head-cut, albeit at a reduced rate in relation to the previous reporting period. The position and continued advance of the head-cut could potentially lead to a new channel between Salty Lagoon and Salty Creek supporting flow in both directions and return Salty Lagoon to the pre-closure state. Erosion monitoring is explained in more detail in **Section 3**.

3. Erosion Monitoring

3.1 Introduction

An eroding head-cut to the east of the infilled artificial channel has been identified as a risk to the freshwater ecosystem values that are emerging in the Salty Lagoon system. The head-cut was first identified as a potential risk after heavy rainfall in 2014 (GeoLINK 2014). In the final years of the MPPC it advanced approximately 20 m towards Salty Lagoon, effectively eroding a channel that could reconnect Salty Lagoon and Salty Creek at much lower water levels than they are currently.

Eventually, the eroding channel has the potential to reverse the work done to restore the freshwater values identified in the Salty Lagoon environment. A monitoring program was implemented in July 2017 to measure the progress of the head-cut over the course of the post closure monitoring program.

3.2 Methods

A series of six monitoring stations, three at the impact site and three at a control site were set up to assess the progression of erosion between Salty Lagoon and Salty Creek. The specific locations of all sites sampled are presented in **Table 3.1** and **Illustration 2.1**.

The stations were set up in July 2017 at the head-cut (Stations ER4, ER5 and ER6), with control sites at points where lateral tributaries from Salty Creek lead towards Salty Lagoon (Stations ER1, ER2 and ER3). At each site the bi-monthly monitoring involves a fixed-point photo and a measurement from a fixed peg to the nearest point of the head-cut. In February 2020 the erosion moved southwards of the monitoring point at ER5. A new monitoring point, ER5A was installed that allows progression of the head-cut to reference site ER5.

Table 3.1 Type and Locations (WGS84) of Erosion Monitoring Sites

Site	*Control/Impact*	*Peg Location*	
		Easting	*Northing*
ER1	Control	541961	6783356
ER2	Control	541934	6783355
ER3	Control	541978	6783342
ER4	Impact	542112	6783277
ER5	Impact	542129	6783262
ER5A	Impact	542128	6783245
ER6	Impact	542121	6783272

3.3 Results

The head-cut at the impact site advanced significantly during this reporting period. The progression of the erosion towards the monitoring pegs at all six monitoring sites is displayed in **Figure 3.1**.

At site ER5, the most easterly of the erosion sites, the head-cut progressed a further 17.55 m towards Salty Lagoon during this monitoring period. The progression of the head-cut towards the other monitoring pegs was slower, 10.3 m and 2.5 m towards stations ER4 and ER6 respectively. The majority of the progression at each of the impact sites happened after February 2020, coinciding with the heavy rainfall experienced during that month and the period of higher water levels in Salty Lagoon that followed (see **Figure 2.2**). The maximum measured progression of erosion at the control sites during this reporting period was 1.3 m at ER2.

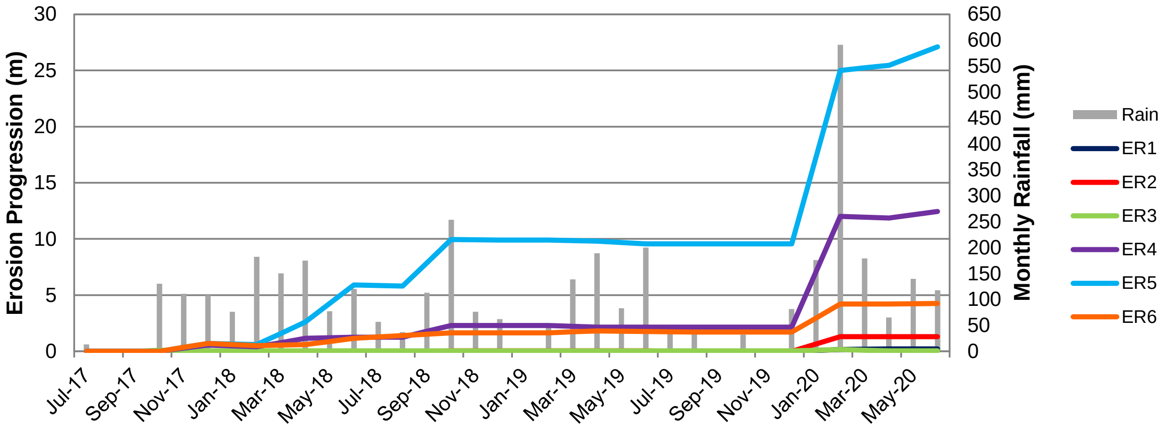


Figure 3.1 Measured erosion progression at all six sites plotted against monthly rainfall (BoM 2020)

3.4 Discussion

The erosion monitoring detected a significant advance in the erosive head-cut between Salty Creek and Salty Lagoon. Station ER5 best monitors the advance of the erosion directly towards Salty Lagoon. The measured advance of the head-cut at Station ER5 was 17.55 m during this reporting period. Stations ER4 and ER6 measure lateral, secondary advance of the head-cut. The measured advance at these two sites was 10.3 m and 2.5 m respectively. The advance measured at the control sites selected was minor.

The erosive head-cut between Salty Creek and Salty Lagoon could result in a new channel forming with the potential to undo the measurable positive benefits of the recent channel closure. This is a very high priority for the ongoing management of Salty Lagoon.

RVC, National Parks and Wildlife Services (NPWS) and GeoLINK have been liaising in relation to the head-cut remediation. Remediation designs have been developed (by GeoLINK via RVC engagement), while a Review of Environmental Factors (Part 5 of the *Environmental Planning and Assessment Act 1979* [EP&A Act] assessment) has been prepared by NPWS. Quotes for remediation works and funding avenues were being investigated at the time of writing.

4. Aquatic Vegetation/ Weeds

4.1 Introduction

Aquatic weed invasion is considered a significant risk during the period following the closure of the artificial channel as Salty Lagoon makes the transition to a fresh water system. In order to assess the response of aquatic vegetation to the changes and to provide a mechanism for adaptive management of aquatic weeds, regular surveys were undertaken as part of the MPPC program and have continued as part of the post closure monitoring program. Incidental observations of aquatic weeds noted during the bi-monthly site inspections are also recorded.

4.2 Methods

Aquatic weeds were monitored on a seasonal basis across all seasons except winter. The dates of the aquatic weed surveys undertaken during this reporting period are 3 September 2019 (spring), 22 January 2020 (summer) and 4 May 2020 (autumn).

The aquatic weed surveys involved following a meandering transect selected to cover most of the open water areas of Salty Lagoon. Each species of aquatic plant, weedy or otherwise, encountered during the survey was recorded. The position of any aquatic weed encountered was recorded with a handheld GPS unit and the aerial extent of the weed population estimated and recorded. Plants that could not be identified in the field were sampled for later identification.

The pathway of the meandering transect was recorded using the tracking feature of a handheld GPS set to track points at intervals of 20 seconds. The approximate transect pathways used during weed surveys are displayed in **Illustration 4.1**.

4.3 Results

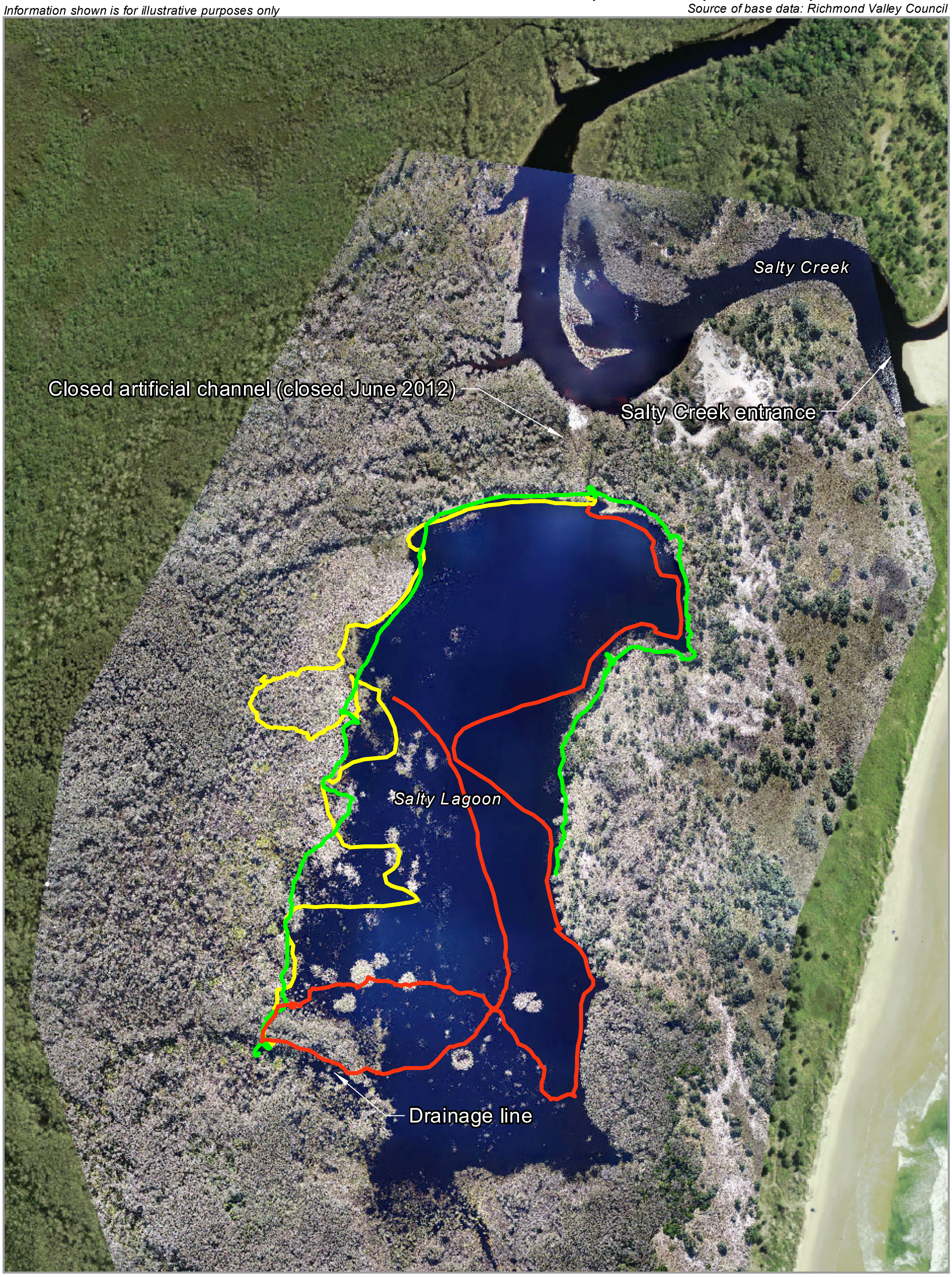
There have been no notable aquatic weeds observed during the current reporting period. A total of 15 plant taxa were observed during this reporting period. Of these, all were observed among the 38 plant taxa identified during the MPPC project. One native aquatic plant sometimes regarded as a nuisance plant, Duckweed (*Lemna sp.*) was encountered. One non-native plant, *Nymphaea capensis*, was identified during surveys.

Blue Green Algae were not detected during the aquatic weed surveys or in any of the water quality samples collected from Salty Lagoon during this reporting period. Duckweed was only encountered on one occasion, at a moderate density to the west of Salty Lagoon, particularly around sites S2 and S4. The abundance of Duckweed tends to fluctuate in response to temperature and freshwater flow. It is less likely to be observed growing at high densities during the winter months.

During the aquatic weed surveys, a list of all aquatic plant species encountered was collected and a basic estimate of their abundance made. The list of aquatic plant species encountered during this reporting period is shown in **Table 4.1**.

Information shown is for illustrative purposes only

Drawn by: DSA Checked by: AB Reviewed by: AB Date: 24/08/2020
Source of base data: Richmond Valley Council



LEGEND

- Spring 2019 weed transect
- Summer 2020 weed transect
- Autumn 2020 weed transect

0 120

Aquatic Weed Monitoring Transects

Table 4.1 List of all Aquatic Plant Species Detected During Aquatic Weed Surveys and an Assessment of Abundance

Species Name	Common Name	Survey		
		Spring 2019	Summer 2020	Autumn 2020
Hydrocotyle verticillata	Shield Pennywort			UC
Enydra fluctuans	Buffalo Spinach	UC		UC
Machaerina articulata	Jointed Twigrush	UC		UC
Machaerina sp.	A Rush	VC	VC	VC
Gahnia sieberiana	Red-fruit Saw-sedge	UC	C	C
Shoenoplectus validus	River Club-rush	C	C	C
Juncus krausii	Sea Rush	VC	VC	C
Lemna sp.	Duckweed			C
Utricularia spp.	Bladderwort			UC
*Nymphaea capensis^*	Cape Waterlily			UC
Bacopa monnieri	Water Hyssop	C	C	VC
Paspalum vaginatum	Saltwater Couch	VC	VC	VC
Phragmites australis	Common Reed	VC	VC	VC
Typha orientalis	Cumbungi	C		UC
Enteromorpha sp.	Enteromorpha	VC	VC	UC

Note *UC = Uncommon, C = Common, VC = Very Common*
^ *Introduced Species*

4.4 Discussion

The aquatic weed surveys undertaken during this reporting period did not detect any significant aquatic weeds. Despite this, the risk of weed invasion into Salty Lagoon remains. The transitions from a saltwater to freshwater system have occurred at a greater frequency than expected due to extreme weather events. These transitions provide aquatic weeds with an opportunity to colonise the Salty Lagoon system.

A change to the overall aquatic plant community in Salty Lagoon was noted during the MPPC (GeoLINK 2017b). The aquatic weed surveys undertaken during this reporting period indicate that continued stabilisation of the freshwater aquatic plant community was disrupted by saline conditions between June 2019 and February 2020. All taxa identified during this reporting period were encountered during the MPPC.

5. Ongoing Monitoring and Management

5.1 Considerations for Remaining PCM Program

The PCM program (GeoLINK 2017a) is based on five years of monitoring (2017/2018 to 2021/2022), with a review at completion of Year 5. In addition to annual water quality, aquatic weed and erosion monitoring, the final year of the program (2021/2022) includes the following additional monitoring activities:

- Vegetation monitoring following the methodology in the MPPC (Hydrosphere 2010a) plus belt transects along the Melaleuca dieback transects (GeoLINK 2017a).
- Provisional macroinvertebrate, fish, waterbird and frog monitoring following the methodologies in the MPPC (Hydrosphere 2010a).

This additional monitoring is no longer recommended. These monitoring activities aimed to detect changes associated with the Salty Lagoon system transforming to a more stable freshwater environment post closure of the artificial channel. Due to the Salty Lagoon system experiencing brackish conditions between February 2019 and June 2020 (as a result of the prolonged dry conditions and a seawater ingress event in February 2019), monitoring of these parameters is unlikely to make observations additional to those previously observed during the MPPC program (GeoLINK 2017b).

5.2 Post PCM Management of Salty Lagoon

GeoLINK (2017a) detailed RVC proposed management of Salty Lagoon post the channel closure trial based on the MPPC results and the Salty Lagoon Rehabilitation Plan recommendations (Hydrosphere 2009b, 2011). This includes:

- Maintain permanent closure of the artificial channel between Salty Lagoon and Salty Creek.
- Continuing discharge of treated water from the Evans Head STP into the creek upstream (known as the ‘Drainage Channel’) of Salty Lagoon for the medium term (i.e. next 15 years).

Recommendations from the MPPC program (GeoLINK 2017a) include:

- Development of a long-term (>15 year) plan for the Evans Head STP, including a clear discharge strategy.
- Continue to liaise with regulatory agencies, Aboriginal stakeholders and other members of the community regarding future management of Salty Lagoon.
- Continue environmental monitoring at Salty Lagoon for the next five years (years 6 to 10 post closure of the artificial channel), with a review at completion of monitoring in 2021/2022.
- Continue to monitor and assess impacts of the head-cut and work with stakeholders in regard to managing this as appropriate.

These recommendations remain valid. Based on the PCM findings to date, ecological monitoring at Salty Lagoon post the PCM program is not warranted as the health of the system has overall improved since closure of the artificial channel. While STP discharge is occurring, RVC would continue monitoring the Evans Head STP discharge (as per licence conditions). A program for head-cut monitoring post rehabilitation is recommended until it is confirmed that water flow between Salty Lagoon and Salty Creek is controlled and the erosion/head-cut risk is low.

6. Conclusion

6.1 Conclusion

The overall health of the Salty Lagoon ecosystem has improved since closure of the artificial channel. Water quality remained adequate during this reporting period. Below average rainfall following by significant rain in January and February 2020 were major factors influencing the system and most instances of poor water quality were related to these factors.

The majority of the median monitoring results complied with the project guiding values and no results indicative of the current Evans Head STP discharge adversely impacting the Salty Lagoon ecosystem were observed. No fish kill events were recorded during the reporting period. Conditions that were related to fish kills in the past did not occur.

The erosive head-cut between Salty Creek and Salty Lagoon that developed during the later years of the MPPC, continued to advance towards Salty Lagoon. It remains a threat to the positive changes recorded in the Salty Lagoon environment during the MPPC. The channel forming, if it reaches Salty Lagoon, could potentially lead to a new channel between Salty Lagoon and Salty Creek supporting flow in both directions and return Salty Lagoon to the pre-closure state. Remediation designs and planning approvals have been obtained, while funding investigations for the works are continuing.

Additional monitoring activities (i.e. vegetation monitoring and provisional macroinvertebrate, fish, waterbird and frog monitoring) scheduled for the final year of the PCM program (2021/2020) are no longer recommended. These additional monitoring activities are unlikely to make observations additional to those previously observed during the MPPC program (GeoLINK 2017b) due to prolonged brackish conditions at Salty Lagoon.

The recommendations of *Salty Lagoon Post MPPC Monitoring Recommendations* (GeoLINK 2017a) remain valid. Based on the PCM findings to date, ecological monitoring at Salty Lagoon post the PCM program is not warranted as the health of the system has overall improved since closure of the artificial channel. Ongoing Evans Head STP discharge and head-cut monitoring is recommended until it is confirmed that water flow between Salty Lagoon and Salty Creek is controlled and the erosion/head-cut risk is low.

References

Bureau of Meteorology (2020). [http://www.bom.gov.au/]. Accessed 03/08/2020.

GeoLINK (2012). Salty Lagoon – Review of Guiding Values 2012. Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2014). *Salty Lagoon – Annual Report 2014.* Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2017a). *Salty Lagoon Post MPPC Monitoring Recommendations*. Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2017b). *Final Evaluation Report – Salty Lagoon Monitoring Program: Pre/Post Closure of the Artificial Channel.* Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

Hydrosphere (2009). *Salty Lagoon Ecosystem Recovery Monitoring Program – Environmental Incident Response Protocol.* Report to Richmond Valley Council. Unpublished report to Hydrosphere Consulting, Ballina.

Hydrosphere (2010a). *Salty Lagoon Monitoring Program Pre/Post Closure of the Artificial Channel*. Unpublished report to Richmond Valley Council. Hydrosphere Consulting, Ballina.

Hydrosphere (2010b). *Salty Lagoon Ecosystem Recovery Monitoring Program: Final Report.* Unpublished report to Richmond Valley Council. Hydrosphere Consulting, Ballina.

Hydrosphere (2011). *Salty Lagoon Rehabilitation Plan: Part C Implementation Plan. Unpublished report to Richmond Valley Council. Hydrosphere Consulting, Ballina.*

Worley Parsons (2007). *Salty Lagoon Ecosystem Recovery Monitoring Program: Final Report.* Unpublished report to Richmond Valley Council. Hydrosphere Consulting, Ballina.

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