Annual Report 2022 V2

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 2022) summarises the results of the monitoring undertaken between July 2021 and June 2022; the final year of the program. Key findings are summarised below.

This reporting period was characterised above average rainfall, with very heavy rainfall between October 2021 and May 2022. Overall rainfall was far greater than average.

Water Quality (Monitored at Salty Lagoon and Salty Creek)

- Water level: The water level in Salty Lagoon remained relatively high for the majority of the reporting period.
- Conductivity: Wet conditions maintained freshwater conditions for the majority of the reporting period, with the exception of short periods following seawater ingress.
- Dissolved oxygen (DO): DO data quality was poor. In the available data, variable DO results were observed. The DO crashes that were associated with fish kill events prior to channel closure did not eventuate during this reporting period.
- pH: The pH measurements at the Salty Lagoon PWQMS were variable.
- 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: Turbidity measurements were relatively unstable.
- Nitrogen: The concentrations of total nitrogen (TN) were variable. The median concentration at one site (S4) exceeded the guiding value. There was no indication that the current release of treated effluent upstream increased nitrogen concentrations.
- Phosphorus: Total phosphorus and orthophosphate concentrations remained relatively low during this reporting period. None of the median results exceed the guiding values and no increasing trends were detected for the PCM.
- Chlorophyll-a: Chlorophyll-a concentrations were relatively high on occasions during this reporting period. The median chlorophyll-a concentrations at one site (S4) exceeded the guiding value.
- Blue green algae: Blue green algae were detected in many of the samples collected during this reporting period, with the median blue green algal concentrations exceeded the guiding value at all the Salty Lagoon sites. Regular detection of blue green algae has been unusual throughout the post closure monitoring. The genera detected varied widely and indicate several potential sources, but concentrations were relatively low and not indicative of blue green algal blooms.
- Faecal indicator organisms: There was a high degree of variation among the faecal indicator organism results collected. All the median enterococcus and faecal coliform concentrations complied with the guiding values. 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 two native species sometimes considered nuisance plants were recorded.
- The risk of weed invasion into Salty Lagoon remains.

Erosion

The erosion control structure (spillway) repaired with geofabric bags in late June/early July 2021 was damaged during floods in March/April 2022. It had not been repaired at the conclusion of the reporting period, although NSW National Parks and Wildlife Service (NPWS) reportedly had scheduled repair works for August 2022. The head-cut advanced to a relatively small degree during this reporting period. Ongoing monitoring and maintenance of the spillway and remediation of the erosion channel/headcut will be required to ensure the benefits of closure of the artificial channel are maintained.

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

The 2021/2022 monitoring period was the final year of the PCM program. A final evaluation report would be prepared to discuss the overall success of the program and outline future monitoring or management considerations for Salty Lagoon.

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 2007]) 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 concludes at the end of this reporting period in June 2022.

1.2 Objectives

The objectives of the PCM 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 2022) summarises the results of the monitoring undertaken between July 2021 and June 2022 as part of the PCM, the final year of the 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 component provides the key information for understanding the Salty Lagoon ecosystem.

Ongoing monitoring of water quality in Salty Lagoon has changed for the PCM 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	Physico-chemical	Temperature, conductivity, DO, pH, turbidity, water level
Monthly discrete sampling and adaptive management response sampling	Physico-chemical	Temperature, conductivity, 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 in Salty Creek (S5) on a bi-monthly basis. An additional quality assurance 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 2021 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 PCM 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.

For much of this reporting period a risk rating of ‘uncertain’ was assigned, due to a perceived risk associated with the status of the eroding head-cut. However, no adaptive management site inspections were undertaken, no environmental incidents were noted, and no adaptive management water quality sampling was required.

Location of Water Quality and Erosion Monitoring Sites - Illustration 2.1

Information shown is for illustrative purposes only
Drawn by: AB Checked by: GJK Reviewed by: DSA
Source of base data: Richmond Valley Council
Date: 30/08/2021

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 program. 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 PCM 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 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 above average rainfall, with very heavy rainfall between October 2021 and May 2022. Total rainfall for this monitoring period was 2434 mm. The annual average rainfall for the Evans Head BOM station is 1512 mm. During this reporting period the rainfall between December 2021 and March 2022 was equal to the annual average rainfall amount. There were thirteen daily rainfall totals of greater than 50 mm during this reporting period.

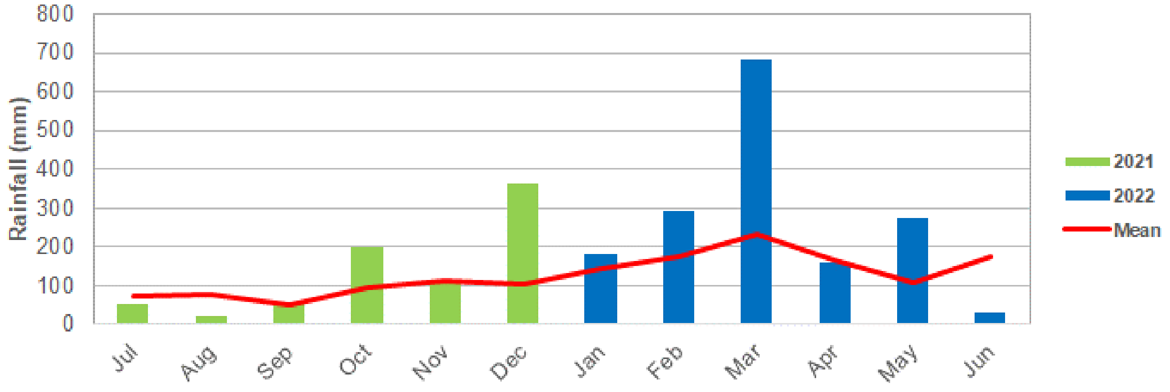


Figure 2.1 Monthly rainfall at the Evans Head BOM weather station for the reporting period displayed against average monthly rainfall (BOM 2022)

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, during the monitoring period there are some gaps in the data from the PWQMS. The gaps are as follows:

- Short-term (between 30 and 60 minute) gaps in the data set associated with changing deployed probes for serviced and calibrated probes.
- A large gap in the Salty Creek DO measurements, between 1 July 2021 and 12 September 2021.
- Three large gaps in the Salty Lagoon DO measurements, between 14 August 2021 and 12 September 2021, between 22 September 2021 and 15 November 2021, and between 12 January 2022 and 30 June 2022 due to faulty probes.
- A large gap in the Salty Lagoon pH, conductivity and turbidity measurements between 13 October 2021 and 15 November 2021 due to battery failure.

- A 3.5-hour gap in the Salty Lagoon pH, conductivity, DO and turbidity measurements on 12 January 2022 where no data was collected due to battery failure.
- A large gap in the Salty Lagoon turbidity measurements from 31 May to 30 June 2022 due to a faulty probe.

Significant gaps in the data are highlighted in **Figures 2.2** and **2.3**. Over the monitoring period the number of missed data points from the Salty Lagoon PWQMS were as follows:

- <0.1% missed water level and temperature data points.
- 1585 (9.0%) missed pH and conductivity data points due to battery failure.
- 12107 (69.1%) missed dissolved oxygen data points due to battery failure and probe error.
- 3060 (17.5%) missed turbidity data points due to battery failure and probe error.

Over the monitoring period the missed data points from the Salty Creek PWQMS were as follows:

- <0.1% missed water level data points.
- Approximately 0.3% temperature, conductivity, pH and turbidity data points due to battery failure.
- 3509 (20.0%) missed DO data points due to probe error and battery failure.

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.

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 remained relatively high in Salty Lagoon for the majority of the reporting period. The lowest levels were recorded after repairs to the erosion control structure were completed in July 2021 and the new level of the structure was set to approximately 1.7 m AHD, approximately 0.2 m below the original intended level of the channel closure structure. However, above average rainfall between October 2021 and May 2022 resulted in sustained high levels for the remainder of the monitoring period and very high levels on 28 February 2022 and 30 March 2022 during floods. The water level displayed in **Figure 2.2** indicate that water would have flowed from Salty Lagoon into Salty Creek for the majority of the reporting period. Electrical conductivity measurements indicate that the flow direction reversed briefly on 13 October 2021 and 3 January 2022 when saline water flowed into Salty Lagoon from Salty Creek. This occurred in response to heavy rainfall on 13 October 2021 and in response to seawater ingress on 3 January 2022.

The water level chart in **Figure 2.2** indicates that the maximum water level reached in Salty Lagoon for the reporting period was 2.483 m AHD (Australian Height Datum), during floods around 28 February 2022. The lowest water level recorded was 1.641 m AHD on 25 September 2021 after three months of average to below average rainfall.

Conductivity

Conductivity is a measure of the saltiness of the water. Water salinity has a strong impact on the ecosystem of Salty Lagoon as many aquatic plants and animals have an affinity for either freshwater (<1.5 mS/cm), brackish water (1.5 – 10 mS/cm) or saline water (>10 mS/cm) conditions. Frequent changes in water salinity can impact ecosystem stability.

The key driving factors causing fluctuations in the conductivity of the water recorded in Salty Lagoon during the reporting period were evaporation, rainfall and saline water ingress from Salty Creek. Evaporation causes a gradual increase in conductivity measurements as salts become more concentrated. Rainfall has the opposite effect but typically operates over shorter timeframes. Rapid increases in conductivity, such as those observed on 13 October 2021 and 3 January 2022 are associated with saline water ingress (**Figure 2.2**).

The conductivity measurements presented in **Figure 2.2** show that the wet conditions maintained freshwater conditions for the majority of the reporting period, with the exception of short periods following seawater ingress. The maximum measurement of 9.87 mS/cm was recorded after saline water ingress from Salty Creek.

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 (bed of the waterway). 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. When water levels are high, DO concentrations at the bottom of the water column tend to be lower.
- 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 DO data quality was poor (**Section 2.2.3.1**). There were a large number of missing data points. In the data that is available, the major features of DO variation in Salty Lagoon were:

- Diurnal fluctuations.
- Wind and flow driven mixing.

- Lower DO concentrations during times of high water levels and brackish conditions.

In the available data from this reporting period the DO concentration measured at the Salty Lagoon PWQMS dropped below 1 mg/L on several occasions. The DO concentration was 6 mg/L or less for approximately 82% of measurements and 1 mg/L or less for approximately 29% of measurements. This is a lower rate of occurrence of hypoxic conditions at the Salty Lagoon PWQMS relative to the previous annual reporting period but a higher rate relative to three annual reporting periods before that. Low levels of mixing at the bottom of the water column associated with stable weather conditions and high water levels during the periods where data is available appear to be the key cause of this observation.

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 rainfall and saline water ingress from Salty Creek and in the short-term mostly in response to oxygen availability and/or sunlight. After heavy rainfall the pH tends to drop in Salty Lagoon and low pH water naturally occurring in the catchment is delivered in runoff. After saline water ingress the pH in Salty Lagoon tends to increase. Both effects appear to be buffered somewhat, particularly the impact of rainfall runoff, as the pH rarely drops to the low levels measured in the catchment. The variation between maximum and minimum pH concentrations was relatively low during this reporting period, with a minimum pH of 6.28 and a maximum of 7.54.

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. Additionally, when water levels are high water temperatures tend to be lower, due to the position of the meter at the bottom of the water column.

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 high during this reporting period with a maximum measured temperature of 33.43°C and a minimum of 11.08°C.

Turbidity

Turbidity measurements in Salty Lagoon fluctuate in response to various factors such as wind driven sediment suspension, runoff from the catchment and microalgal growth. During the current monitoring period turbidity measurements were relatively unstable, remaining below 5 NTU for 36.1% of measurements (compared with more less than 15% in the previous monitoring period and more than 90% of measurements in the monitoring period before that).

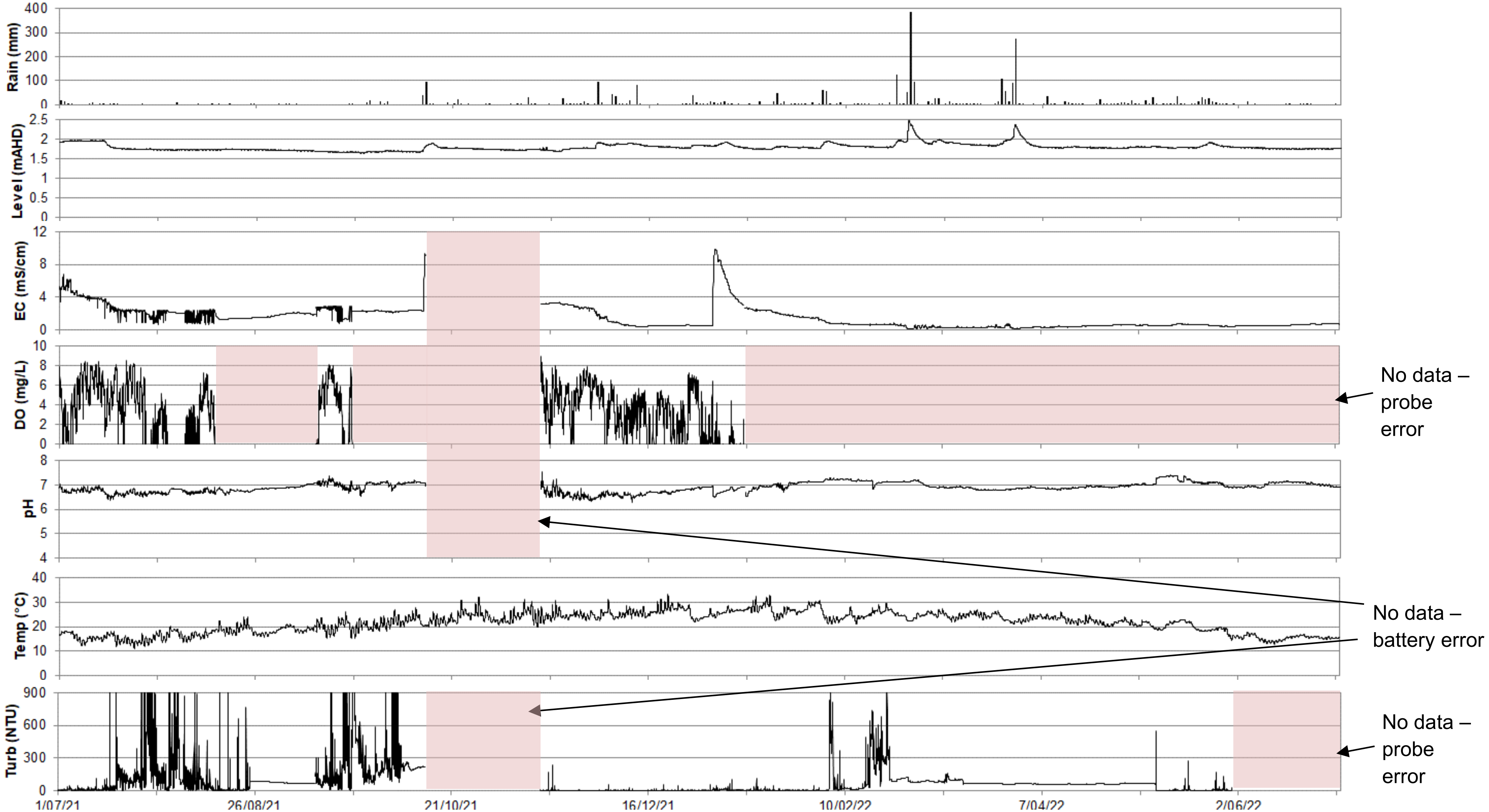


Figure 2.2 Data from the Salty Lagoon PWQMS for the 2021/22 reporting period

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 assembled data indicates that the entrance to Salty Creek opened at least seven 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 water level of Salty Creek increased sharply on three occasions during this reporting period as a result of seawater ingress during large swell and storm surge conditions, and on at least five 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. This occurred on at least two occasions during this reporting period and resulted in relatively high water levels at the end June 2022. There were two occasions during this monitoring period when high water levels in Salty Creek allowed saline water to flow from Salty Creek into Salty Lagoon, on 13 October 2021 and 3 January 2022.

Conductivity

The conductivity measurements from the Salty Creek PWQMS fluctuated widely in response to the dynamic state of the entrance, tidal movements, seawater ingress, and medium and heavy rainfall events. However, the water in Salty Creek was saline for most of the reporting period. Periods of freshwater or brackish water quality tend to be short in Salty Creek, as tidal movements resulting from open entrance conditions usually closely follow the heavy rainfall events that cause them. The median conductivity measurement was 27.2 mS/cm, slightly more than 50% the value of seawater.

Dissolved Oxygen

DO concentrations measured at the Salty Creek PWQMS fluctuated widely throughout the monitoring period. A variety of factors influence the DO concentrations in Salty Creek. In general, the data presented in **Figure 2.3** indicates that:

- Low DO concentrations accompanied most periods of saline water dominance.
- DO concentrations in Salty Creek fluctuated diurnally for a significant proportion of the reporting period. Diurnal fluctuations were most prominent when there were stable conditions and lower 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 97% of the measurements and 1 mg/L or less for approximately 43% of the measurements. For the fifth consecutive monitoring period these figures indicate that low DO concentrations in Salty Creek are more prevalent than during the MPPC period.

pH

The pH measurements from the Salty Creek PWQMS generally fluctuated according to predictable patterns. 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. Seawater ingress has the opposite effect, leading to alkaline pH measurements. A pH buffering effect is visible over time when stable conditions persist. The maximum pH measurement was 8.09, close to the pH of seawater, and the minimum pH measurement was 3.83. The average pH measurement in Salty Creek during this reporting period was 5.85 and the median was 6.57.

Temperature and Turbidity

Temperature measurements in Salty Creek fluctuated on a daily and seasonal basis. Daily fluctuations in temperature were strongest when water levels were low. Turbidity measurements from the Salty Creek PWQMS were generally low, with a median of 2.72 NTU. Periods of greater turbidity generally occurred during seawater ingress events and after heavy rainfall.

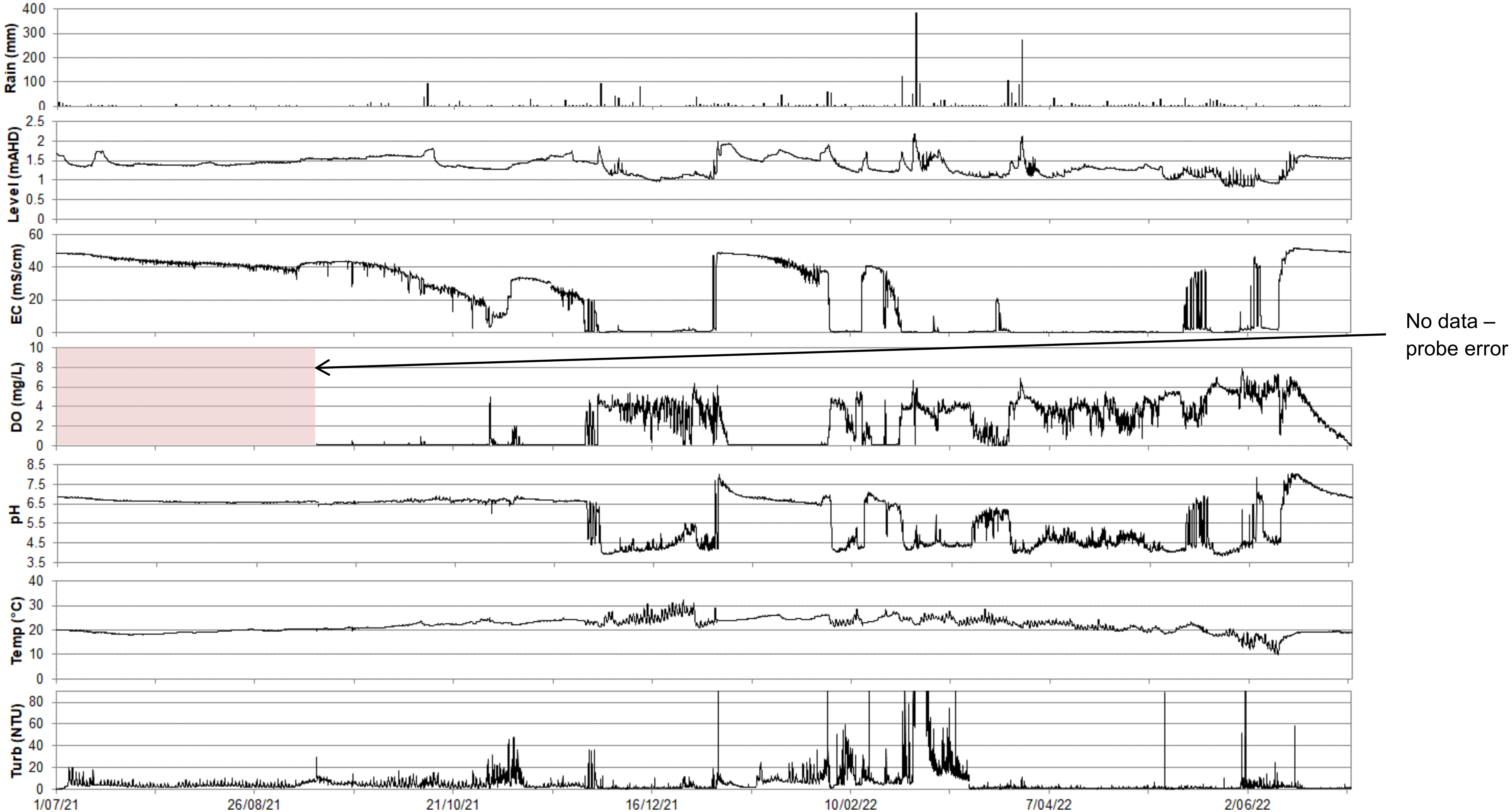


Figure 2.3 Data from the Salty Creek PWQMS for the 2021/22 reporting period

2.3.3 Discrete Water Quality Samples

This section describes the results of discrete water quality samples collected during 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 2021 and 30 June 2022

Indicator	***Salty Lagoon***					***Salty Creek***	
	Guiding Value	***S1***	***S2***	***S3***	***S4***	***Guiding Value***	***S5***
Nitrite nitrogen (mg/L)	**0.01**	0.01	0.01	0.01	0.01	**0.01**	0.01
Nitrate nitrogen (mg/L)	**0.01**	0.01	0.01	**0.02**	0.01	**0.01**	0.01
Oxidized nitrogen (mg/L)	**-**	0.02	0.01	0.03	0.01	**-**	0.01
Ammonia nitrogen (mg/L)	**0.05**	0.01	0.01	0.01	0.01	**0.11**	0.01
Total kjeldahl nitrogen (mg/L)	**1.60**	1.16	1.07	1.21	**1.74**	**1.63**	1.00
Total nitrogen (mg/L)	**1.60**	1.18	1.08	1.22	**1.74**	**1.63**	1.01
Total phosphorus (mg/L)	**0.14**	0.05	0.07	0.05	0.03	**0.04**	0.03
Orthophosphate (mg/L)	**0.11**	0.02	0.04	0.02	0.01	**0.01**	0.01
Chlorophyll-a (µg/L)	**5**	1	1	2	**7**	**3**	2
Enterococcus (CFU/100mL)	**170**	28	83	20	15	**40**	23
Faecal coliforms (CFU/100mL)	**135**	8	35	8	5	**150**	25
Blue green algae (cells/L)	**0**	**50**	**100**	**50**	**100**	**0**	0
Temp (˚C)	**25.9**	19.84	19.10	21.31	19.42	**13.10-28.80**	20.51
pH	**6.9**	6.52	6.05	6.70	4.99	**4.30-6.80**	4.79
ORP (mV)	**-**	210	172	179	223	**-**	274
Cond (mS/cm)	**8.0**	1.505	0.331	1.551	1.200	**0.3-21.5**	2.092
Turbidity (NTU)	**13**	0.9	3.5	1.3	3.9	**11**	0.7
DO (mg/L)	**4.09**	6.61	**1.74**	7.22	**2.19**	**5.52**	**4.97**
DO (% sat)	**-**	73.8	19.1	84.3	24.0	**-**	55.7
TDS (ppt)	**-**	1.03	0.26	1.04	1.41	**-**	3.26
Salinity (ppt)	**-**	0.82	0.18	0.83	1.17	**-**	2.97

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 PCM 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 and some of the forms nitrogen takes in water can be toxic at high concentrations. 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 PCM, 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).

During the current reporting period the concentrations of TN were variable but within the ranges measured during the MPPC program (**Figure 2.4**). During this reporting period a moderate number of TN measurements did not comply with the guiding values and the median TN and nitrate concentrations at sites S4 and S3 respectively did not comply with the guiding values. The highest TN concentrations for every site inspection this reporting period were collected at site S4. The highest concentrations from each site were all measured during the December 2021 site inspection after a sustained period of regular moderate to heavy rainfall events.

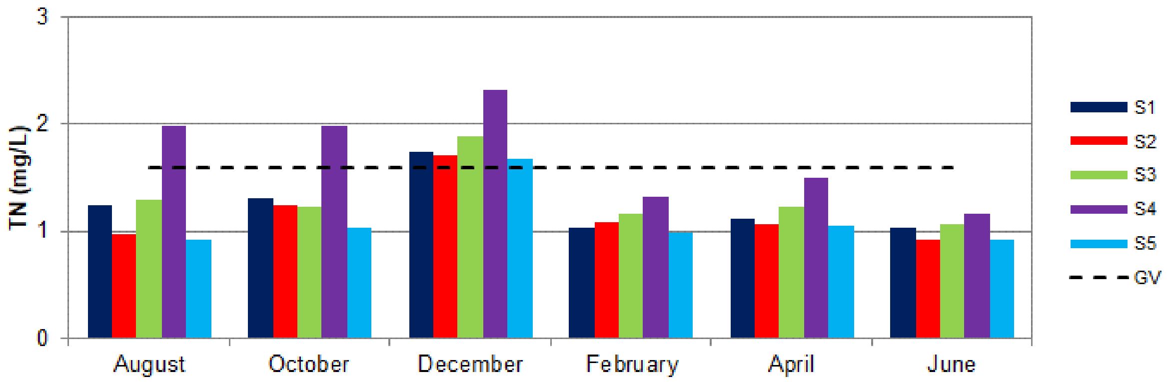


Figure 2.4 TN concentrations at all sites for the current reporting period

Aside from a spike in the concentration of ammonia at S1 in December 2021, DIN concentrations were relatively low at all sites for this reporting period (**Figure 2.5**) and, except for the median nitrate concentration from S3, 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.

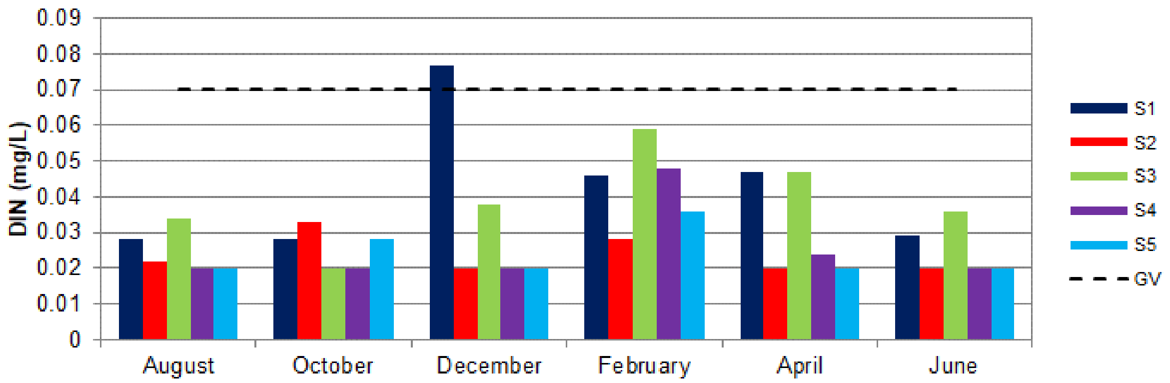


Figure 2.5 DIN concentrations at all sites for the current reporting period

Application of the Mann-Kendall test to the TN and DIN results since the beginning of the PCM found a possible upwards trend in the concentration of DIN at site S4 and a statistically significant downwards trend in the concentration of TN at site S2 (**Table 2.6**). All of the other results indicated no detectable trend. A closer look at the DIN concentrations from S4 indicates that the average DIN concentration has reduced since the previous monitoring period.

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

Parameter	*Statistic*	*S1*	*S2*	*S3*	*S4*	*S5*
DIN	S	8	44	23	80	0
	Variance (S)	2774.67	2024.00	2746.33	2248.00	2024.00
	Tau	0.02	0.14	0.06	0.24	0.00
	p	0.894	0.339	0.675	0.096	1.000
	Trend	**No Trend**	**No Trend**	**No Trend**	**Possible Increasing**	**No Trend**
TN	S	5	-108	4	26	-4
	Variance (S)	2841.00	2837.33	2833.33	2832.67	2840.00
	Tau	0.01	-0.27	0.01	0.06	-0.01
	p	0.940	0.045	0.955	0.639	0.955
	Trend	**No Trend**	**Decreasing**	**No Trend**	**No Trend**	**No Trend**

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.

As there were no TP or orthophosphate measurements above guiding values this reporting period, the median TP and orthophosphate concentrations complied with guiding values. There were no obvious trends in the data collected this year (refer to **Figure 2.6** and **Figure 2.7**). The data indicates that:

- 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.
- Phosphorus was not detected in Salty Creek during this reporting period.
- The highest concentrations of phosphorus were measured at S2 during the warmer part of the year.
- Orthophosphate concentrations were closely related to the total phosphorus concentrations, particularly in the samples where total phosphorus concentrations were highest, during the summer months (**Figure 2.7**).

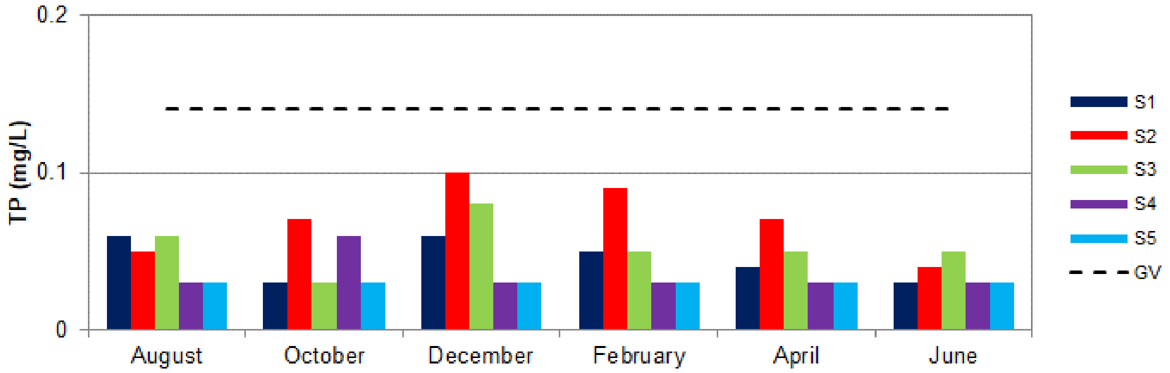


Figure 2.6 TP concentrations at all sites for the current reporting period

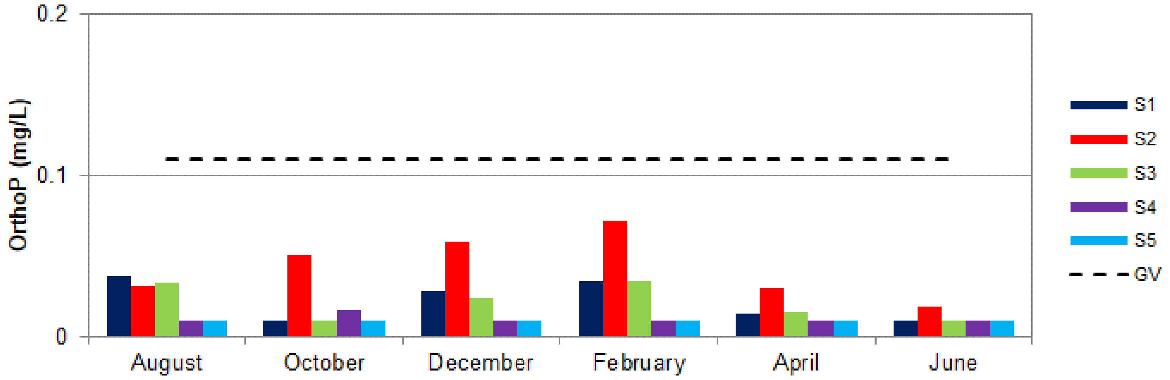


Figure 2.7 Orthophosphate concentrations at all sites for the current reporting period

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.

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

Parameter	*Statistic*	*S1*	*S2*	*S3*	*S4*	*S5*
TP	S	-85	-72	-58	-2	1
	Variance (S)	2804.33	2812.00	2779.33	1740.67	541.00
	Tau	-0.22	-0.18	-0.15	-0.01	0.01
	p	0.113	0.181	0.280	0.981	1.000
	Trend	**Stable**	**Stable**	**Stable**	**No Trend**	**No Trend**
Ortho-P	S	-12	-27	-21	52	0
	Variance (S)	2772.67	2839.00	2771.00	1404.67	0.00
	Tau	-0.03	-0.07	-0.05	0.21	n/a
	p	0.835	0.626	0.704	0.174	n/a
	Trend	**No Trend**	**Stable**	**Stable**	**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 some of the samples collected during this reporting period (**Figure 2.8**) and the median chlorophyll-a concentration measured at S4 for this reporting period did not comply with guiding values.

The highest chlorophyll-a concentrations measured were collected in August and October 2021 at S4 (**Figure 2.8**), at times when the highest TN concentrations were also measured. The highest chlorophyll-a concentrations at site S4 indicated moderate to large level algal blooms.

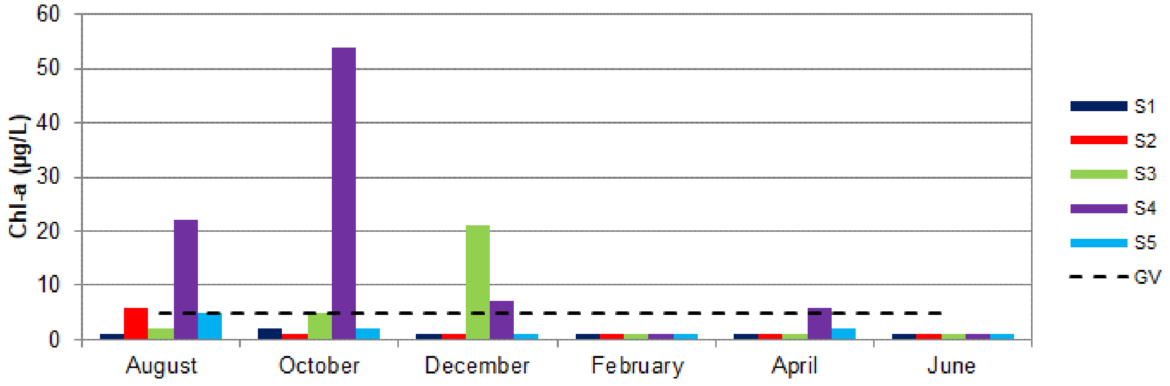


Figure 2.8 Chlorophyll-a concentrations at all sites for the current reporting period

Application of the Mann-Kendall test to the chlorophyll-a concentrations measured since the beginning of the PCM found either no trend or a decreasing trend (**Table 2.8**). It is thought that the high chlorophyll-a concentrations measured in recent years are more likely to have arisen from a combination of historical pollution and environmental conditions rather than from current management (e.g. GeoLINK 2017). In effect, nutrients stored in the system from historical pollution have a greater impact during dry periods when the release of stored nutrients from sediments into the water column is not offset by loss of nutrients from the system in rainfall runoff and nutrients released into the water column are further concentrated when water lost to evaporation is not replaced by rainfall. The results obtained during the current reporting period support this hypothesis.

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

Parameter	*Statistic*	*S1*	*S2*	*S3*	*S4*	*S5*
Chlorophyll-a	S	-4	-129	12	69	41
	Variance (S)	2498.67	2617.67	2738.67	2710.33	2021.00
	Tau	-0.01	-0.35	0.03	0.18	0.13
	p	0.952	0.012	0.834	0.192	0.374
	Trend	**No Trend**	**Decreasing**	**No Trend**	**No Trend**	**No Trend**

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 detected in many of the samples collected during this reporting period. In the history of monitoring at Salty Lagoon, regular detection of blue green algae has been unusual. The median blue green algal concentrations exceeded the guiding value at all the Salty Lagoon sites, S1, S2, S3 and S4. The genera detected varied widely and indicate several potential sources, but concentrations were relatively low and not indicative of blue green algal blooms.

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 sites S2 and S4 and the highest faecal coliform concentrations were measured at S5. All the median enterococcus and faecal coliform concentrations complied with the guiding values.

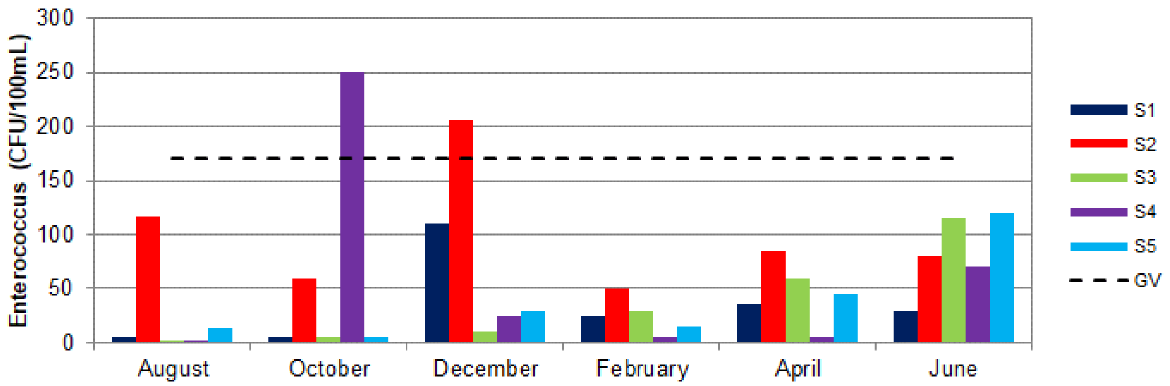


Figure 2.9 Enterococcus concentrations at all sites for the current reporting period

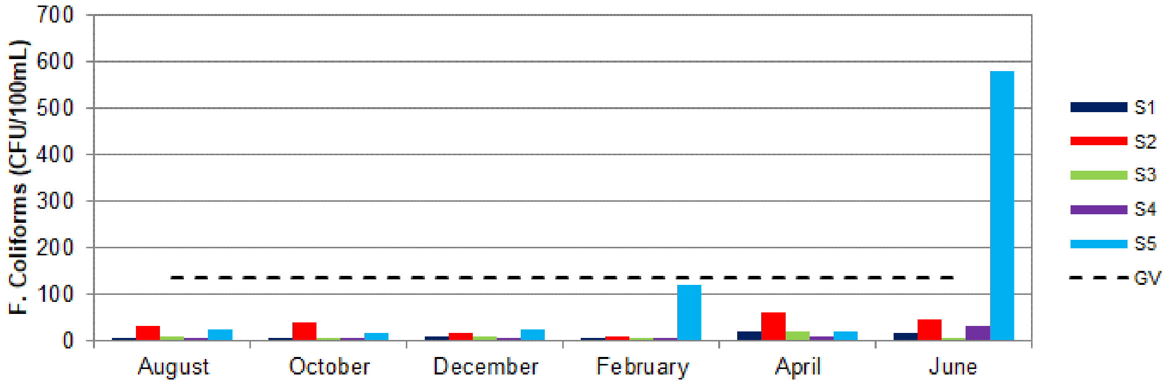


Figure 2.10 Faecal coliform concentrations at all sites for the current reporting period

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 faecal indicator organism concentrations measured since the beginning of the PCM did not find any upwards trends in concentration (**Table 2.9**). All the results indicated either stable concentrations, no detectable trend or 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	49	-46	76	23	-17
	Variance (S)	2829.67	2832.00	2822.67	2827.67	2825.67
	Tau	0.12	-0.11	0.19	0.06	-0.04
	p	0.367	0.398	0.158	0.679	0.763
	Trend	**No Trend**	**Stable**	**No Trend**	**No Trend**	**No Trend**
Faecal Coliforms	S	-64	-122	-83	32	7
	Variance (S)	2833.33	2832.67	2815.00	2812.67	2832.33
	Tau	-0.16	-0.30	-0.21	0.08	0.02
	p	0.237	0.023	0.122	0.559	0.910
	Trend	**Stable**	**Decreasing**	**Stable**	**No Trend**	**No Trend**

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 PCM and inform any pollution incidents that may occur during the program. 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 Daily discharge volumes from the Evans Head STP (maximum allowed discharge volume in red)

The daily discharge volumes from the Evans Head STP exceeded the licensing limits set by the EPA on six occasions during this reporting period. The highest discharge volumes were all associated with very heavy rainfall events and the six measurements that exceeded the licensing limits occurred during floods. 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 but two 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 PCM program. 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.

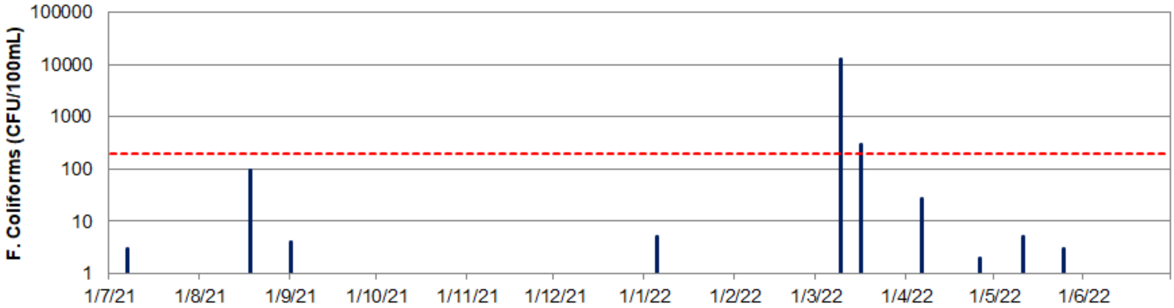


Figure 2.12 Faecal coliform concentrations from the Evans Head STP discharge (90th percentile limit in red, Log scale)

The TN concentrations in discharged effluent from the Evans Head STP complied with the licensing limits. The 90th percentile limit was not exceeded during this 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 most 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 program, Hydrosphere 2010a). It is also likely that dilution with unpolluted water from the broader catchment contributes to this effect. It is possible that elevated nitrogen concentrations in Salty Lagoon may be partially maintained in the long term by the input from the Evans Head STP.

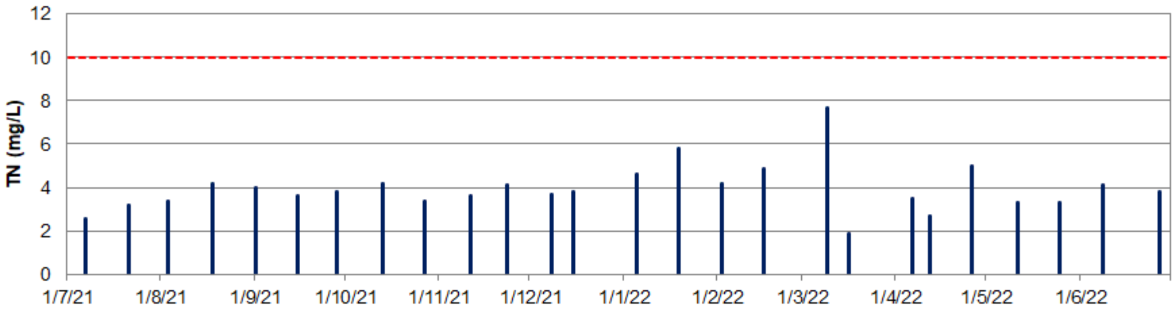


Figure 2.13 TN concentration from the Evans Head STP discharge (90th percentile limit in red)

The TP concentrations in discharged effluent from the Evans Head STP complied with the licensing limits. The 90th percentile limit was exceeded in one of the 26 samples during this reporting period.

The concentrations of TP in discharged effluent are generally 1.5 – 2 times greater than 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. In the previous two years the average TP concentration at S2 has reduced contributing to an overall weak trend towards reducing concentrations, indicating that the phosphorus load from the Evans Head STP is not exceeding the capacity of the Salty Lagoon ecosystem to process phosphorus.

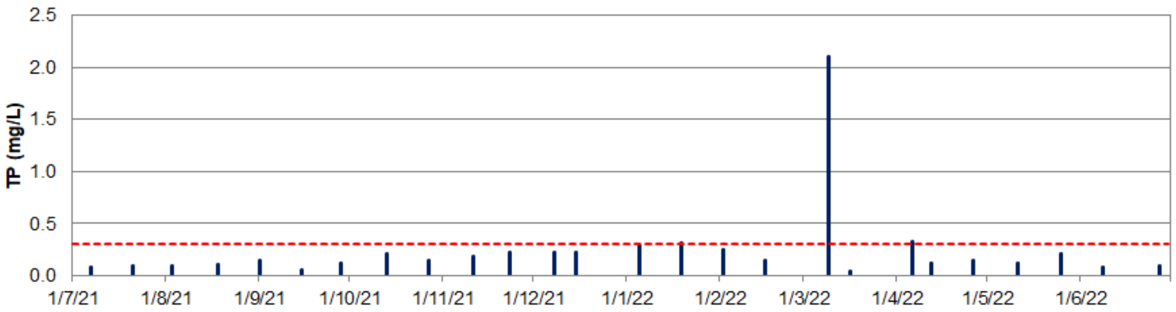


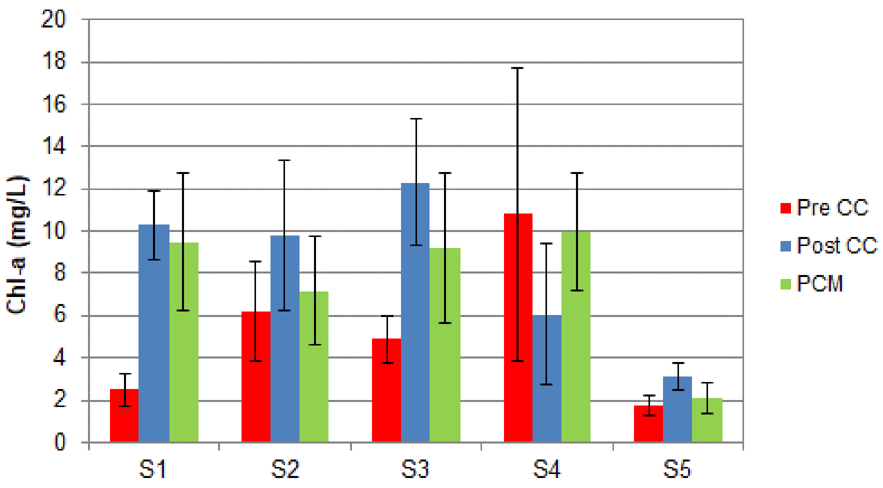
Figure 2.14 TP concentration from the Evans Head STP discharge (90th percentile limit in red)

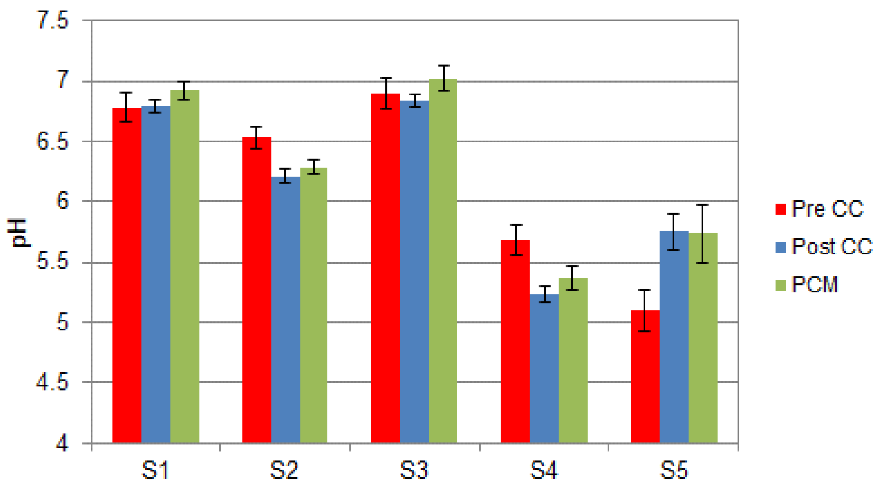
2.3.5 Comparison Against Rehabilitation Targets

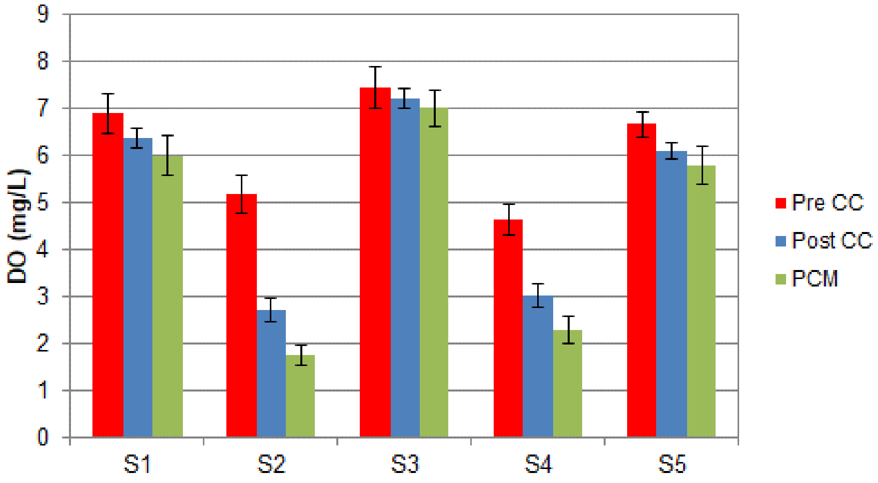
The primary purpose of the PCM program is to confirm predictions that closure of the artificial channel will result in an overall improvement to the ecological and cultural values of Salty Lagoon. A key objective of the post closure monitoring program is to monitor water quality and the ecological attributes 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 closure 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.

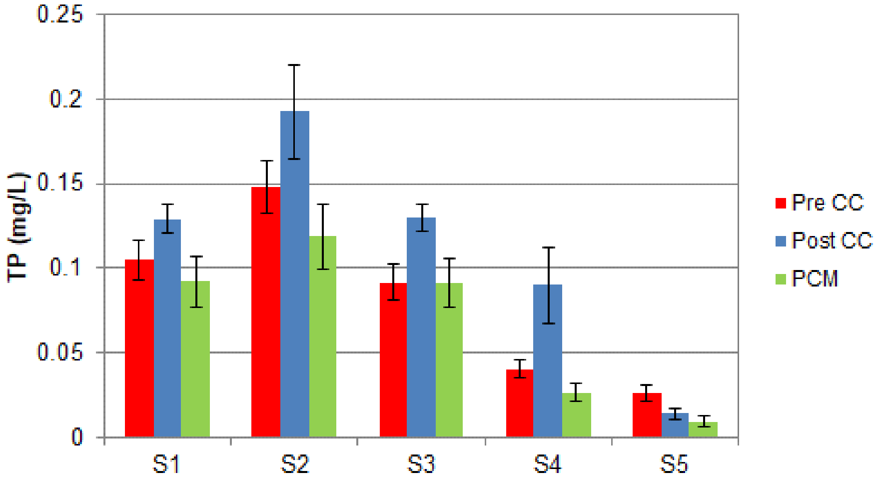
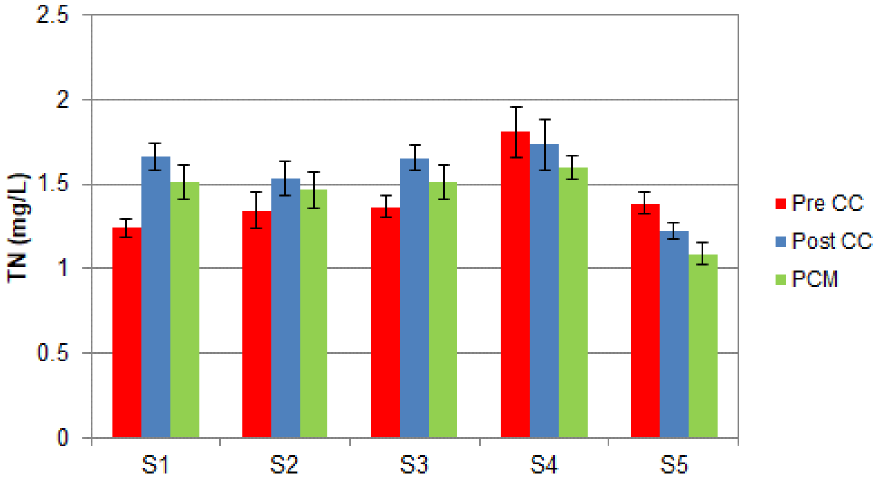
Table 2.10 Predicted Major Changes to the Salty Lagoon System and Outcomes for the 2021-2022 Reporting Period

Predicted Major Changes to System	***Summary of Annual Reporting Period Findings***
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 the heaviest rainfall events.
Less frequent saline water ingress.	Positive outcome for this reporting period. Although saline conditions persisted for some of this reporting period saline ingress only occurred on two occasions. Saline ingress occurred once in response to very large tidal movements on 3 January 2022 at the same time as very large swell conditions and once during a large rainfall event on October 10, 2021, when saline water stored in Salty Creek was pushed into Salty Lagoon as water levels rose in response to rainfall runoff.
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 12% of the captured data and water levels of 1.8 m AHD or greater for 35% of the captured data. However, high water levels occurred for a lesser proportion of this reporting period than for the previous reporting period and a lesser extent than predicted. The salinity regime was relatively 'natural' during this reporting period, with a median measured conductivity result of 0.71 mS/cm at the Salty Lagoon PWQMS.
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. Nutrient concentrations and chlorophyll-a measurements indicate different results for the open water and the western sites. Deoxygenation at the bottom of the water column was recorded during this reporting period. Where observed, it was most often associated with calm stable conditions and high water levels.

Predicted Major Changes to System	***Summary of Annual Reporting Period Findings***
Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.	Positive outcome for this reporting period. With respect to nutrient and microalgal concentrations the results are positive. The average TN and TP concentrations are slightly lower than those from the previous annual reporting period at most sites. Analysis using the Mann-Kendall test did not find any trends towards worsening water quality. With respect to turbidity, pH and DO the outcomes have been variable during this reporting period. Mann-Kendall analyses either failed to detect trends or indicated stability for these parameters since the beginning of the PCM. There were no specific poor water quality episodes during this reporting period. 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.
Reduced water column algal biomass.	Mixed outcome for this reporting period. Average chlorophyll-a concentrations were moderate for this reporting period but the median chlorophyll-a concentrations at one site (S4) did not comply with guiding values. The highest chlorophyll-a concentrations were associated with prolonged dry conditions at the beginning of the reporting period and high total nitrogen concentrations. Overall, as indicated below average chlorophyll-a concentrations have been relatively stable at the western sites and have increased at the open water sites since closure of the artificial channel. During the post-closure monitoring period the chlorophyll-a concentrations have mostly fluctuated without trend except at S3, where the trend is decreasing. 
Less temperature variability.	Positive outcome for this reporting period. Generally, daily and seasonal temperature variations were lower than usual during this reporting period due to consistently high water levels.

Predicted Major Changes to System	*Summary of Annual Reporting Period Findings*
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.	Neutral outcome for this reporting period. This prediction has been realised, most notably in the persistently low DO concentrations in discrete samples collected from surface water at S2 and S4 (where marsh sediments are likely to have the highest BOD) and the often-low DO concentrations at the bottom of the water column measured at the Salty Lagoon PWQMS (29% of measurements were less than 1mg/L). However, in the open water sites of Salty Lagoon the DO concentrations in discrete samples have typically been healthy (**Table 2.4**), indicating that microalgal photosynthesis during daylight hours has offset impacts from photo-oxidation of tannins and/or the oxygen demand of marsh sediments.
Reduced average and maximum pH values.	Mixed outcome for this reporting period. Prior to channel closure the average logged pH at S1 was 6.88 with a 90th percentile value of 7.42 and a 10th percentile value of 6.34. During this reporting period the average logged pH was 6.90, the 90th percentile value was 7.14 and the 10th percentile value was 6.63. On the other hand, average pH measurements in discrete samples have continued to decrease over the course of the PCM at all sites and Mann-Kendall trend analyses indicated decreasing or possible decreasing trends at all sites since the beginning of the PCM. 
Reduced severity of Salty Creek drawdown during draining events.	Neutral outcome for this reporting period. There were a small number of draining events and the maximum measured drawdown over a period of 1 hour was 17.1 cm on 1 April 2022. 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.	Neutral outcome for this reporting period. Opening events at the Salty Creek entrance were variable in their persistence 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 (refer to **Section 4**).

Predicted Major Changes to System	*Summary of Annual Reporting Period Findings*
Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.	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 S2 and S4 (refer to figure below).  The proportions of logged data below 1mg/L and 6 mg/L for this reporting period were lower than the previous reporting period but higher than other years of the PCM project. On the other hand, the available logged DO concentrations generally varied according to a relatively predictable diurnal pattern and the DO crashes that were associated with fish kill events prior to channel closure have not eventuated during this reporting period. It is also clear that more stable water levels have contributed to lower DO concentrations at the bottom of the water column, where the logger is located.

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.	Positive 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. However, phosphorus concentrations have been variable and there are no downward trends apparent since the inception of the PCM program. A reduction in the average orthophosphate concentration over the course of the PCM is also evident, pointing to greater microbial uptake as a potential driver for reduced average total phosphorus concentrations. 
Reduced TN concentrations and continued dominance of dissolved organic nitrogen (DON).	Neutral/Positive outcome for this reporting period. Average TN measurements for the PCM to date are lower at some sites but variability among results is high. There is a statistically significant downward trend at site S2 and no trend at the other sites. The predicted continued dominance of DON as the major form of nitrogen in samples has continued although DIN concentrations at S1 and S3 have increased in the PCM years. 
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.	Positive outcome. High risk periods such as low water levels and high temperatures did not eventuate during this reporting period.
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 continued to present a threat during this reporting period. Ongoing monitoring has observed continued advancement of the head-cut. An erosion control structure in the form of a spillway across the northern end of the channel were installed in late 2020 and repaired/upgraded at the start of this reporting period. It failed again after flooding in March/April 2022. 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 hydraulically connect 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 NSW National Parks and Wildlife Service (NPWS) undertook initial remediation in late 2020 through creation of a rock, geofabric and sand spillway at the outlet with a spillway height of approximately 1.55 m AHD. The spillway was damaged by significant rainfall events in February 2021, then repaired with geofabric bags in late June/early July 2021, with a new spillway height of approximately 1.7 m AHD.

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 erosion control structure (spillway) was damaged again during floods in March/April 2022. It had not been repaired at the conclusion of this reporting period, although repair works were scheduled (refer to **Section 3.4**).

The head-cut at the impact site advanced to a relatively small degree during this reporting period. The progression of the erosion towards (and in some cases past) 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 relatively small distance (1.6 m) towards Salty Lagoon during this reporting period. However, much of the progression of the head cut was not captured in the data because the movement was perpendicular to the direction of measurement. The progression of the head-cut towards the other monitoring pegs did not eventuate. The majority of the progression at each of the impact sites happened after March 2022, coinciding with flooding, associated damages to the scour spillway and the period of higher water levels in Salty Lagoon that followed (refer to **Figure 2.2**). The maximum measured progression of erosion at the control sites during this reporting period was 0.55 m at ER2.

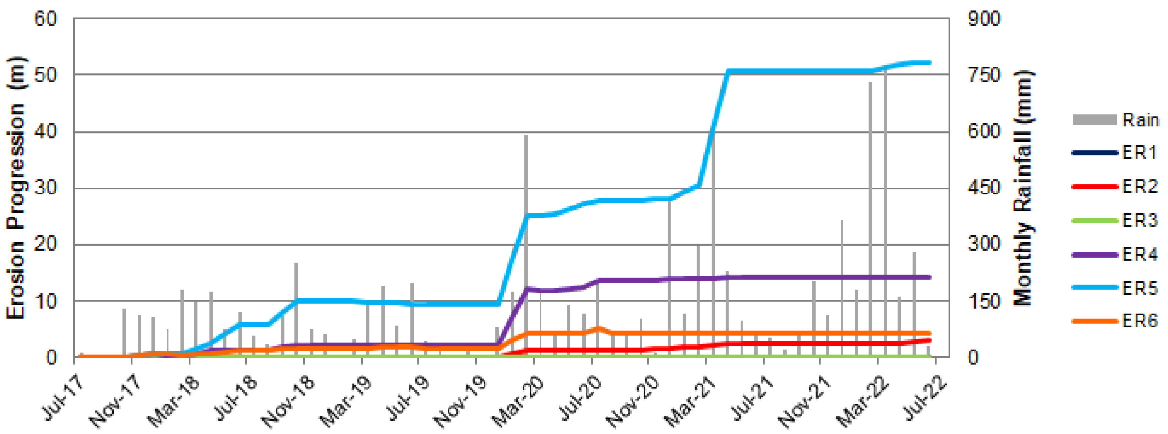


Figure 3.1 Measured erosion progression at all six sites plotted against monthly rainfall (BoM 2022)

3.4 Discussion

The erosion monitoring detected a continued 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 at least 1.6 m during this reporting period but the lengthening of the eroding channel was much further (**Plate 3.1 and 3.2**). The advance measured at the control sites was minor and no advance was measured at the other sites.

Without remediation of the erosive head-cut/channel between Salty Creek and Salty Lagoon, a completely new channel will form with potential to undo the measurable positive benefits of the channel closure. Remediating and maintaining both the spillway and erosive head-cut/channel is a very high priority for the ongoing management of Salty Lagoon.

Liaison between RVC and NPWS in July 2022 revealed that the erosion control structure (spillway) was on NPWS assets register and repair to the structure was scheduled in August 2022 (Craig Connolly, RVC, pers. comms, 26/07/2022). Ongoing monitoring and maintenance of this structure, and remediation of the erosion channel/headcut will be required to ensure the benefits of closure of the artificial channel are maintained.

Plate 3.1 Position of the headcut in August 2021

Plate 3.2 Position of the headcut in June 2022

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 freshwater 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 PCM 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 15 November 2021 (spring), 12 January 2022 (summer) and 8 May 2022 (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.

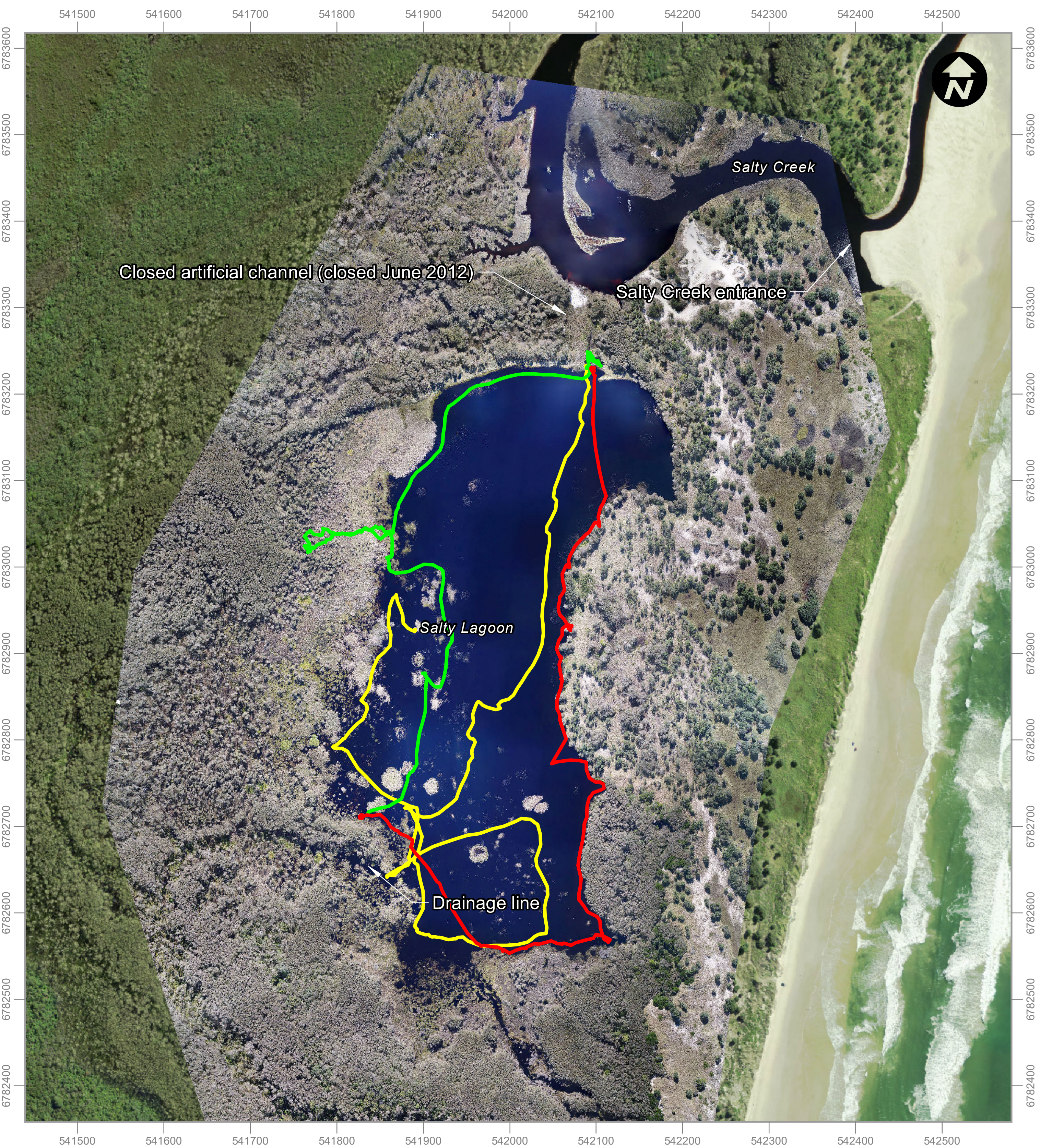
The pathway of the meandering transect was recorded using the tracking feature of a handheld GPS set to track points at intervals of 20 seconds. The approximate transect pathways used during weed surveys are displayed in **Illustration 4.1**.

4.3 Results

There have been no notable aquatic weeds observed during the current reporting period. A total of 22 plant taxa were observed during this reporting period. Of these, all but five were observed among the 38 plant taxa identified during the MPPC program. Two native aquatic plants sometimes regarded as nuisance plants, Pacific Azolla (*Azolla filiculoides*) and Duckweed (*Lemna sp.*), were encountered. No non-native plants were identified during surveys.

Blue Green Algae were detected during one of the aquatic weed surveys but were also observed in many of the water quality samples collected from Salty Lagoon during this reporting period. Duckweed was encountered during two of the three surveys, but never at very high densities. Pacific Azolla was encountered in all three surveys, but never at high densities. The abundance of Duckweed and Pacific Azolla tends to fluctuate in response to temperature and freshwater flow. They are 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**.



GDA 1994 MGA Zone 56

LEGEND

- Spring 2021 weed transect
- Summer 2022 weed transect
- Autumn 2022 weed transect

0 120 Metres

Aquatic Weed Monitoring Transects - Illustration 4.1

GeoLINK environmental management and design

Annual Report 2021 - 2022
Salty Lagoon Post-Closure Monitoring Program (Years 6 - 10)
1731-1355

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Source of base data: Richmond Valley Council
Date: 30/08/2021

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 2021	*Summer 2022*	*Autumn 2022*
Alternathera denticulata	Lesser Joyweed		UC	
Hydrocotyle verticillata	Shield Pennywort	C	C	C
Enydra fluctuans	Buffalo Spinach	UC	UC	C
Lobelia anceps	Angled Lobelia		UC	
Ceratophyllum demersum	Hornwort	VC	VC	VC
Machaerina articulata	Jointed Twigrush	UC		UC
Machaerina sp.	A Rush	VC	VC	VC
Cyperus polystachyos	Bunchy Sedge	C	UC	UC
Eleocharis acuta	Common Spike Rush	UC		UC
Fimbristylis ferruginea	Rusty Sedge	UC		
Gahnia sieberiana	Red-fruit Saw-sedge	C	UC	C
Shoenoplectus validus	River Club-rush	VC	VC	VC
Juncus krausii	Sea Rush	VC	UC	UC
Lemna sp.	Duckweed		C	UC
Nymphoides indica	Water Snowflake	UC	UC	UC
*Nymphaea capensis^*	Cape Waterlily	UC		
Bacopa monnieri	Water Hyssop	VC	C	C
Paspalum vaginatum	Saltwater Couch	VC	UC	UC
Phragmites australis	Common Reed	C	VC	VC
Azolla filiculoides	Pacific Azolla	C	C	C
Typha orientalis	Cumbungi	VC	VC	VC
Various	Blue Green Algae		VC	

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). However, the aquatic weed surveys undertaken during this reporting period (and the previous two) indicate that continued stabilisation of the freshwater aquatic plant community has been continually disrupted by intermittent saline conditions.

5. Ongoing Monitoring and Management

5.1 Post PCM Management of Salty Lagoon

The 2021/2022 monitoring period was the final year of the PCM program. A final evaluation report would be prepared to discuss the overall success of the program and outline future monitoring or management considerations for Salty Lagoon.

6. Conclusion

6.1 Conclusion

The overall health of the Salty Lagoon ecosystem has improved since closure of the artificial channel, with the water quality remaining adequate during this reporting period.

The majority of the median monitoring results complied with the program 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.

Failure of the erosion control structure (spillway) and relatively small advancement of the erosive headcut was observed during the reporting period. Ongoing monitoring and maintenance of the spillway and remediation of the erosion channel/headcut will be required to ensure the benefits of closure of the artificial channel are maintained.

The final evaluation report for the PCM program will discuss the overall success of the program and outline future monitoring or management considerations.

References

Bureau of Meteorology (2022). [http://www.bom.gov.au/]. Accessed July 2022.

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.*

Newell, C. J., Aziz, J.J. & Vanderford, m. (2007) *Statistical Trend Analysis Methods*. In: AFCEE Monitoring and Remediation Optimization System Software.

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

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