Final Evaluation Report

Salty Lagoon Post Closure Monitoring Program

GeoLINK
environmental management and design

PO Box 119
Lennox Head NSW 2478
T 02 6687 7666

PO Box 1446
Coffs Harbour NSW 2450
T 02 6651 7666

PO Box 1267
Armidale NSW 2350
T 0488 677 666

PO Box 229
Lismore NSW 2480
T 02 6621 6677

info@geolink.net.au

AQUATIC SCIENCE AND MANAGEMENT

PO Box 214
Bellingen, NSW 2454
T 02 6655 2140
M 0410 470 204

Prepared for: Richmond Valley Council

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Executive Summary

GeoLINK and Aquatic Science and Management were engaged by Richmond Valley Council (RVC) to implement the *Salty Lagoon Post Closure Monitoring Program* (PCM). The program comprised continued monitoring of most of the environmental parameters associated with the *Salty Lagoon Monitoring Program: Pre-Post Closure of Artificial Channel* (MPPC) although at a reduced frequency. The PCM program was undertaken between July 2017 and June 2022, with the objectives of:

1. Monitoring 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. Monitoring water quality and ecological attributes of the MPPC where predicted trends have not been confirmed and risks to the ecosystem remain.
3. Observing medium-term changes in the Salty Lagoon system in response to the channel closure.

The successful (positive) MPPC program outcomes lead to the trial channel closure being a permanent component of the Salty Lagoon rehabilitation strategy. The PCM program results similarly recorded positive outcomes that are overall supportive of this rehabilitation strategy.

Key findings from the MPPC and PCM in relation to Evans Head STP discharge relevant to future management at Salty Lagoon are summarised as follows:

- The current discharge from the Evans Head STP does not appear to increase the water levels in Salty Lagoon.
- At current discharge levels it is unlikely that discharged effluent from the Evans Head STP is contributing significantly to faecal coliform measurements in Salty Lagoon.
- At current discharge levels the majority of the nitrogen in discharged effluent appears to be processed by the ecosystems occurring along the drainage channel upstream of Salty Lagoon. 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.
- At current discharge levels it is not likely that current phosphorus concentrations in discharged effluent are sufficient to maintain the phosphorus concentrations in the waters of Salty Lagoon.

The MPPC and PCM programs have found that, at current discharge volumes and pollutant levels, continued discharge from the Evans Head STP has minimal effect on bioavailable nutrient concentrations within Salty Lagoon. Residual nutrients from historic pollution are currently the primary contributor of nutrients causing periodic poor water quality episodes in the system, and continuing the current discharge regime from the Evans Head STP is unlikely to adversely affect the overall health of the system for at least the medium term.

Future necessary upgrades to the Evans Head STP may seek an increase to the licensed discharge volume, possibly doubling the current volume in order to allow for increases in the population of Evans Head and holiday visitation. The potential impacts of this upon Salty Lagoon should be considered in the planning phase for the upgrades.

Maintaining water levels in Salty Lagoon through ongoing monitoring and management of the spillway and erosive head-cut/ channel between Salty Lagoon and Salty Creek is a very high priority for the ongoing management of Salty Lagoon.

RVC are currently considering upgrade options for the Evans Head STP, including the option to continue discharging into the Salty Lagoon system. With this, the following recommendations are provided:

- Develop 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 to monitor water being discharged from the Evans Head STP in accordance with licence conditions set by the NSW EPA.
- Liaise with NPWS in relation to the erosive head-cut/ channel between Salty Lagoon and Salty Creek and associated spillway to ensure appropriate rehabilitation, monitoring and maintenance.
- Continue to monitor water levels in Salty Lagoon to observe any drawdown events associated with the erosive head-cut/ channel and associated spillway failure. The water level monitoring method and responsibility would be determined through discussion between RVC and NPWS. A corresponding Environmental Response Protocol would be prepared outlining water level triggers, management responses, and roles and responsibilities.
- Potential future STP upgrade options that result in increased discharge volumes or pollutant levels should consider potential impacts on the Salty Lagoon system during the planning phase.

1. Introduction

1.1 Introduction

This *Final Evaluation Report* documents the findings of the *Salty Lagoon Post Closure Monitoring Program* (PCM [GeoLINK 2017]) undertaken between July 2017 and June 2022 against the overall project objectives. Prior to the PCM, the Salty Lagoon Monitoring Program: Pre/ Post Channel Closure (MPPC [Hydrosphere 2010a]) was undertaken over a five-year period to confirm prediction that closure of the artificial channel between Salty Lagoon and Salty Creek would result in overall improved ecological and cultural values of Salty Lagoon. The MPPC was successful, with the following key findings:

- The Salty Lagoon system continued to move towards a predominantly freshwater lagoon system, with the monitoring recording relatively stable water quality conditions.
- Many of the predicted changes of the MPPC (Hydrosphere 2010a) are occurring, including positive changes such as a more natural hydrology and salinity regime; reduced magnitude and rate of water level variation; less frequent saline water ingress; and reduced risk of fish kill.
- While other monitoring attributes have recorded no clear trend or negative trends, the results indicated overall improved ecological health at Salty Lagoon.

Based on the MPPC findings and the *Salty Lagoon Rehabilitation Plan* recommendations (Hydrosphere 2009b; 2011), RVC proposed to:

- Maintain permanent closure of the artificial channel between Salty Lagoon and Salty Creek.
- Continue to discharge treated water from the Evans Head Sewerage Treatment Plant (STP) into the creek upstream of Salty Lagoon for the medium term (i.e. next 15 years).

RVC also adopted recommendations to continue environmental monitoring at Salty Lagoon for an additional five year period (i.e. the PCM).

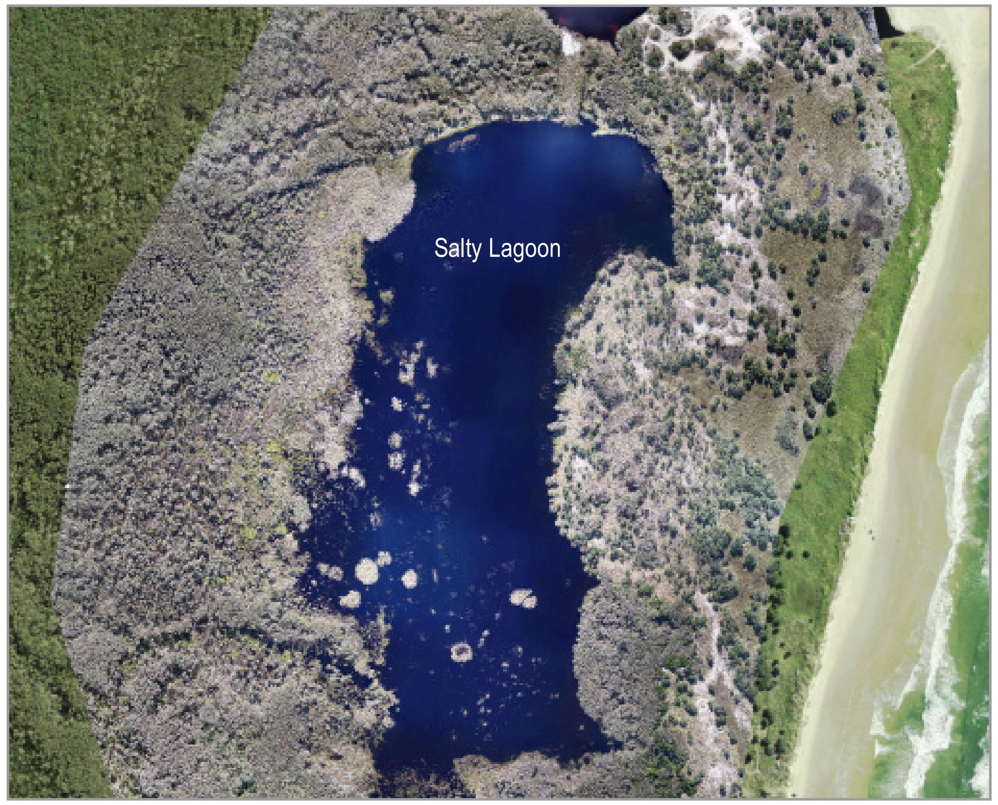
The objectives of the PCM are to:

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-term changes in the Salty Lagoon system in response to the channel closure.

The PCM program continued from the MPPC monitoring with a reduced frequency of site visits and a reduced overall suite of monitoring components (GeoLINK 2017); spanning from June 2017 to June 2022.

Salty Lagoon 2009:
Pre-closure of the artificial channel
(Salty Creek mouth closed)
Image source: Richmond Valley Council

Salty Lagoon 2013:
Approximately 1 year post-closure of the artificial channel
(Salty Creek mouth open)
Image source: Google Earth



Salty Lagoon 2017:
5 years post-closure of the artificial channel
(Salty Creek mouth open)
Image source: Richmond Valley Council

Salty Lagoon 2022
10 years post-closure of the artificial channel
(Salty Creek mouth open)
Image source: Nearmap

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Aerial Photographs of Salty Lagoon - Pre and Post Artificial Channel Closure

2. Water Quality

2.1 Introduction

Adequate water quality is important to the maintenance of ecosystem processes in aquatic systems, including Salty Lagoon. Previous monitoring of Salty Lagoon has highlighted issues with water quality such as high nutrient concentrations and rapid changes in conductivity and dissolved oxygen. Poor water quality in the past has led to fish kills, indicating ecosystem collapse (Hydrosphere 2009a). Water quality monitoring is the key aspect of the PCM program and the main method of assessing the health of the ecosystem and informing adaptive management responses.

A varied approach to water quality sampling involving the deployment and maintenance of permanent water quality monitors, discrete bimonthly sampling of surface waters and an adaptive management program comprised the water quality monitoring for the PCM. 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 PCM

Approach	*Sampling Type*	*Parameters*
Permanent water quality monitoring stations/loggers (PWQMS)	Physico-chemical	Temperature, conductivity, dissolved oxygen (DO), pH, turbidity, water level measured at 30-minute intervals
Bimonthly discrete sampling and adaptive management response sampling	Physico-chemical	Temperature, conductivity, dissolved oxygen (DO), pH, turbidity, secchi depth, redox
	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

Two permanent water quality monitoring stations (PWQMS) were in place for the duration of the PCM program, measuring water level, temperature, pH, conductivity, turbidity and dissolved oxygen (DO) concentration at 30-minute intervals. Each PWQMS was fitted with an YSI EXO 3 sonde and a HOBO water level logger. Data from the PWQMS was downloaded during bi-monthly site visits.

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 (29 events in total). An additional quality assurance (QA) replicate sample was collected from a randomly chosen site each event. The specific locations of all sites sampled are presented in **Table 2.2** and displayed in **Illustration 2.1**.

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

Site	*S 1*	*S 2*	*S 3*	*S 4*	*S 5*
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

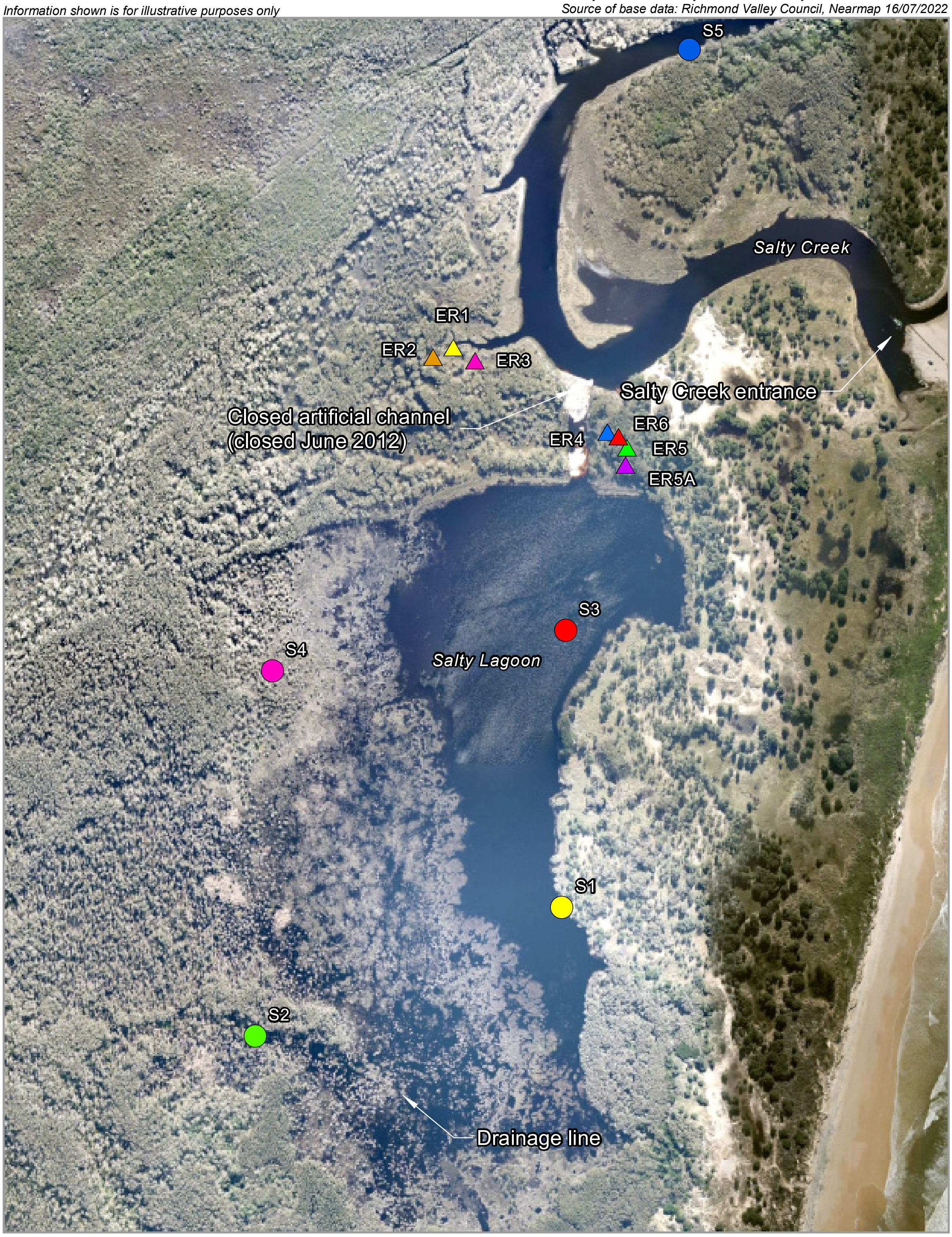
Physico-chemical water quality parameters in discrete surface water samples were measured with an HORIBA U-52 hand held water quality meter. Depth profiling of physicochemical parameters was undertaken at one metre intervals at sites where depth was sufficient to allow it. Discrete samples were collected in jars for analysis of chemical and biological parameters at the Coffs Harbour Laboratory (CHL).

2.2.3 Adaptive Management WQ Sampling

The PCM project also included an '*adaptive management response*'. The response process is described in detail in the *Post Closure Environmental Response Protocol* (GeoLINK 2017). Adaptive management water quality sampling never eventuated during the PCM project.

Drawn by: AB Checked by: RE Reviewed by: DSA Date: 06/12/2022
Source of base data: Richmond Valley Council, Nearmap 16/07/2022

Information shown is for illustrative purposes only



LEGEND

Water Quality Site	Erosion Monitoring Site
S1	ER1
S2	ER2
S3	ER3
S4	ER4
S5	ER5
	ER5A
	ER6

0 120

Location of Water Quality and Erosion Monitoring Sites

2.2.4 Guiding Values

Guiding values were developed to assist with the contextualisation of monthly water monitoring results, rather than as a measure of the health of the waterway. They also provide a yardstick, around which the adaptive management of Salty Lagoon can be discussed.

Guiding values for the MPPC monthly reports (revised in September 2012; GeoLINK 2012) were also used for the PCM. They were generated using pre-channel closure water quality data collected between April 2011 and September 2012. Guiding values were developed separately for Salty Lagoon and Salty Creek, and based on data collected from surface water at all sites. They incorporated all parameters measured as part of the MPPC and PCM.

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 dissolved oxygen 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 developed based on the above methodology 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)	1.6	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)	1.6	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 (GeoLINK 2017). Rainfall conditions, in combination with historical pollution, appear to have a had a greater impact upon water quality during the PCM than current discharge from the Evans Head STP (GeoLINK 2017). Monthly rainfall measurements during the PCM program are displayed in **Figure 2.1** and 12-month totals are presented in **Figure 2.2**. There were some notable weather events with significant impacts upon the water quality in Salty Lagoon. These were:

- A very dry period between July 2019 and December 2019.
- A very wet period between December 2020 and April 2021.
- A very wet period between October 2021 and March 2022.

In general, the rainfall was below average for the first half of the PCM and above average for the second half.

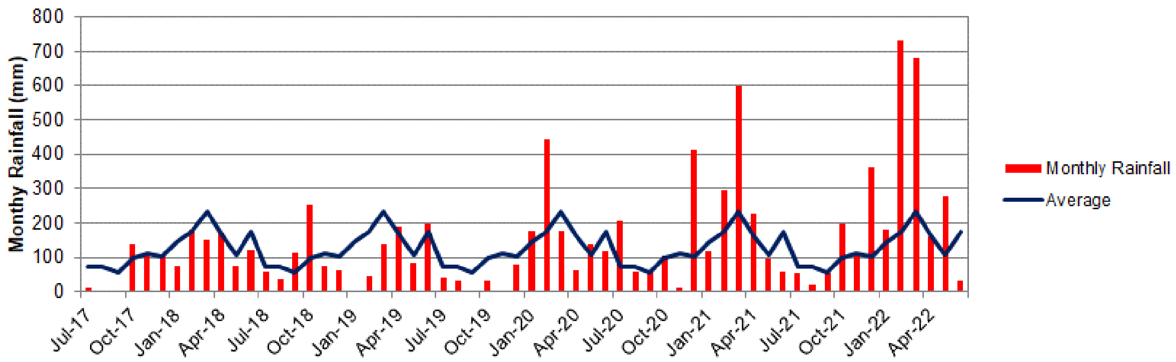


Figure 2.1 Monthly rainfall at the Evans Head BOM weather station for the extent of the project displayed against average monthly rainfall from the Woodburn BOM station (BOM 2022)

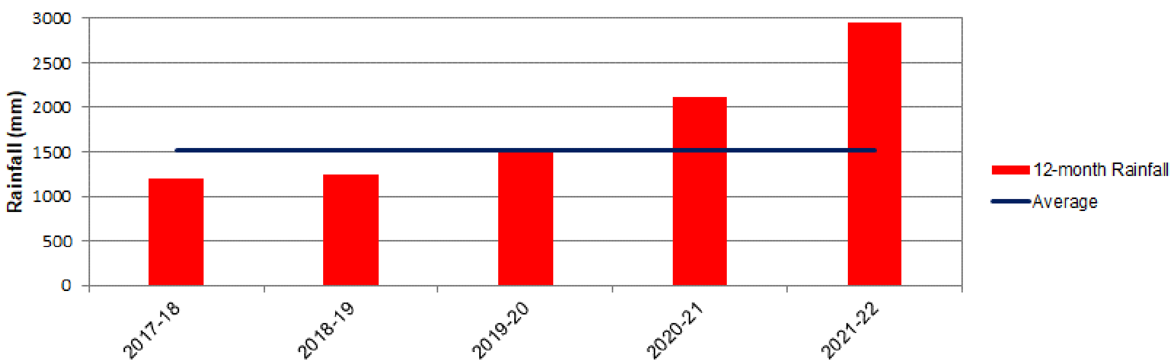


Figure 2.2 12-month rainfall (July – June) at the Evans Head BOM weather station for the extent of the project displayed against average annual rainfall (BOM 2022)

2.3.2 Permanent Water Quality Monitoring Stations

The combined results from the Salty Lagoon PWQMS and the Salty Creek PWQMS for the duration of the PCM are presented in **Appendix B**.

The PWQMS were fitted with YSI EXO sondes at the beginning of the PCM. This improved the reliability and accuracy of the logged data in comparison with the YSI Series 6 sondes utilised for the MPPC program. However, over the course of the PCM there were still a number of gaps in the data from the PWQMS. These are either:

- A large gap in 2017 while sensors were not maintained between the MPPC and PCM programs.
- Large gaps resulting from sonde or sensor failure.
- Large gaps resulting from battery failure.
- Gaps where erroneous data, occurring as a result of faulty sensors, have been highlighted within the dataset. These data have been removed from the presented data.

In total during the PMC, there were:

- 10185 (11.6 %) missed pH data points at the Salty Lagoon PWQMS.
- 2198 (2.5 %) missed temperature data points at the Salty Lagoon PWQMS.
- 10038 (11.5 %) missed electrical conductivity data points at the Salty Lagoon PWQMS.
- 14777 (16.9 %) missed turbidity data points at the Salty Lagoon PWQMS.
- 33107 (37.8 %) missed dissolved oxygen data points at the Salty Lagoon PWQMS.
- 10220 (11.7 %) missed water level data points at the Salty Lagoon PWQMS.
- 15485 (17.7 %) missed pH data points at the Salty Creek PWQMS.
- 3416 (3.9 %) missed temperature data points at the Salty Creek PWQMS.
- 7373 (8.4 %) missed electrical conductivity data points at the Salty Creek PWQMS.
- 10635 (12.1 %) missed turbidity data points at the Salty Creek PWQMS.
- 13739 (15.7 %) missed dissolved oxygen data points at the Salty Creek PWQMS.
- 6890 (7.9 %) missed water level data points at the Salty Creek PWQMS.

At the Salty Lagoon PWQMS, the key findings from the logged dataset include:

- Freshwater input from Evans Head STP does not maintain water levels in Salty Lagoon. Evaporation, groundwater drawdown and runoff into Salty Creek have a greater impact, leading to reducing water levels in Salty Lagoon during times of low rainfall.
- The salinity in Salty Lagoon is mostly low in the post channel closure environment. However, in the five years of the PCM program there were six occasions when saline water from Salty Creek flowed into Salty Lagoon after heavy rainfall, leading to brackish or saline conditions. In the drought conditions of late 2019 brackish water became strongly saline as a result of evaporation. In total, 42.4 % of PCM measurements fell into the freshwater (EC ≤ 1.5 mS/cm) range, 31.9 % of the measurements fell into the brackish (1.5 mS/cm < EC < 10 mS/cm) range and 25.6 % of the measurements fell into the saline (EC ≥ 10 mS/cm) range. High conductivity measurements were strongly associated with dry conditions. **Figure 2.3** clearly shows that in 2018-19 and 2019-20, the driest years of the PCM, that median, 75th percentile and maximum conductivity values at the Salty Lagoon PWQMS far exceeded the other years.

- Average water levels in Salty Lagoon are 1.78 mAHD and there is lower variability in water levels during wet years, indicating that Salty Lagoon drains into Salty Creek at a level of approximately 1.8 mAHD.
- Reverse flow from Salty Creek into Salty Lagoon happens when the entrance berm to Salty Creek is closed at a high level (> 1.8 mAHD).
- The key factors that influenced dissolved oxygen (DO) concentration in Salty Lagoon are:
  - 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. This effect is most notable in the diurnal patterns of DO concentrations, where DO increases during the daytime and falls at night.
  - 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.
- Although it is not apparent from the logged data, the water column in Salty Lagoon is often stratified with respect to DO concentration. The bottom of the water column can be hypoxic whilst the water at the surface is well oxygenated. This occurs most often when water levels are high and, therefore, is likely to occur with increasing regularity as a result of the closure of the artificial channel.
- The percentage of logged DO concentration measurements that are <1 mg/L has trended upwards during the PCM.
- Apart from the periods of saline water ingress and/or very low water levels, pH measurements remained relatively stable at the Salty Lagoon PWQMS. The median logged pH value for the PCM was 6.95.
- There is a relationship between water level in Salty Lagoon and the magnitude of daily temperature variation. When water levels are low, daily temperature variations can be up to 10 °C. This can have a large impact on the overall ecology of Salty Lagoon, particularly during hot, dry summers. Water temperature impacts upon a number of other parameters such as DO and microalgal concentrations.
- Logged turbidity measurements were consistently higher in the wetter years of the PCM. This contrasts with the MPPC results where turbidity was highest when water levels were low, due to wind driven resuspension of sediments.

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 **Appendix B**. Key findings from the Salty Creek PWQMS include:

- The most important factor affecting the water level, pH and conductivity in Salty Creek is the status of its entrance.
- The water column in Salty Creek is often distinctly stratified with respect to salinity, pH, dissolved oxygen and turbidity.
- Logged DO concentrations tend to be higher during periods of freshwater dominance and when water levels were low.
- Turbidity measurements from the Salty Creek PWQMS are generally low, with periods of greater turbidity following seawater ingress and heavy rainfall.

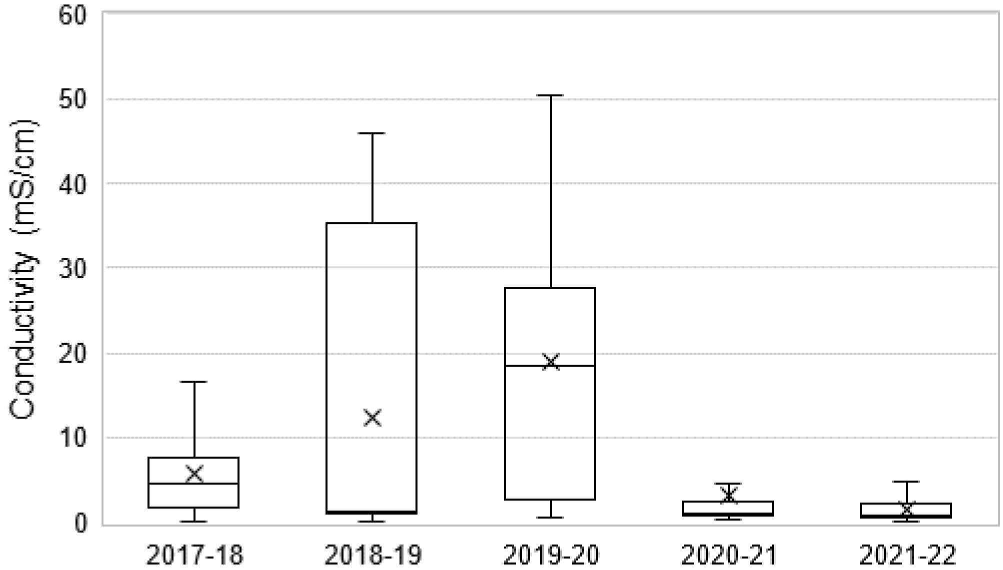


Figure 2.3 Box and whisker plots of logged EC measurements at the Salty Lagoon PWQMS by annual report period (outliers removed, inclusive medians)

Note: The boxes show the 25th percentile (bottom), mean (line across) and 75th percentile (top) values. The plots also show the median (X) and the maximum and minimum (whiskers) values.

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 (refer to **Appendix B** for box and whisker plot data analysis). No additional water quality samples were collected under the environmental response protocol during the PCM.

2.3.3.1 Nitrogen

Some of the factors that have been found to influence nitrogen concentrations in Salty Lagoon and Salty Creek include seawater ingress, historical pollution and rainfall runoff (GeoLINK 2017). Current effluent discharge from the Evans Head STP does not appear to be a factor that strongly influences nitrogen concentrations in Salty Lagoon, as the concentration of total nitrogen (TN) at S2 (located closest to the STP) is often lower than the concentration measured further downstream and the average TN and DIN concentrations at S2 for the PCM are lower than those downstream (**Figure 2.4** and **Figure 2.5**).

The TN concentrations from all sites collected during the PCM are displayed in **Figure 2.6**. The highest TN concentrations observed occurred during drought conditions in late 2018 and early 2020.

The highest TN concentrations during the MPPC also occurred in drought conditions. In general, TN concentrations have reduced after heavy rainfall and increased during extended dry periods. This indicates that nitrogen already in the Salty Lagoon system is a major contributor to elevated TN concentrations observed on occasion. Sources of nitrogen in the system include those stored in sediments, which may be elevated as a result of historical pollution, and those that occur as a result of the breakdown of organic matter. Death and breakdown of aquatic plants as a result of saline water incursion or drought conditions has been a common observation over the PCM and MPPC programs. Average and maximum TN concentrations were lower at all sites in the PCM compared with MPPC post closure period. Median TN concentrations were lower at all sites except S2 (**Figure C.2**).

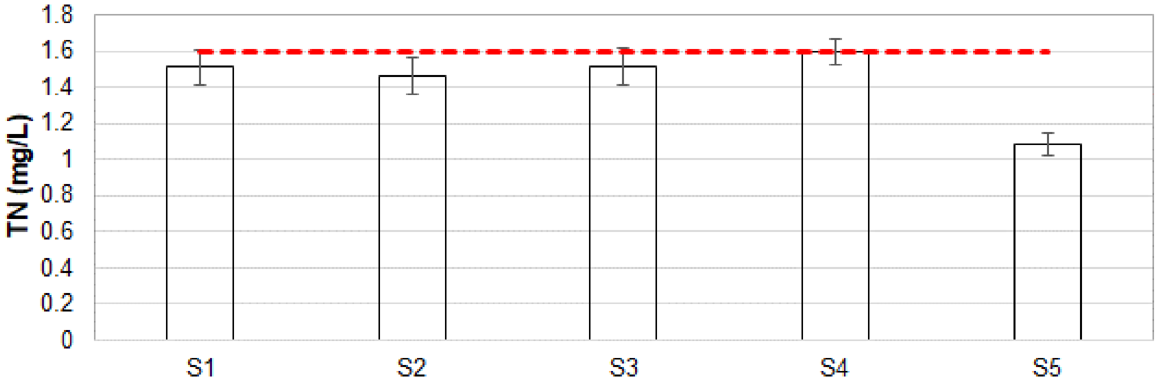


Figure 2.4 Average (±SE) TN concentrations at all sites for the PCM against the guiding value

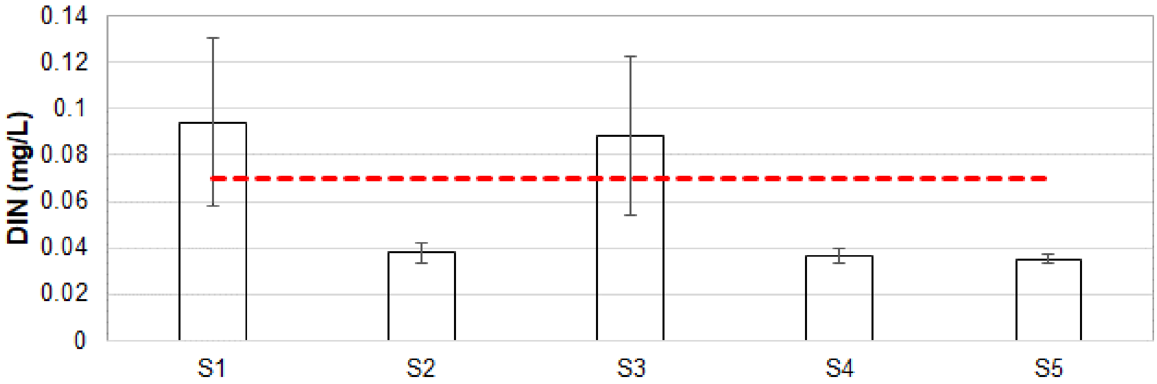


Figure 2.5 Average (±SE) DIN concentrations at all sites for the PCM against the guiding value

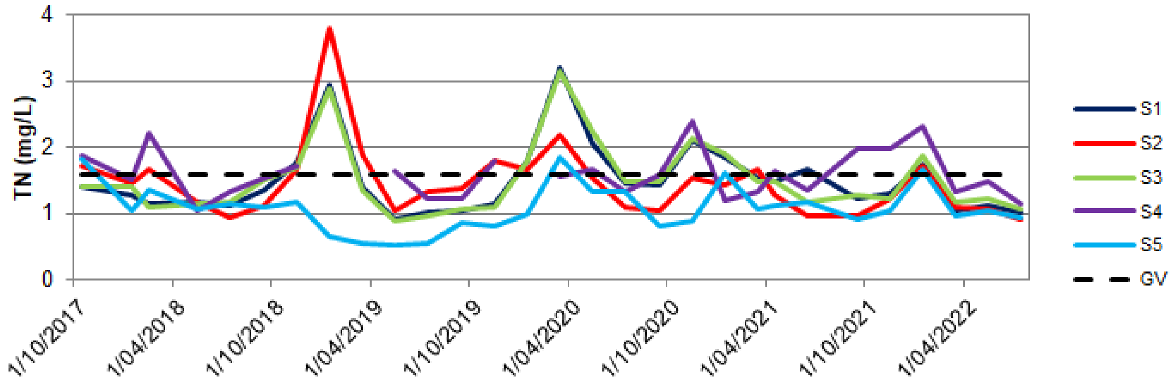


Figure 2.6 Time series of TN concentrations at all sites for the PCM project

The highest dissolved inorganic nitrogen (DIN) concentrations recorded during the PCM also occurred during drought periods (**Figure 2.7**). Median and maximum DIN concentrations recorded during the PCM were lower at all sites in comparison with MPPC post closure period and average DIN concentrations were lower at all sites except S1 and S3. While the overall average DIN concentrations increased in the period after channel closure the annual average DIN concentrations appear to be trending downwards in the open water (S1 and S3) of Salty Lagoon (**Figure C.1**).

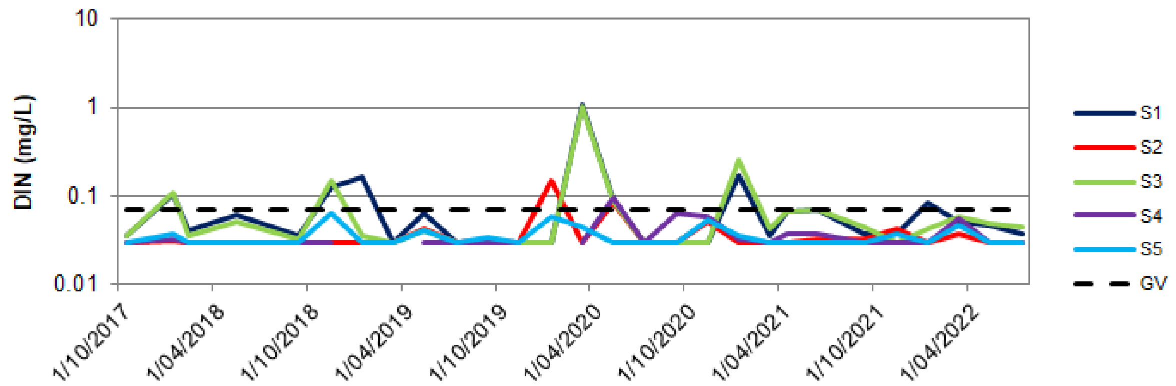


Figure 2.7 Time series of DIN concentrations at all sites for the MPC project

Spatial variability in the TN concentrations measured during the PCM was limited. However, there is a clear difference in the DIN concentrations measured in the open water of Salty Lagoon and those measured at the sites located to the west of Salty Lagoon. A much greater proportion of the total nitrogen is present as DIN at sites S1 and S3 (**Figure 2.5**).

2.3.3.2 Phosphorus

The highest total phosphorus and orthophosphate (bioavailable phosphorus) concentrations also occurred during drought conditions (**Figure 2.8**). Average total phosphorus and orthophosphate concentrations both increased in the MPPC post closure period at all the Salty Lagoon sites but reduced to below the pre closure average concentrations at all sites during the PCM project (**Figure C.3**, **Figure C.4**).

The data collected allows for some general observations:

- Site S2 is the site historically most influenced by discharged effluent from the Evans Head STP and has had the highest average TP and orthophosphate concentrations in all monitoring phases (**Figure 2.10**, **Figure 2.11**).
- Concentrations of phosphorus in Salty Lagoon were higher during the warmer months.
- TN and TP concentrations appear to have varied independently, except during drought conditions, indicating that the processes governing them are separate.
- For the majority of the results, the greater proportion of the total phosphorus 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. However, the relationship between available phosphorus and algal concentrations is cryptic.
- Phosphorus concentrations measured in Salty Creek have continued to reduce since channel closure (**Figure 2.19**, **Figure C.3**, **Figure C.4**).

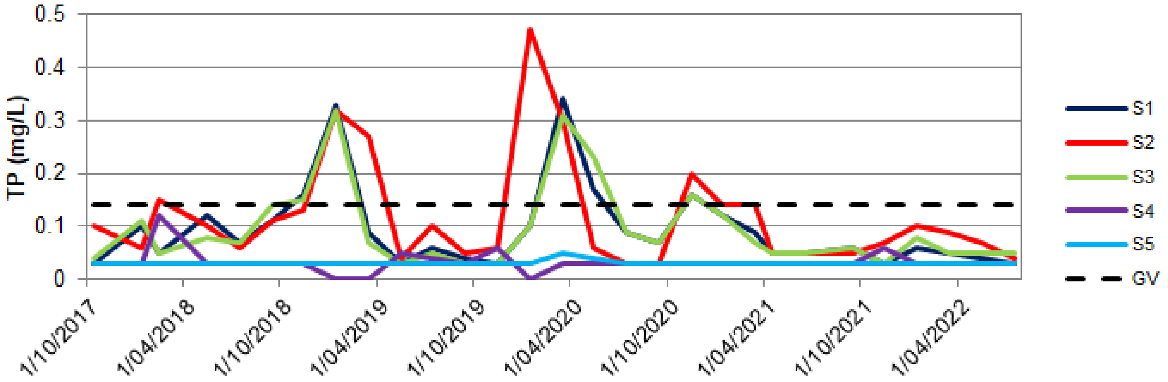


Figure 2.8 Time series of TP concentrations at all sites for the PCM project

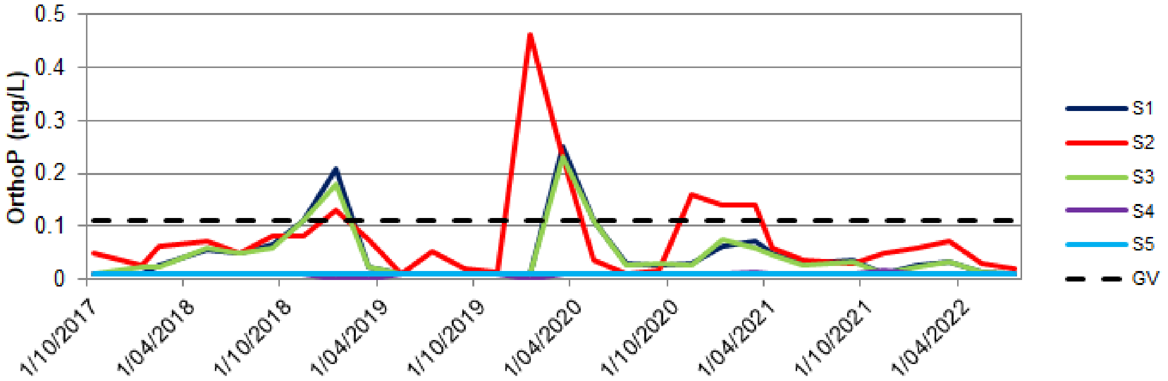


Figure 2.9 Time series of orthophosphate concentrations at all sites the PCM project

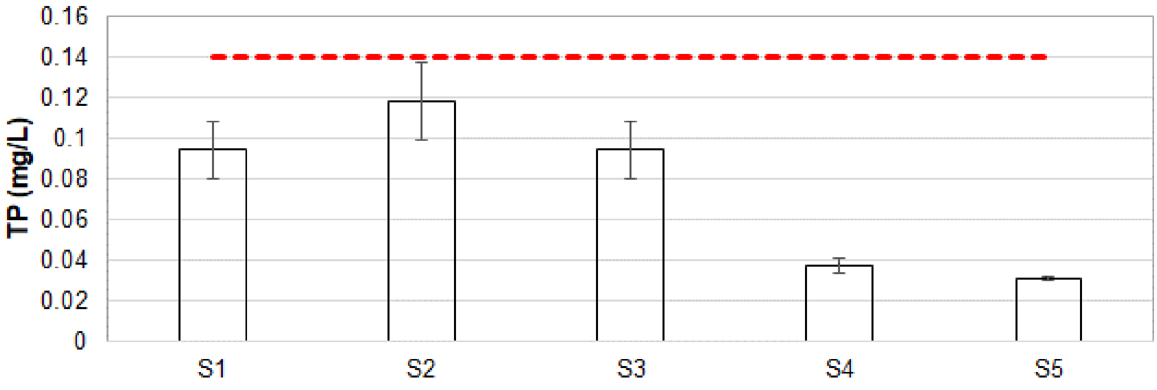


Figure 2.10 Average (±SE) TP concentrations at all sites for the PCM against the guiding value

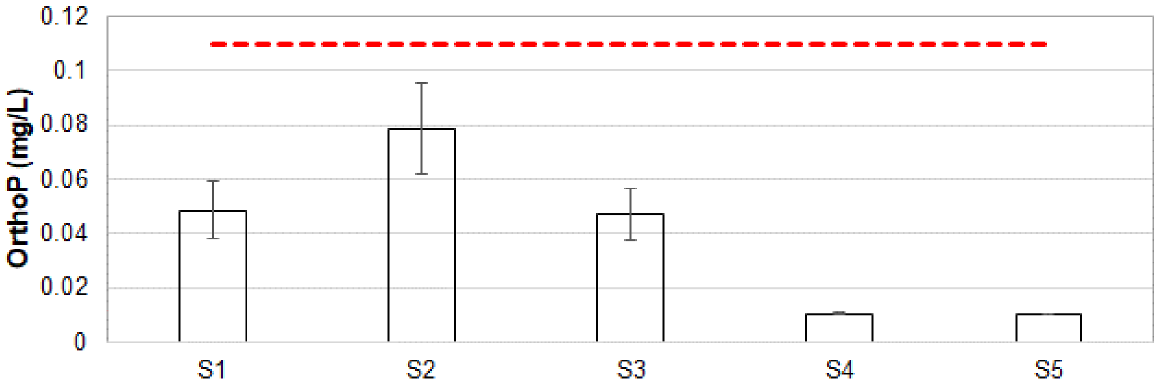


Figure 2.11 Average (±SE) orthophosphate concentrations at all sites for the PCM against the guiding value

2.3.3.3 Chlorophyll-a

Chlorophyll-a concentrations were highly variable during the PCM, fluctuating between below detection limits and large-scale algal blooms at all Salty Lagoon sites. The highest chlorophyll-a concentrations measured coincided with drought conditions, summer, and the highest nutrient concentrations (**Figure 2.12**). Average chlorophyll-a concentrations were above the guiding value at all Salty Lagoon sites (**Figure 2.13**).

Although spatial variability in chlorophyll-a concentrations during individual sampling occasions, overall there was little spatial variability in average concentrations of Salty Lagoon sites for the PCM. Concentrations in Salty Creek were typically lower than in Salty Lagoon. Average chlorophyll-a concentrations have increased at all sites in the post closure period (**Figure C.5**) and although the trends are less clear, it appears that the very high concentrations measured during drought periods are the major factor driving this change. However, it is possible that the more stable freshwater conditions are contributing to an overall stabilisation of the microalgal population in the water column.

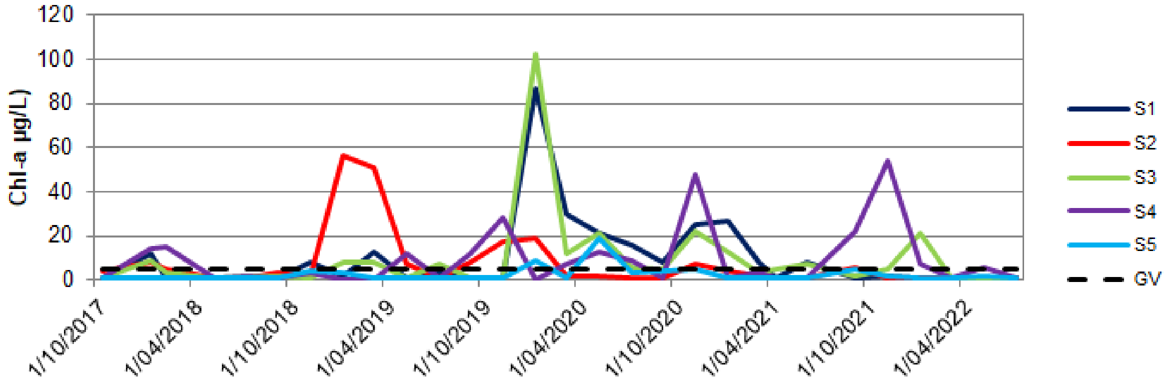


Figure 2.12 Time series of chlorophyll-a concentrations at all sites for the PCM project

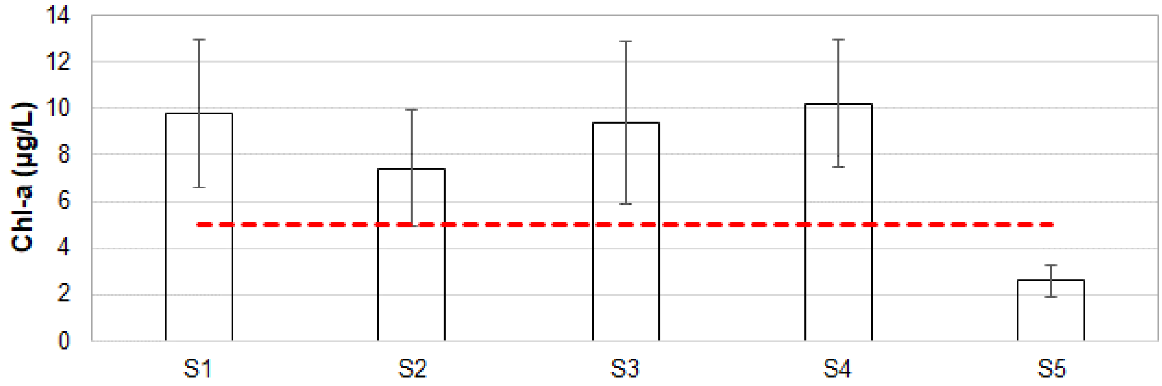


Figure 2.13 Average (±SE) chlorophyll-a concentrations at all sites for the PCM against the guiding value

2.3.3.4 Blue Green Algae

Blue green algae were regularly detected during the PCM after only been detected on two occasions during the MPPC. No patterns can be determined pre/ post closure in relation to blue green algae.

2.3.3.5 Faecal Indicator Organisms

There was a high level of variation in faecal indicator organism concentrations during the PCM (**Figure 2.14** and **Figure 2.15**). Spatial variability was evident with average concentrations at S2 and S4 higher than those measured in the open water of Salty Lagoon (**Figure 2.16**, **Figure 2.17**). This is the reverse of the trend observed during pre-closure monitoring.

Temporal variation at individual sites appears to have been mostly driven by rainfall and waterbird use of Salty Lagoon and Salty Creek. 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 strongly influencing the concentrations of faecal indicator organisms.

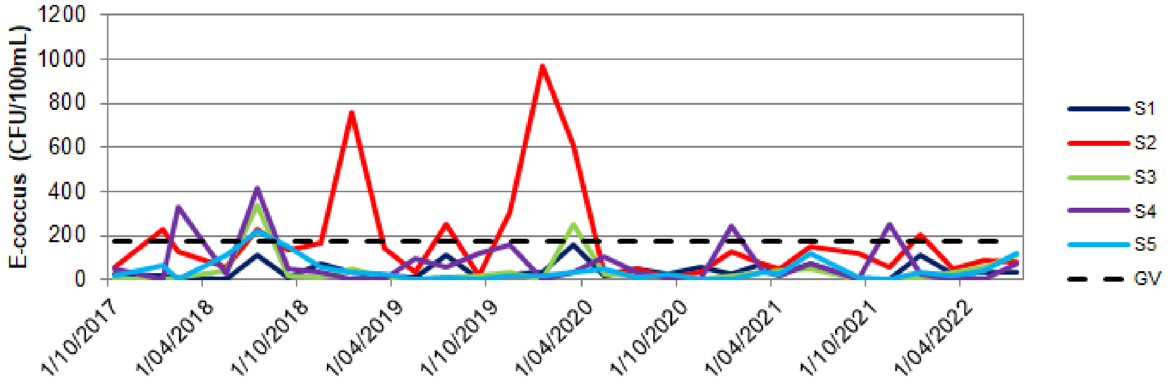


Figure 2.14 Time series of enterococcus concentrations at all sites for the MPPC project

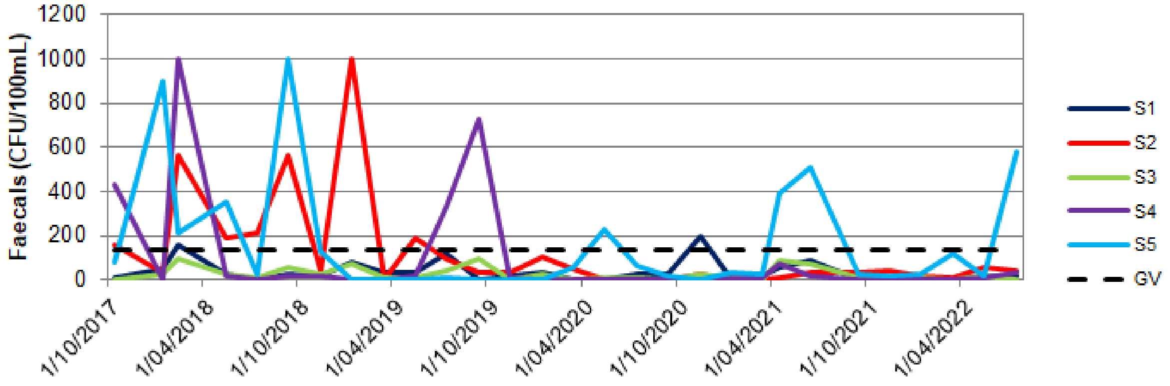


Figure 2.15 Time series of faecal coliform concentrations at all sites for the MPPC project

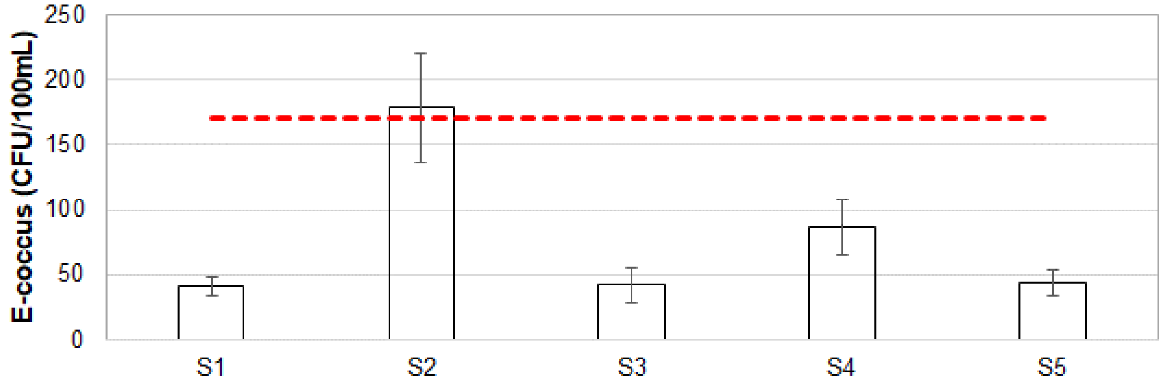


Figure 2.16 Average (±SE) enterococcus concentrations at all sites for the PCM against the guiding value

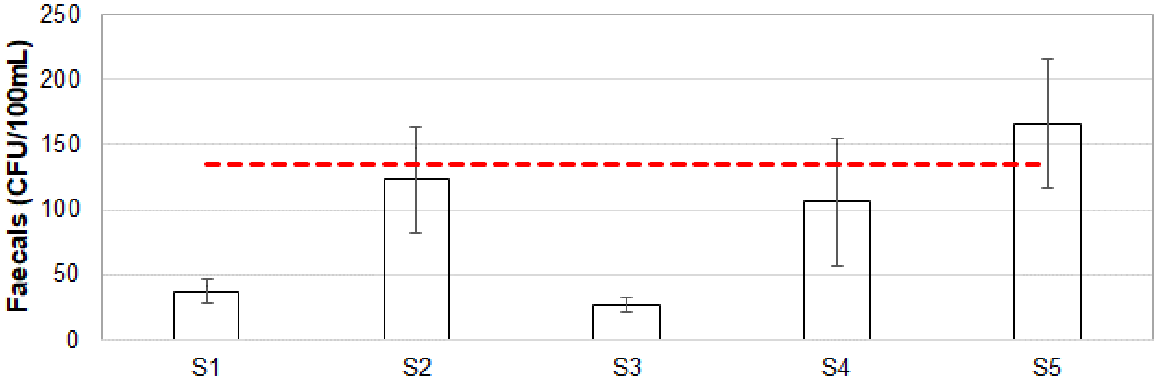


Figure 2.17 Average (±SE) faecal coliform concentrations at all sites for the PCM against the guiding value

2.3.4 STP Discharge Monitoring

The vast majority of results from the Evans Head STP comply with the licence conditions set by the NSW Environmental Protection Authority (EPA). The discharge from the Evans Head STP does not appear to increase the water levels in Salty Lagoon as there is usually a downward trend in water levels during dry times, even when levels are below the level of the overflow to Salty Creek.

In general, faecal coliform concentrations in discharged effluent are very low. 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 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.

The concentrations of TN in discharged effluent are generally two to four times higher than those measured at any site within Salty Lagoon. 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 2010b). It is also likely that dilution with unpolluted water from around the catchment contributes to this effect. Although average TN concentrations in the PCM are lower than the post closure period at all sites, 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.

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 and where phosphorus concentrations are highest. However, it is not likely that current phosphorus concentrations in discharged effluent are sufficient to maintain the phosphorus concentrations in the waters of Salty Lagoon. Hydrosphere (2010b) 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. The average concentrations of TP and orthophosphate measured during the PCM are lower at all sites than those measured in the post closure period, indicating that the Salty Lagoon ecosystem may be processing some of the stored phosphorus in the sediments over time.

2.3.5 Comparison against Rehabilitation Targets

Closure of the artificial channel was anticipated to have a dramatic effect on the hydrology and water quality of Salty Lagoon (Hydrosphere 2011). Alongside the general goal of improved water quality Hydrosphere (2010a and 2011) listed a number of anticipated benefits and changes resulting from channel closure. These followed on from an ecosystem response model (ABER 2010) and are as follows:

- More natural hydrology and salinity regime including higher water levels – 1.9 m AHD in Salty Lagoon for approximately 63% of the time.
- A reduced magnitude and rate of water level variation.
- Less frequent saline water ingress.
- Improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation reduced algal blooms and reduced potential for deoxygenation.
- A reduced water column algal biomass.
- Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.
- Less temperature variability.
- Reduced average and maximum pH values.
- Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.
- 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.
- Reduced probability of wind driven turbidity increases and no draining related turbidity spikes.
- Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.
- Poor water quality episodes around high-risk periods such as low water levels and high temperatures.
- Reduced TN concentrations and continued dominance of DON.
- Reduced severity of Salty Creek drawdown during draining events.
- Less protracted entrance opening of Salty Creek.

In general, the data indicates that many of the predicted changes are being realised but that some are not. The data from the post closure period are strongly affected by extreme weather events. There was no comparable weather scenario during the pre-closure period. This is important to consider in the context of considering changes to water quality and hydrological conditions.

A comparison of the results obtained during the PCM and the predicted changes to the Salty Lagoon environment follows.

More natural hydrology and salinity regime including higher water levels – 1.9 m AHD in Salty Lagoon for approximately 63% of the time.

This change has been realised, but to a slightly lesser extent than predicted. From January 2011 until channel closure in June 2012 the average water level at the Salty Lagoon PWQMS was 1.33 mAHD and the water level was >1.85 mAHD for approximately 2% of the time. The average water level for the period from the closure of the artificial channel until the end of the MPPC in June 2017 was 1.82

mAHD and the water level was >1.85 mAHD for approximately 64% of the time. For the PCM, the average water level was 1.78 mAHD and the water level was >1.85 for approximately 45 % of the time.

A reduced magnitude and rate of water level variation.

There has been a reduction in the variation of water level in Salty Lagoon. The difference between the 10th and 90th percentile water levels since the channel closure has reduced from 0.65 m to 0.47 m in the MPPC post closure period and 0.44 m in the PCM.

Less frequent saline water ingress.

This anticipated change has been realised. There were five incidences of saline water ingress into Salty Lagoon in the five years from closure of the artificial channel until the end of the MPPC and six in the five years of the PCM. In the 14 months prior to closure there were over 20. Since closure the average logged conductivity has reduced from 15.97 mS/cm in the pre closure environment, to 2.04 mS/cm in the MPPC post closure period and 8.28 mS/cm in the PCM.

Improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation reduced algal blooms and reduced potential for deoxygenation.

It is uncertain if the productivity of the benthic macroalgal assemblage has changed since the closure of the artificial channel. In the assembled data there are some positive indications. For example, the average logged DO concentrations at the bottom of the water column has increased during the PCM (from 4.63 mg/L MPPC pre closure and 3.84 mg/L MPPC post closure period, to 5.05 mg/L in the PCM). Phosphorus concentrations have reduced, particularly during the PCM (Figure 2.18, **Figure 2.19**). Turbidity has reduced (**Figure 2.20**) and the reduced incidence of saline water ingress has created a more stable environment for benthic macroalgae. However, there are also some negative indications in the data. For example, average DO concentrations at the surface of the water column have remained relatively stable (or reduced slightly) in the open water area of Salty Lagoon since channel closure (**Figure 2.21**) but nutrient concentrations have increased slightly (**Figure 2.22**).

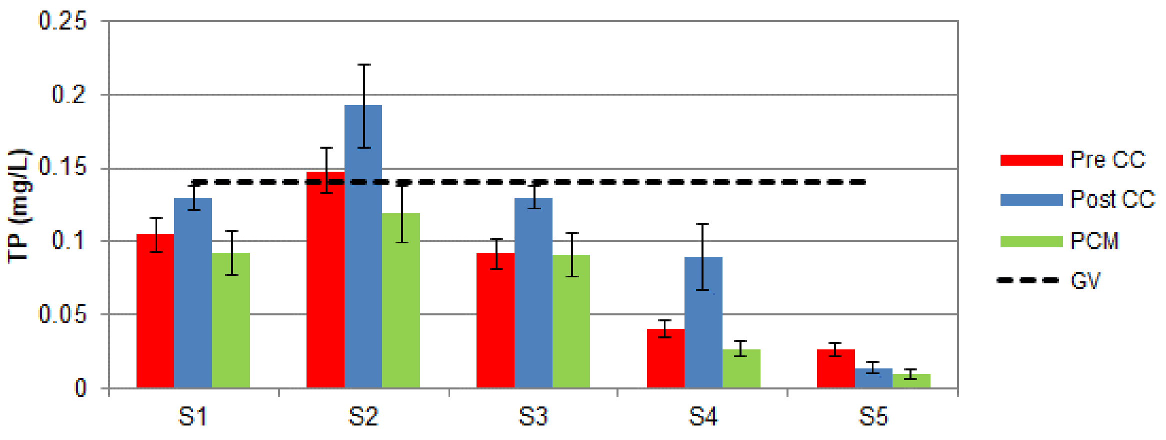


Figure 2.18 Mean ± SE TP concentrations at all sites in each of the monitoring periods

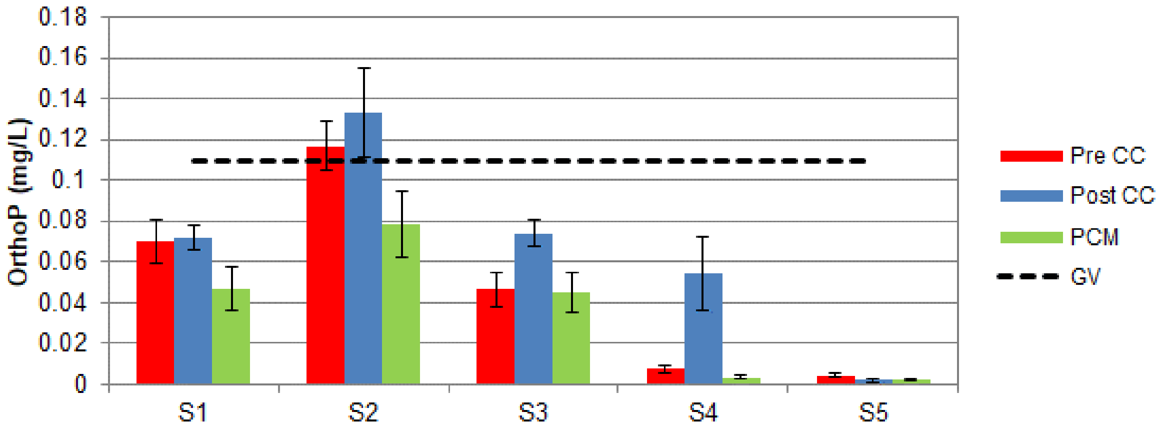


Figure 2.19 Mean ± SE orthophosphate concentrations at all sites in each of the monitoring periods

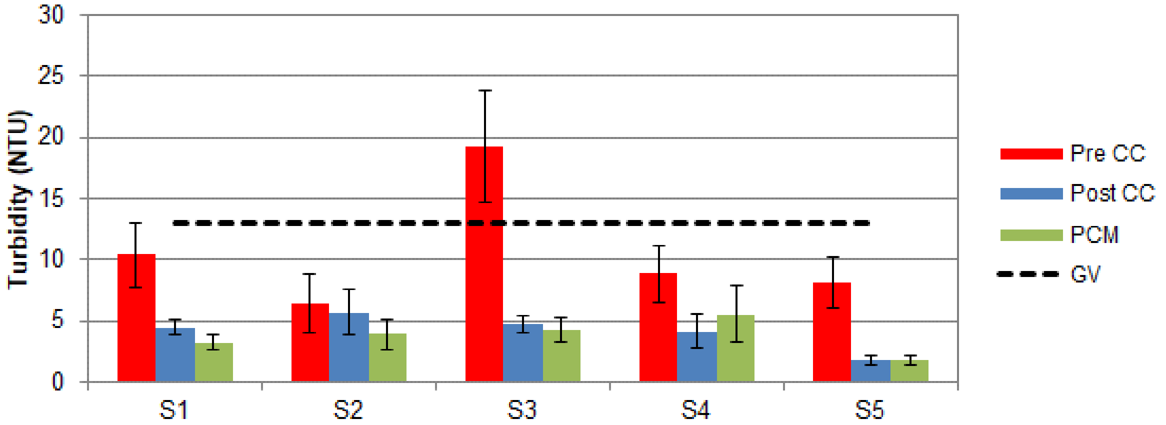


Figure 2.20 Mean ± SE turbidity concentrations at all sites in each of the monitoring periods

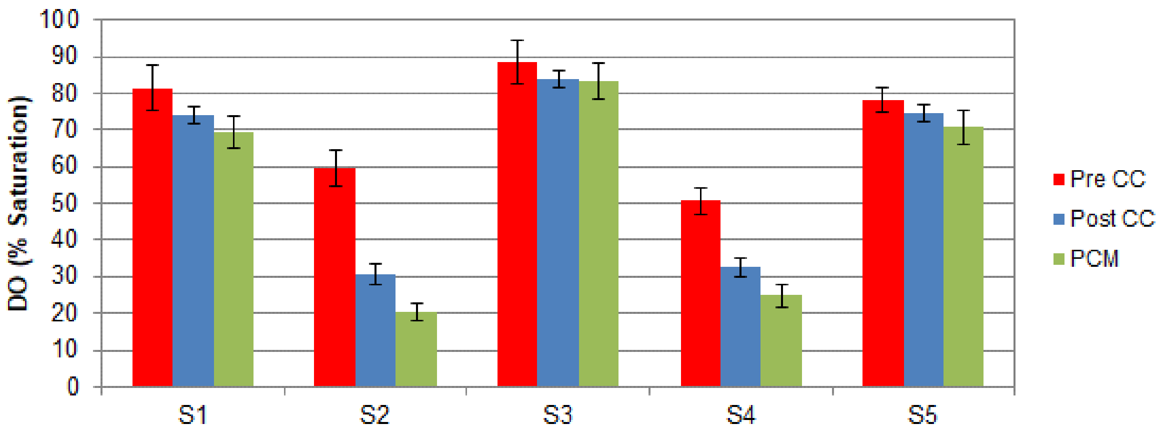


Figure 2.21 Mean ± SE DO concentrations at all sites in each of the monitoring periods

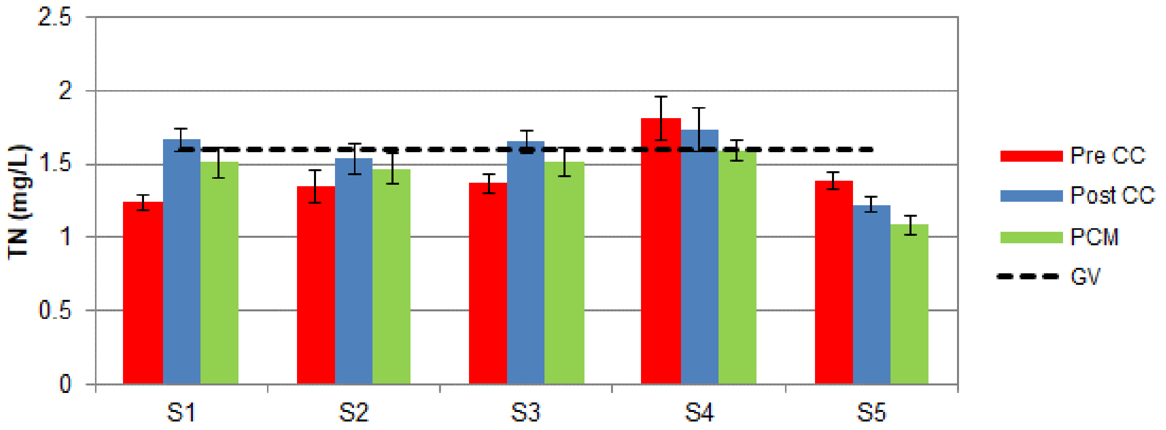


Figure 2.22 Mean ± SE TN concentrations at all sites in each of the monitoring periods

A reduced water column algal biomass.

This anticipated change has not been realised. Using chlorophyll-a as a proxy for water column algal biomass there has been a significant increase in algal biomass in the open water of Salty Lagoon (**Figure 2.23**). This is likely to be related to a number of other changes, including increased nutrient concentrations and a more stable freshwater environment.

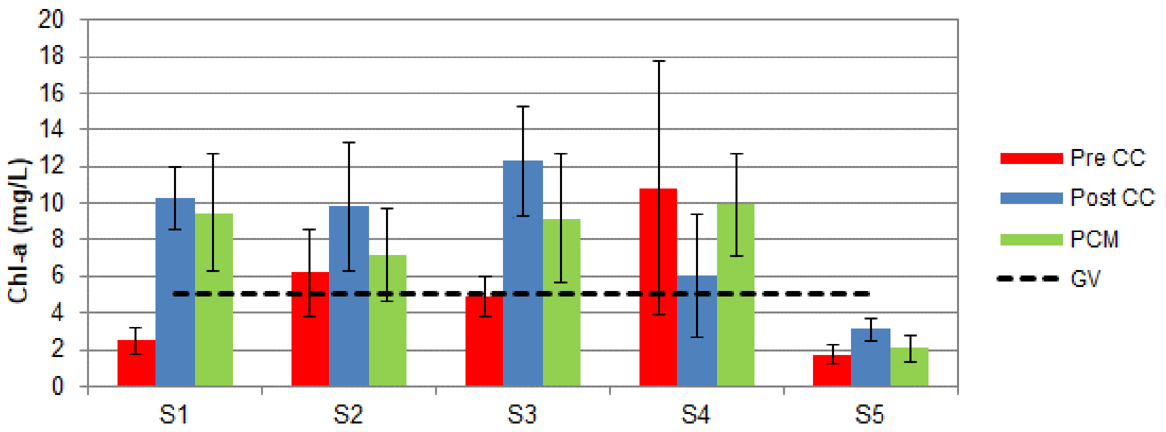


Figure 2.23 Mean ± SE chlorophyll-a concentrations at all sites in each of the monitoring periods

Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.

With respect to nutrient and microalgal concentrations there has not been an improvement in the average water quality conditions since the closure of the artificial channel. With respect to DO concentrations there has not been a significant change in the average condition since channel closure, although the likelihood of hypoxic (low DO) conditions has reduced. With respect to turbidity and pH there has been an improvement and stabilisation of water quality. The risk of poor water quality episodes in the period following the channel closure was realised during the drought conditions that persisted between October 2013 and March 2014, and January and March 2017, and again in late 2018 and late 2019. Poor water quality conditions resulted in algal blooms but have not resulted in a fish kill or other ecological incident.

Less temperature variability.

The logged data from the Salty Lagoon PWQMS indicates that this has been realised (see **Appendix B**). The standard error of the mean for temperature at the Salty Lagoon PWQMS reduced from 0.021 in the MPPC pre closure period to 0.012 in the MPPC post closure period and 0.16 in the PCM period. However, the difference between the 10th and 90th percentile logged temperatures has increased slightly since the closure of the artificial channel (from 11.78 °C in the pre closure period, to 12.35 °C in the MPPC post closure period, to 12.09 in the PCM period °C).

Reduced average and maximum pH values.

This prediction has not been fully realised. There has been a significant reduction in the average measured surface water pH at sites S2 and S4 since channel closure during both MPPC and PCM periods, but increases at S1 and S3 (**Figure 2.24**). Since closure of the channel there have been reduced incidences of the high pH maxima that occurred with seawater ingress prior to closure and there has been less variability in the pH results in surface waters.

Prior to channel closure the average logged pH at the Salty Lagoon PWQMS was 6.88 with a 90th percentile value of 7.42 and a 10th percentile value of 6.34. From channel closure until the end of the MPPC in June 2017 the average logged pH increased to 7.02 with a 90th percentile value of 7.40 and a 10th percentile value of 6.4. During the PCM the average logged pH was 7.08, the 90th percentile value was 7.63 and the 10th percentile value was 6.49.

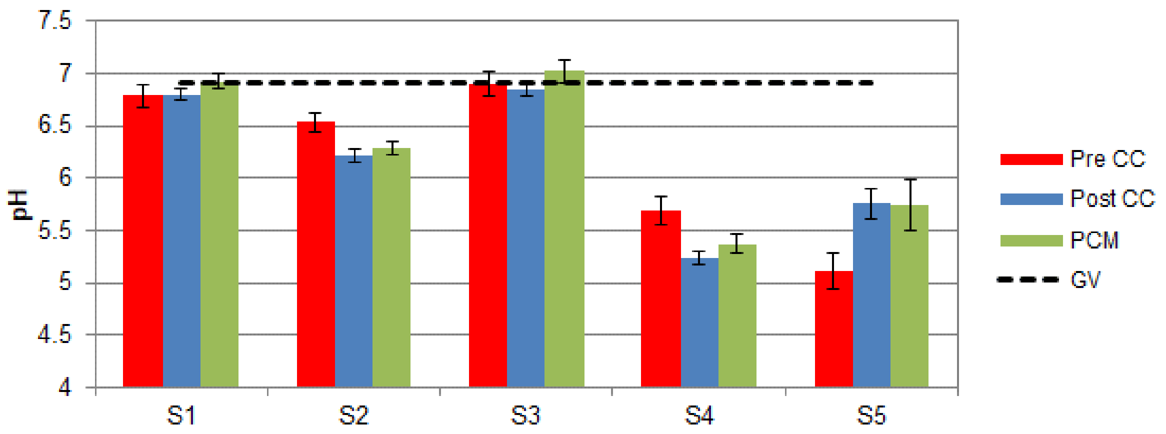


Figure 2.24 Mean ± SE pH at all sites in each of the monitoring periods

Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.

This prediction has not been fully realised. The DO concentrations in surface waters have not increased since channel closure (**Figure 2.21**), although they have not significantly reduced at the open water sites (S1 and S3) either. At sites S2 and S4 there has been a significant reduction in the DO concentrations measured since the closure of the artificial channel. However, this is thought to reflect the natural conditions at these sites and probably reflects the more natural hydrological regime since channel closure.

While regular periods of low DO concentrations at the bottom of the water column measured at the Salty Lagoon PWQMS have occurred on occasion in the MPPC post channel closure and PCM monitoring periods, the dramatic DO crashes that were associated with fish kill events prior to channel closure have not eventuated. In the available logged data from the PCM period, extended periods of low DO concentrations are often associated with saline water ingress from Salty Creek.

Diurnal variation in DO concentrations is strongly evident in the PCM data from the Salty Lagoon PWQMS (**Appendix B**).

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.

These anticipated changes have been realised to an extent and provide a good insight into the DO patterns that have been observed since channel closure. Persistent low DO concentrations at sites S2 and S4, particularly since channel closure (**Figure 2.21**) are likely to be widely related to the BOD of the rich organic sediments at these sites, along with the naturally low DO runoff from the catchment upstream of these sites. Also, although the pattern is not entirely clear, maximum daily DO concentrations in the summer months have tended to be lower than the winter months in both the PCM and post closure MPPC monitoring periods.

Reduced probability of wind driven turbidity increases and no draining related turbidity spikes.

This anticipated change has been realised. Turbidity has reduced significantly at S1 and S3 since channel closure (**Figure 2.20**). Also, there have been no draining related turbidity spikes in Salty Lagoon since channel closure. Finally, wind driven turbidity increases were not recorded in the PCM period, with the exception of the periods where water levels were very low in early 2019 and early 2020.

Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.

This prediction has been realised to a degree, with lower average TP and orthophosphate concentrations at all sites in the PCM compared to other monitoring periods (**Figure 2.18** and **Figure 2.19**). Additionally, although there is still a fairly high degree of variation in phosphorus measurements during the PCM, the lowest annual average phosphorus measurements occurred in the later part of the PCM. Furthermore, outside of drought conditions, TP and orthophosphate concentrations mostly remained low at all sites during the PCM.

Poor water quality episodes around high-risk periods such as low water levels and high temperatures.

This predicted risk has been realised. During the summer months of 2018/2019 and 2019/2020 water quality became very poor when water levels were at extreme lows and temperatures were very high. There are a number of factors that lead to poor water quality scenarios during periods of low water levels. These are:

- Existing nutrients concentrating as a result of water loss to evaporation.
- Increased temperature variation and increased daily maximum temperatures due to reduced overall volume of water.
- Increased algal concentrations and increased frequency of algal bloom conditions resulting from increased nutrient availability and increased temperatures.

- Increased turbidity resulting from wind driven resuspension of sediments and increased algal concentrations.
- Reduced minimum DO concentrations due to night-time respiration of increased algal concentrations.

Reduced TN concentrations and continued dominance of DON.

This predicted reduction in TN concentrations has not been realised to date (Figure 2.22). However, the extreme dry conditions that have characterised a large proportion of the post closure period have clearly contributed to higher average total nitrogen concentrations.

The predicted continued dominance of DON as the major form of nitrogen in samples has continued post closure of the artificial channel, and at S2 and S4 the proportion of TN as DON has increased in the post closure period (**Figure 2.25**).

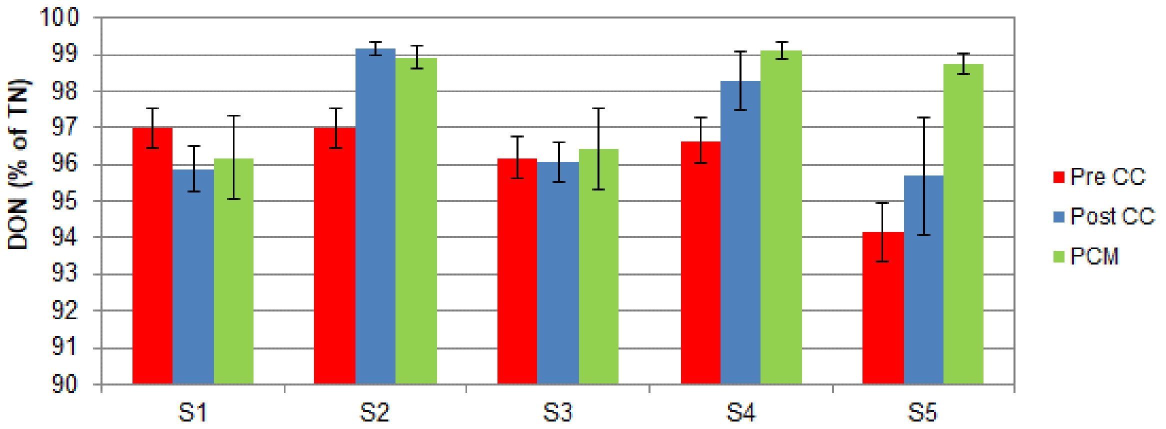


Figure 2.25 Mean ± SE DON concentrations as a percentage of TN at all sites before and after channel closure

Reduced severity of Salty Creek drawdown during draining events.

This prediction has not been realised. The maximum, 98th and 95th percentile values for drawdown over one hour at the Salty Creek PWQMS were all higher in the PCM than during the MPPC pre closure or post closure periods (**Table 2.4**). The maximum drawdown occurred on 10 February 2020 in extreme conditions. Nearly 400 mm of rain fell in the week leading up to the entrance opening event and the highest water level recorded during the PCM was collected at the Salty Creek PWQMS. There were also other events during the PCM with drawdowns greater than those recorded in the MPPC, for example on 14 December 2020 and 24 April 2018 (maximum drawdowns 59 cm/h and 25 cm/h respectively).

Table 2.4 Summary of drawdown events from the Salty Creek PWQMS

	Drawdown over 1 hour (cm)		
Statistic	***Pre CC***	***Post CC***	***PCM***
Max Drawdown	13.7	15.4	63.9
98th % Drawdown	2.2	1.2	3.0
95th % Drawdown	1.1	0.5	1.4

Less protracted entrance opening of Salty Creek.

This anticipated change has not been consistently realised. Although it is difficult to assess the change due to differences in the conditions that cause entrance opening and closing there does appear to have been a change in the dynamics of the entrance and the trends of opening and closing.

In the PCM period Salty Creek has opened on several occasions. The period of time that the open entrance has remained tidal has tended to be short, with the exception of a two scenarios where tidal movements persisted for approximately 1 month.

The minimum level of Salty Creek during the pre closure period was 0.963 mAHD and the 2^{nd} percentile level was 1.0 mAHD. In the MPPC post closure period the minimum and 2^{nd} percentile levels were higher, 1.099 mAHD and 1.185 mAHD respectively. However, in the PCM the trend was reversed, with a minimum level of 0.702 mAHD and a 2^{nd} percentile level of 0.831 mAHD. These figures indicate that the entrance to Salty Creek has been opened to a greater extent in the PCM period.

The entrance to Salty Creek has been increasingly stable since closure. In the period from March 2011 until channel closure in July 2012, the entrance opened 17 times. In the five years from channel closure until the end of the MPPC the entrance opened a total of 39 times, approximately half as frequently. During the five years of the PCM Salty Creek entrance opened approximately 31 times, less frequently again.

3. Aquatic Weeds

3.1 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 permanently freshwater system. To assess the response of aquatic vegetation to the changes and to provide a mechanism for adaptive management of aquatic weeds a regular survey was undertaken as part of the MPPC program and continued as part of the PCM. Incidental observations of aquatic weeds noted during the PCM bi-monthly site inspections are also recorded.

3.2 Methods

Aquatic weeds were monitored on a seasonal basis across all seasons except winter. 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 hand-held GPS unit and the aerial extent of the weed population estimated and recorded. Plants that could not be identified in the field were sampled and transported back to the laboratory for identification.

A detailed description of methods and transects surveyed each season is provided in the respective annual monitoring report for that year (GeoLINK 2018a; 2019a; 2020; 2021a; 2022).

3.3 Results

A total of 29 aquatic plant taxa were observed during the aquatic weed surveys during the PCM program (**Table 3.1**). Three types of native aquatic plant sometimes regarded as nuisance plants have been encountered. These were blue green algae (BGA, various species), Pacific Azolla (*Azolla pinnata* and *A. filiculoides*) and Duckweed (*Lemna sp*.).

BGA were only observed once during an aquatic weed survey but were detected in several water samples during the PCM. Pacific Azolla and Duckweed have been encountered at varying densities to the west of Salty Lagoon, particularly around water quality site S2. The abundance of these two plants 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.

There were no notable aquatic weeds observed during the PCM. An individual species of introduced plant, Cape Waterlily (*Nymphaea capensis*) was identified, but this is not a weed of concern. Its occurrence in Salty Lagoon is attenuated by the occasional saline water ingress.

Table 3.1 List of all Aquatic Plant Species Detected During Aquatic Weed Surveys and an Assessment of Abundance

Species Name	***Common Name***	***Survey***														
		Spr '17	***Sum '18***	***Aut '18***	***Spr '18***	***Sum '19***	***Aut '19***	***Spr '19***	***Sum '20***	***Aut '20***	***Spr '20***	***Sum '21***	***Aut '21***	***Spr '21***	***Sum '22***	***Aut '22***
Alternathera denticulata	Lesser Joyweed														UC	
Hydrocotyle verticillata	Shield Pennywort	C	C	C	C	C				UC	C	UC	C	C	C	C
Enydra fluctuans	Buffalo Spinach	C	C	C	C	UC	UC	UC		UC	C	UC	C	UC	UC	C
Lobelia anceps	Angled Lobelia		UC												UC	
Ceratophyllum demersum	Hornwort		UC											VC	VC	VC
Machaerina articulata	Jointed Twigrush	UC	UC		UC	C	UC	UC		UC	UC	UC	UC	UC		UC
Machaerina sp.	A Rush	VC	C	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC
Cyperus exaltatus	Giant Sedge	UC										UC				
Cyperus difformis	Dirty Dora	C	UC	C	C	VC	C									
Cyperus lucidus	Leafy Flat Sedge										UC					
Cyperus polystachyos	Bunchy Sedge										C	C	UC	C	UC	UC
Eleocharis acuta	Common Spike Rush					UC					UC			UC		UC
Fimbristylis ferruginea	Rusty Sedge												UC	UC		
Gahnia sieberiana	Red-fruit Saw-sedge	C	UC	UC	VC	VC	C	UC	C	C	VC	UC	C	C	UC	C
Shoenoplectus validus	River Club-rush	VC	VC	VC	VC	VC	VC	C	C	C	VC	C	VC	VC	VC	VC
Shoenoplectus mucronatus	Marsh Club-rush			UC												
Juncus krausii	Sea Rush	UC	C	UC	UC	UC	UC	VC	VC	C	C	C	C	VC	UC	UC
Triglochin striata	Streaked Arrowgrass										UC					
Lemna sp.	Duckweed	UC	UC	UC	C	C				C	UC	UC	C		C	UC
Utricularia spp.	Bladderwort	VC	C	C	VC	C				UC	UC	UC	VC			
Nymphoides indica	Water Snowflake	UC		UC								UC	UC	UC	UC	UC
Nymphaea capensis^	Cape Waterlily				UC	UC				UC				UC		
Bacopa monnieri	Water Hyssop	UC	UC	UC	C	VC	VC	C	C	VC	VC	C	VC	VC	C	C
Paspalum vaginatum	Saltwater Couch	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	UC	UC
Phragmites australis	Common Reed	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	VC	C	VC	VC

Species Name	Common Name	Survey														
		Spr '17	Sum '18	Aut '18	Spr '18	Sum '19	Aut '19	Spr '19	Sum '20	Aut '20	Spr '20	Sum '21	Aut '21	Spr '21	Sum '22	Aut '22
Azolla filiculoides	Pacific Azolla	UC	UC	UC	VC	UC							VC	C	C	C
Typha orientalis	Cumbungi	VC	VC	VC	VC	C	C	C		UC	UC	C	C	VC	VC	VC
Enteromorpha sp.	Enteromorpha	C	VC	C	C	VC	VC	VC	VC	UC						
Various	Blue Green Algae														VC	

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

3.4 Discussion

The aquatic weed surveys did not detect any significant aquatic weeds. Despite this, the risk of weed invasion into Salty Lagoon remains.

The aquatic plant community in Salty Lagoon was less diverse and variable during the PCM than during the MPPC. This is a result of the lessened opportunities for salt tolerant plants, such as Mangroves, Sea Purslane, Bead Weed and Seablight, to recruit and the more stable and higher water levels.

There were several species of plants observed during the PCM that were not observed during the MPPC. These were:

- *Triglochin striata* (Streaked Arrowgrass).
- *Fimbristylis ferruginea* (Rusty Sedge).
- *Eleocharis acuta* (Common Spikerush).
- *Cyperus polystachyos* (Bunchy Sedge).
- *Cyperus lucidus* (Leafy Flat Sedge).
- *Alternanthera denticulata* (Lesser Joyweed).

Interestingly, most of these plants are commonly associated with brackish environments, and recruited after environmental conditions resulted in persistent brackish or saline environments.

The targeted weed surveys, in addition to incidental observations made during normal bi-monthly sampling, have been a cost-effective way to address the continuing risk of aquatic weed invasion and to assess vegetation changes over a relatively short time scale.

3.4.1 Comparison against Rehabilitation Targets

With respect to aquatic plant life there was one relevant predicted change and one risk identified prior to the start of the MPPC. The predicted change to a freshwater dominated, more robust, more diverse aquatic ecology has been consistently realised with respect to the aquatic plants identified during aquatic weed surveys. There have been a number of specialist freshwater plants observed since the closure of the artificial channel that were not observed in the pre closure surveys. The risk of aquatic weed invasion has not been realised during the MPPC or PCM programs. There have been no significant freshwater weed species observed since the closure of the artificial channel.

4. Erosion Monitoring

4.1 Introduction

An eroding head-cut to the east of the infilled artificial channel was 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 2015). In the final years of the MPPC it advanced approximately 20 m towards Salty Lagoon, effectively eroding a channel that risked hydraulically connecting Salty Lagoon and Salty Creek at much lower water levels than planned. Had this eventuated, the eroding channel had potential to reverse the work done to restore the freshwater values of Salty Lagoon.

NSW National Parks and Wildlife Service (NPWS) undertook initial remediation in late 2020 through creation of a rock, geofabric and sand spillway at the northern end of the channel 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. The spillway was damaged again during floods in March/April 2022. It had not been repaired at the conclusion of the PCM, however the spillway is on NPWS assets register and repair to the structure was scheduled in August 2022 (Craig Connolly, RVC, pers. comms, 26/07/2022). The spillway has been designed below 1.8 m AHD and functions as a focal drainage point for water moving between Salty Lagoon and Salty Creek.

4.2 Methods

A series of six monitoring stations, three at the impact site and three at a reference 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 4.1** and **Illustration 2.1**.

The stations were set up in July 2017 at the head-cut (Stations ER4, ER5 and ER6), with reference 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 4.1 Type and Locations (WGS84) of Erosion Monitoring Sites

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

4.3 Results

The head-cut at the impact site advanced significantly during the PCM. The progression of the erosion towards (and in some cases past) the monitoring pegs at all six monitoring sites is displayed in **Figure 4.1**.

At site ER5, the most easterly of the erosion sites, the head-cut progressed more than 50 m towards Salty Lagoon during the PCM. 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 was relatively small in comparison, but still greater than head cut progression at the reference sites. The majority of the progression at each of the impact sites happened after periods of very heavy rainfall, coinciding with flooding. The maximum measured progression of erosion at the reference sites during the PCM was 3.05 m at ER2.

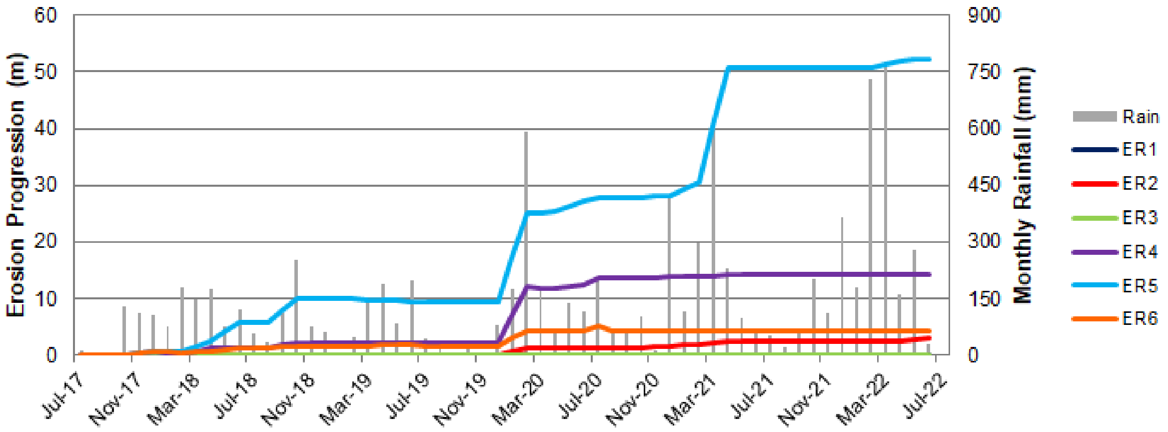


Figure 4.1 Measured erosion progression at all six sites plotted against monthly rainfall (BoM 2022)

4.4 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 52.25 m during the PCM period but the lengthening of the eroding channel was much further. The advance measured at the reference sites was minor and a lesser advance was measured at the other impact stations.

Without remediation of the erosive head-cut and channel between Salty Creek and Salty Lagoon, a completely new channel would 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.

5. Assessment of Closure Effectiveness

5.1 Assessment of Closure Effectiveness

The primary purpose of the MPPC and PCM program is to confirm prediction that closure of the artificial channel will result in an overall improvement to the ecological and cultural values of Salty Lagoon. A summary of the predicted major changes to the Salty Lagoon system and the combined MPPC/ PCM findings are provided in **Table 5.1**. Collectively the outcomes of the MPPC and PCM programs indicate that the closure of the artificial channel has been successful, as:

- The Salty Lagoon system has continued to move towards a predominantly freshwater lagoon system, with the monitoring recording relatively stable water quality conditions.
- Many of the predicted changes are occurring, including positive changes such as a more natural hydrology and salinity regime; reduced magnitude and rate of water level variation; less frequent saline water ingress; and reduced risk of fish kill.
- While other monitoring attributes have recorded no clear trend or negative trends, the results indicate overall improved ecological health at Salty Lagoon.

Table 5.1 Predicted Major Changes to the Salty Lagoon System and Collective Outcomes of the MPPC and PCM Programs

Predicted Major Changes to System	*Summary of MPPC and PCM Findings*
More natural hydrology and salinity regime including higher water levels – 1.9 m AHD for approximately 63% of the time.	Positive Outcome - this prediction has been realised.
A reduced magnitude and rate of water level variation.	Positive Outcome - this prediction has been realised.
Less frequent saline water ingress.	Positive Outcome - this prediction has been realised.
Improved productivity of the benthic microalgal assemblage resulting in nutrient assimilation reduced algal blooms and reduced potential for deoxygenation.	Unclear Outcome - it is uncertain if the productivity of the benthic macroalgal assemblage has changed since the closure of the artificial channel.
Reduced water column algal biomass.	Negative Outcome - this prediction has not been realised.
Improved water quality generally with a risk of poor water quality episodes in the period immediately following the channel closure.	Variable Outcome - with respect to nutrient and microalgal concentrations there has not been an improvement in the average water quality conditions since the closure of the artificial channel. With respect to turbidity and pH there has been an improvement and stabilisation of water quality. The risk of poor water quality episodes following the channel closure has been realised during drought conditions. Poor water quality conditions resulted in algal blooms but have not resulted in a fish kill or other ecological incident.
Less temperature variability.	Positive Outcome - this prediction has been realised.
Reduced average and maximum pH values.	Positive Outcome - this prediction has been realised.
Generally higher DO concentrations with a reduction in dramatic DO crashes and more predictable diurnal variation of DO.	Variable Outcome - the DO concentrations in surface waters have not increased since channel closure. While regular periods of low DO concentrations measured at the Salty Lagoon PWQMS have continued since channel closure, the DO crashes that were associated with fish kill events prior to channel closure have not eventuated.

Predicted Major Changes to System	*Summary of MPPC and PCM 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 - this prediction has been realised (to an extent).
Reduced probability of wind driven turbidity increases and no draining related turbidity spikes.	Positive Outcome - this prediction has been realised.
Reduced TP concentrations over time resulting from greater benthic microbial uptake and higher burial rates.	Positive Outcome - this prediction has been realised (to an extent; improvement recorded between MPPC and PCM).
Poor water quality episodes around high-risk periods such as low water levels and high temperatures.	Negative Outcome - this predicted risk has been realised.
Reduced TN concentrations and continued dominance of DON.	Neutral Outcome - the predicted reduced TN concentrations have not been realised to date.
Reduced severity of Salty Creek drawdown during draining events.	Neutral Outcome - this prediction had been realised during the MPPC, but not the PCM.
Less protracted entrance opening of Salty Creek.	Neutral Outcome - This anticipated change has not been consistently realised.
Macroinvertebrates: Change to freshwater dominated, more diverse, more robust aquatic ecology.	Positive Outcome - this prediction has been realised (to an extent) as part of the MPPC program (*note: macroinvertebrates were not monitored as part of the PCM program*).
Change of saltmarsh community to freshwater macrophyte/ macroalgae in Salty Lagoon with change to freshwater.	Positive Outcome - this prediction has been realised (*note: terrestrial flora was not monitored as part of the PCM program*).
Melaleuca re-colonisation and reduction in area of dieback.	Neutral Outcome - this prediction had not been realised during the MPPC program (*note: terrestrial flora was not monitored as part of the PCM program*).
Potential for aquatic weed growth in early stages with change to freshwater.	Positive Outcome - the risk of aquatic weed invasion has not been realised.
Reduced risk of fish kills.	Positive Outcome - this anticipated change has been realised. There have been no fish kill events since closure of the artificial channel and many of the conditions that were related to fish kills in the past have not eventuated or have eventuated to a lesser extent.
Increased Mosquitofish dominance.	Positive Outcome - this perceived risk was not realised during the MPPC program (*note: fish were not monitored as part of the PCM program*).
Potential for reduced freshwater eel migration to Salty Lagoon.	Unclear Outcome - it is not certain whether this predicted risk was realised or not during the MPPC program (*note: fish were not monitored as part of the PCM program*).
A dominance of freshwater fish species, a larger fish population and reduced fish diversity.	Neutral Outcome - this anticipated change was not consistently realised during the MPPC program (*note: fish were not monitored as part of the PCM program*).
A positive impact on bird populations with an increased abundance of waterfowl but a reduction in opportunistic waders.	Neutral Outcome - this anticipated change has been realised during the MPPC program (*note: waterfowl were not monitored as part of the PCM program*).
Reduction in area of wading bird habitat	Neutral Outcome - This anticipated change has been realised.
Increase in acid frog (*Crinia tinnula, L. freycineti* and L. *olongburensis*) distribution.	Negative Outcome - this prediction was not realised during the MPPC program (*note: frogs were not monitored as part of the PCM program*).

5.2 Emerging Trends and Issues

The need for ongoing monitoring and maintenance of the spillway at the northern end of the erosive head-cut/ channel between Salty Lagoon and Salty Creek was observed during the PCM to maintain the improved ecological conditions at Salty Lagoon associated with closure of the artificial channel.

The spillway structure failed on two occasions in the two years following construction in late 2020. The erosive head-cut/ channel has not been remediated meaning that when the spillway fails, there is a real risk of the head-cut progressing and forming a complete channel between Salty Lagoon and Salty Creek.

6. Considerations and Recommendations

6.1 MPPC/ PCM Findings and Management Considerations

The *Salty Lagoon Rehabilitation Plan: Part B Options Assessment* (Hydrosphere 2009b) assessed management options to address the key issues at Salty Lagoon and provided the following key recommendations:

- Pursue the option to temporarily close the artificial channel connecting Salty Lagoon to Salty Creek for a nominal five-year trial period.
- Maintain STP discharges to Salty Lagoon in the medium term (5 to 20 years), depending on environmental outcomes during the artificial channel closure trial.
- Continue to investigate long-term options for alternative disposal/ reuse of the effluent from the Evans Head STP. Progression of any of these options should consider the risks of effluent reduction to both the Drainage Channel and Salty Lagoon environments and appropriate management of these risks.
- Continue to monitor environmental condition and processes within the Salty Lagoon environment in order to document the anticipated long-term improvement due to the upgrade of the STP and the ecological response to artificial channel closure.
- Continue to liaise with regulatory agencies, Aboriginal stakeholders and other members of the community regarding future management of Salty Lagoon.

The successful (positive) MPPC program outcomes lead to the trial channel closure being a permanent component of the Salty Lagoon rehabilitation strategy (refer to **Section 1.1**). The results of the PCM program support this rehabilitation strategy.

Key findings from the MPPC and PCM in relation to Evans Head STP discharge relevant to future management at Salty Lagoon are summarised as follows:

- The current discharge from the Evans Head STP does not appear to increase the water levels in Salty Lagoon. In effect, the current Evans Head STP discharge is not enough to maintain water levels and water losses to evaporation and groundwater are larger than the input from the STP.
- At current discharge levels it is unlikely that discharged effluent from the Evans Head STP is contributing significantly to faecal coliform measurements in Salty Lagoon.
- At current discharge levels the majority of the nitrogen in discharged effluent appears to be processed by the ecosystems occurring along the drainage channel upstream of Salty Lagoon. 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.
- At current discharge levels it is not likely that current phosphorus concentrations in discharged effluent are sufficient to maintain the phosphorus concentrations in the waters of Salty Lagoon. Hydrosphere (2010b) 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.

The MPPC and PCM programs have found that, at current discharge volumes and pollutant levels, continued discharge from the Evans Head STP has minimal effect on bioavailable nutrient concentrations within Salty Lagoon. Residual nutrients from historic pollution are currently the primary contributor of nutrients causing periodic poor water quality episodes in the system, and continuing the current discharge regime from the Evans Head STP is unlikely to adversely affect the overall health of the system for at least the medium term.

Future necessary upgrades to the Evans Head STP may seek an increase to the licensed discharge volume, possibly doubling the current volume in order to allow for increases in the population of Evans Head and holiday visitation. If the nutrient concentrations in discharged effluent remain at the current levels this will lead to a significant increase in the potential maximum nutrient load to Salty Lagoon and an actual increase in the nutrient load as the population around Evans Head increases over time. The impacts of this upon Salty Lagoon are beyond the scope of this report but should be considered in the planning phase for the upgrades.

Maintaining water levels in Salty Lagoon through ongoing monitoring and management of the spillway and erosive head-cut/ channel between Salty Lagoon and Salty Creek is a very high priority for the ongoing management of Salty Lagoon. The existing water level regime is the key factor determining the positive freshwater ecological values that the system is currently exhibiting under most circumstances. If Salty Lagoon reverts back to an Intermittently Open and Closed Lake or Lagoon (ICOLL) through permanent two-way hydraulic connection with Salty Creek, the degraded brackish conditions that prompted the channel closure are the likely outcome.

6.2 Ongoing Management of Salty Lagoon

RVC are currently considering upgrade options for the Evans Head STP, including options to continue discharging into the Salty Lagoon system at current discharge volumes and pollutant levels and options to discharge at increased volumes. With this, the following recommendations are provided:

- Develop 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 to monitor water being discharged from the Evans Head STP in accordance with licence conditions set by the NSW EPA.
- Liaise with NPWS in relation to the erosive head-cut/channel between Salty Lagoon and Salty Creek and associated spillway to:
  - Outline the roles and responsibilities of each organisation.
  - Ensure appropriate monitoring and maintenance of the spillway structure.
  - Undertake remediation of the erosive head-cut/ channel.
- Continue to monitor water levels in Salty Lagoon, with the objective of observing any drawdown events associated with the erosive head-cut/ channel and associated spillway failure. The water level monitoring method and responsibility would be determined through discussion between RVC and NPWS. A corresponding Environmental Response Protocol would be prepared outlining water level triggers, management responses, and roles and responsibilities.

- Potential future STP upgrade options that result in increased discharge volumes or pollutant levels should consider potential impacts on the Salty Lagoon system during the planning phase.

The MPPC and PCM results indicate that, as long as the eroding channel between Salty Lagoon and Salty Creek does not fully and permanently open, ongoing detailed environmental monitoring at Salty Lagoon is not warranted. These recommendations are in line with Salty Lagoon Salty Lagoon Rehabilitation Plan recommendations (Hydrosphere 2009b; 2011).

7. Conclusion

7.1 Conclusion

The *Salty Lagoon Post Closure Monitoring Program* (PCM) was undertaken between July 2017 and June 2022, continuing monitoring of most environmental parameters associated with the MPPC program. The results of the MPPC and PCM collectively indicate that closure of the artificial channel between Salty Lagoon and Salty Creek has been successful, as:

- The Salty Lagoon system has continued to move towards a predominantly freshwater lagoon system, with the monitoring recording relatively stable water quality conditions.
- Many of the predicted changes of the MPPC (Hydrosphere 2010a) are occurring, including positive changes such as a more natural hydrology and salinity regime; reduced magnitude and rate of water level variation; less frequent saline water ingress; and reduced risk of fish kill.
- While other monitoring attributes have recorded no clear trend or negative trends, the results indicate overall improved ecological health at Salty Lagoon.

RVC are currently considering upgrade options for the Evans Head STP, including options to continue discharging into the Salty Lagoon system at current discharge volumes and pollutant levels and options to discharge at increased volumes. With this, the following recommendations are provided:

- Develop 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 to monitor water being discharged from the Evans Head STP in accordance with licence conditions set by the NSW EPA.
- Liaise with NPWS in relation to the erosive head-cut/ channel between Salty Lagoon and Salty Creek and associated spillway to ensure appropriate rehabilitation, monitoring and maintenance.
- Continue to monitor water levels in Salty Lagoon to observe any drawdown events associated with the erosive head-cut/ channel and associated spillway failure. A corresponding Environmental Response Protocol would be prepared outlining water level triggers, management responses, and roles and responsibilities.
- Potential future STP upgrade options that result in increased discharge volumes or pollutant levels should consider potential impacts on the Salty Lagoon system during the planning phase.

References

ABER (2010). *Final Report: Development of an ecosystem response model of Salty Lagoon*. Unpublished report for Richmond Valley Council.

BOM (2022). *Climate Data Online.* Bureau of Meteorology website: http://www.bom.gov.au/climate/data/

GeoLINK (2012). *Salty Lagoon – Monitoring: Pre-Post Closure of Artificial Channel Project Management and Ecosystem Health Report September 2012.* Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2015). *Annual Report 2015 – Salty Lagoon Monitoirng Program: Pre/ Post Closure of the Artificial Channel.* Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

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

GeoLINK (2018). *Annual Report 2018 – Salty Lagoon Post closure Monitoring Program (Years 6 – 10)*. Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2019). *Annual Report 2019 – Salty Lagoon Post closure Monitoring Program (Years 6 – 10)*. Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2020). *Annual Report 2020 – Salty Lagoon Post closure Monitoring Program (Years 6 – 10)*. Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2021). *Annual Report 2021 – Salty Lagoon Post closure Monitoring Program (Years 6 – 10)*. Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

GeoLINK (2022). *Annual Report 2022 – Salty Lagoon Post closure Monitoring Program (Years 6 – 10)*. Unpublished report to Richmond Valley Council. GeoLINK, Lennox Head.

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

Hydrosphere (2009b). *Salty Lagoon Rehabilitation Plan: Part B Options Assessment.* 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.*

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Appendix A

Sample of Fixed Photo Point Results

Appendix A Fixed Photo Points Results Sample

Sites 1-5 correspond with discrete water quality monitoring sites, with sites 1-4 located within Salty Lagoon and site 5 located within Salty Creek (refer to **Section 2.2.2** for specific site location details). Site 6 is located at the infilled artificial channel.

Site 1 North August 2011

Site 1 North November 2013

Site 1 North April 2017

Site 1 North August 2018

Site 1 North June 2020

Site 1 North June 2022

Site 2 South August 2011

Site 2 South November 2013

Site 2 South April 2017

Site 2 South August 2018

Site 2 South June 2020

Site 2 South June 2022

Site 3 East August 2011 | Site 3 East November 2013

Site 3 East February 2017 | Site 3 East August 2018

Site 3 East August 2020 | Site 3 East June 2022

Site 4 East August 2011

Site 4 East November 2013

Site 4 East April 2017

Site 4 East August 2018

Site 4 East August 2020

Site 4 East June 2022

Site 5 East August 2011

Site 5 East November 2013

Site 5 East February 2017

Site 5 East October 2018

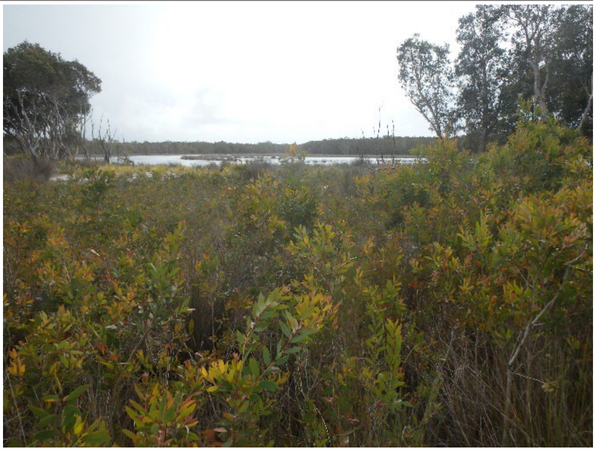
Site 5 East August 2020

Site 5 East June 2022

Site 6 South November 2012

Site 6 South November 2013

Site 6 South April 2017



Site 6 South August 2018

Site 6 South June 2020

Site 6 South June 2022

Appendix B

PWQMS Results

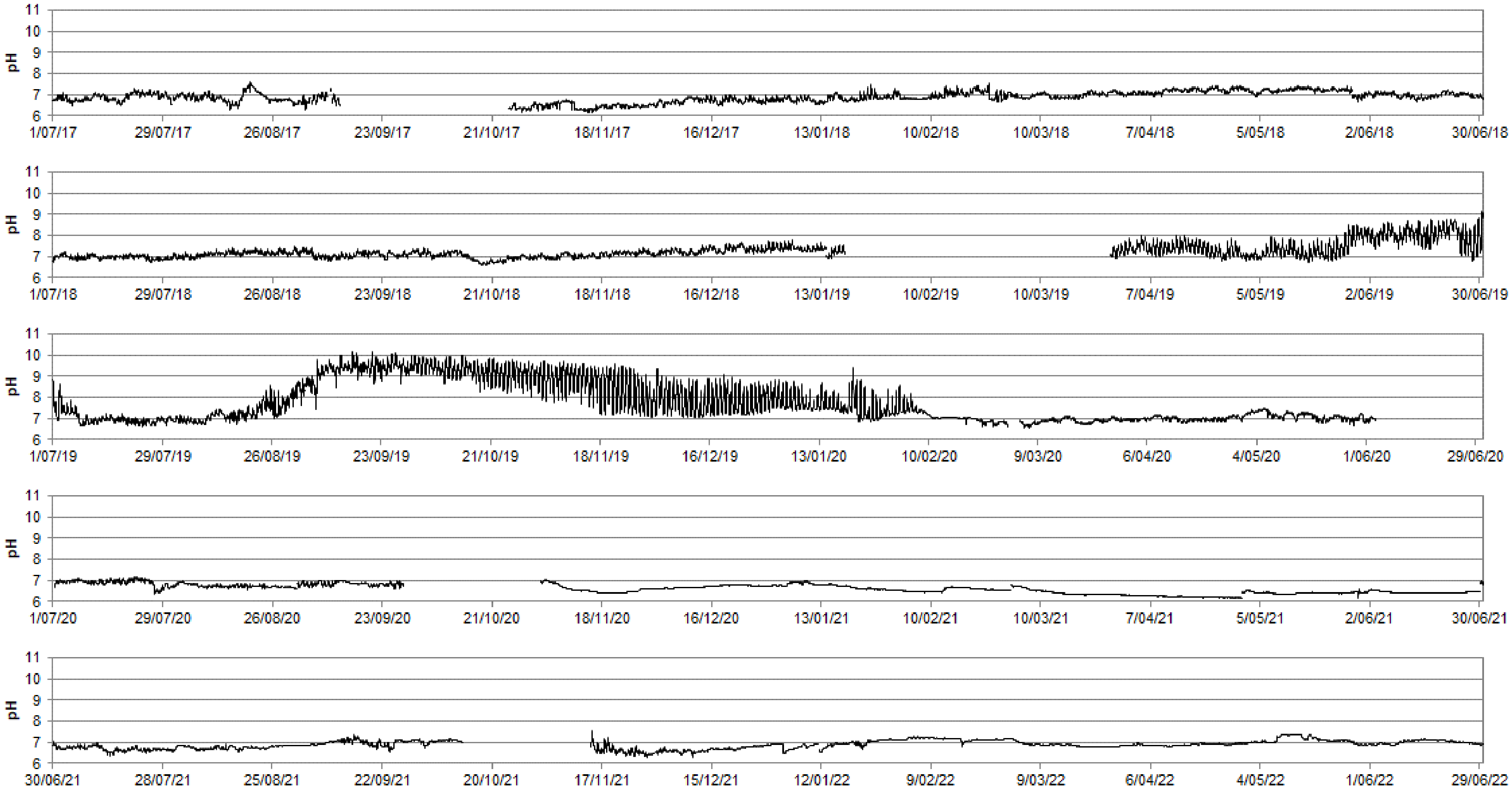


Figure B1 pH measurements from the Salty Lagoon PWQMS for the duration of the PCM

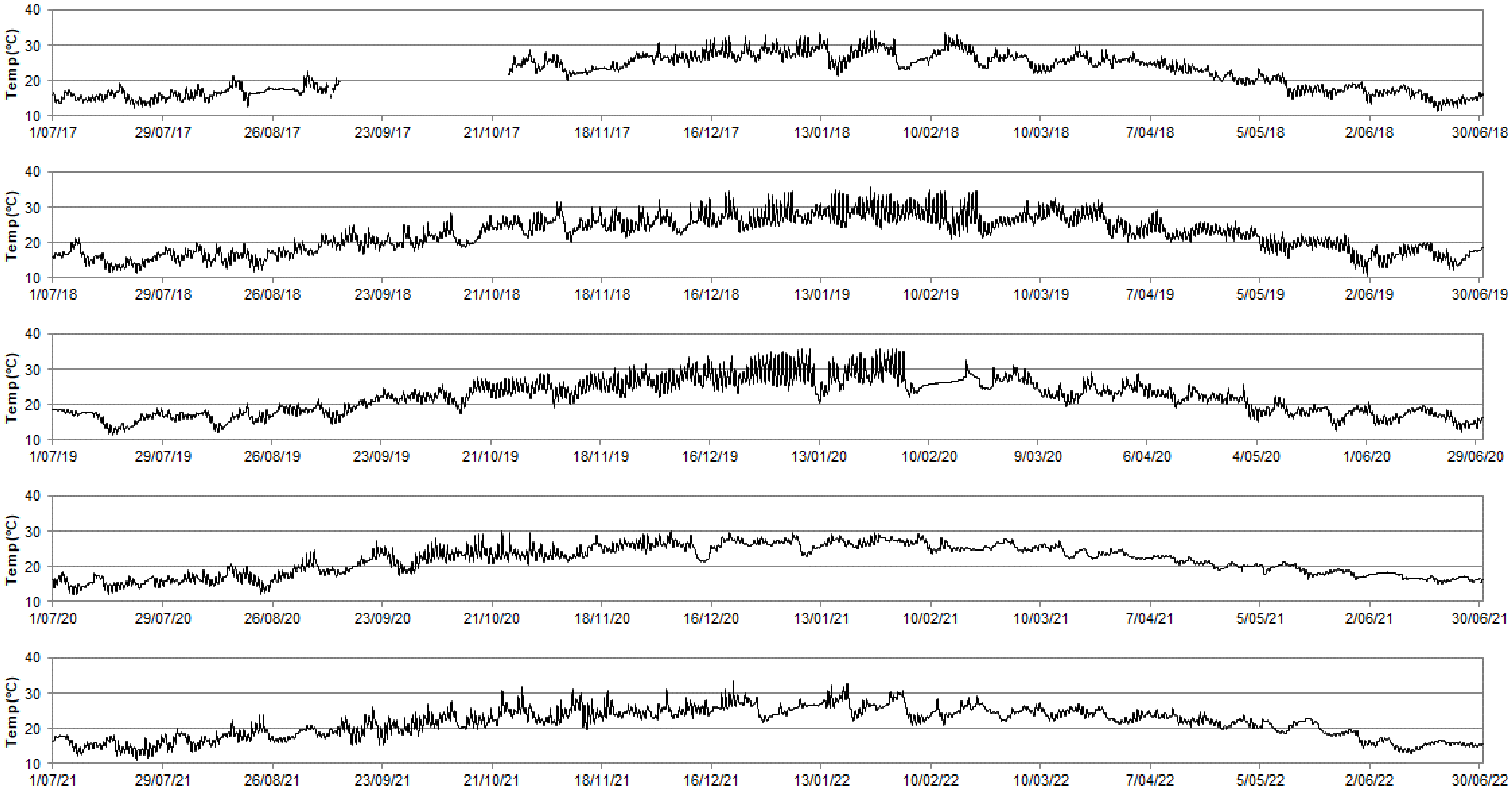


Figure B2 Temperature measurements from the Salty Lagoon PWQMS for the duration of the PCM

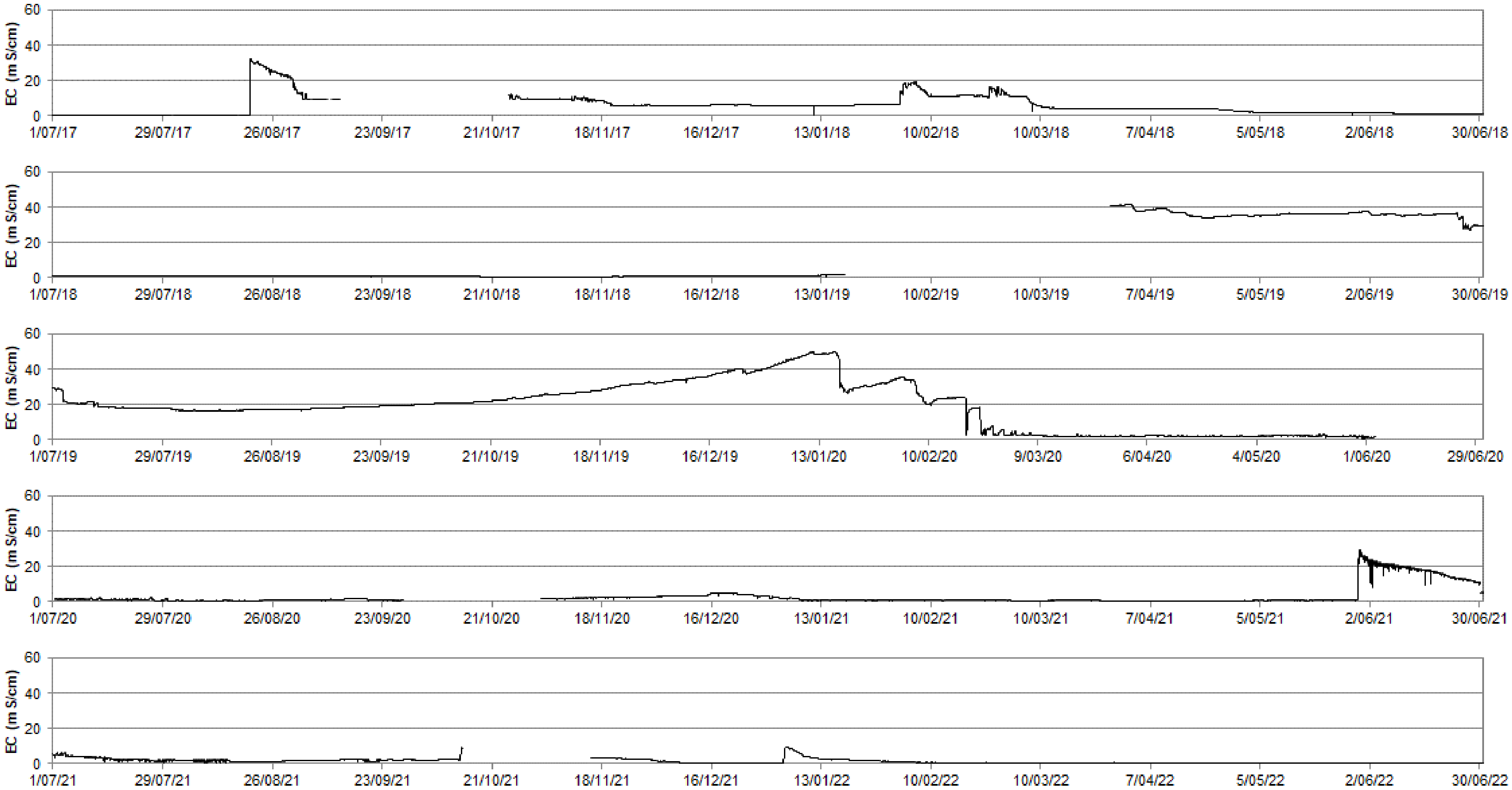


Figure B3 Electrical conductivity measurements from the Salty Lagoon PWQMS for the duration of the PCM

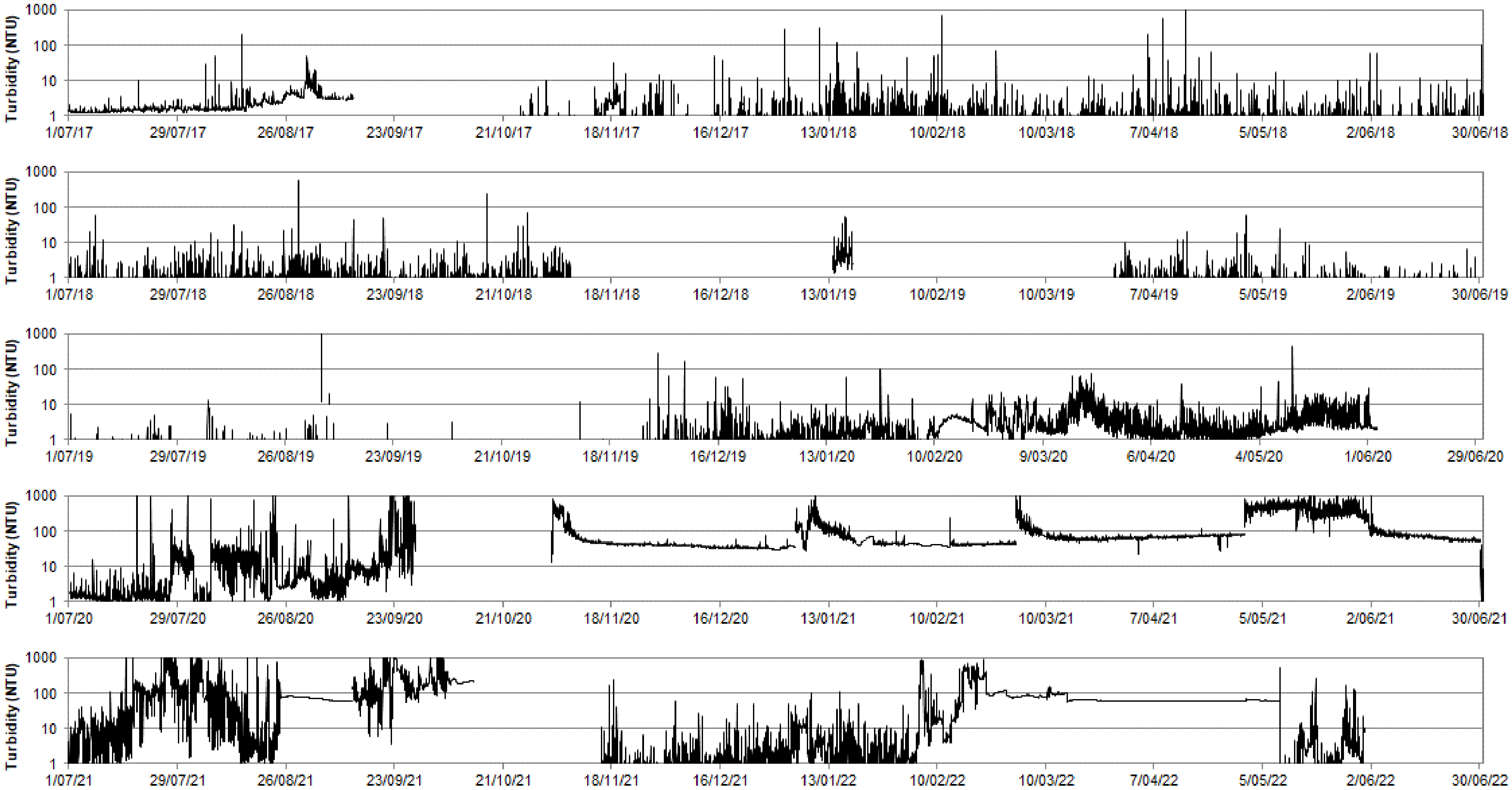


Figure B4 Turbidity measurements from the Salty Lagoon PWQMS for the duration of the PCM (log_{10} scale)

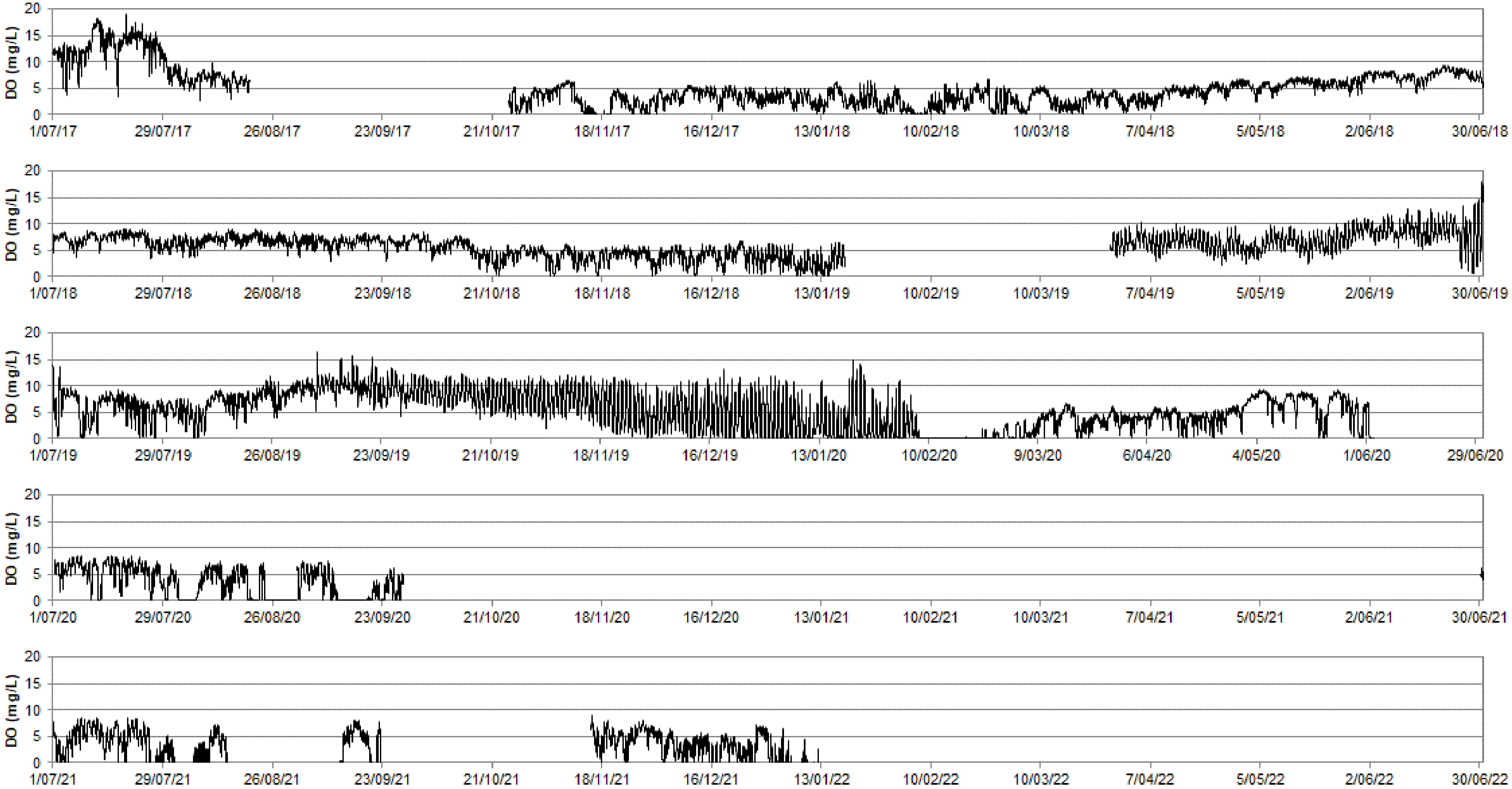


Figure B5 DO measurements from the Salty Lagoon PWQMS for the duration of the PCM

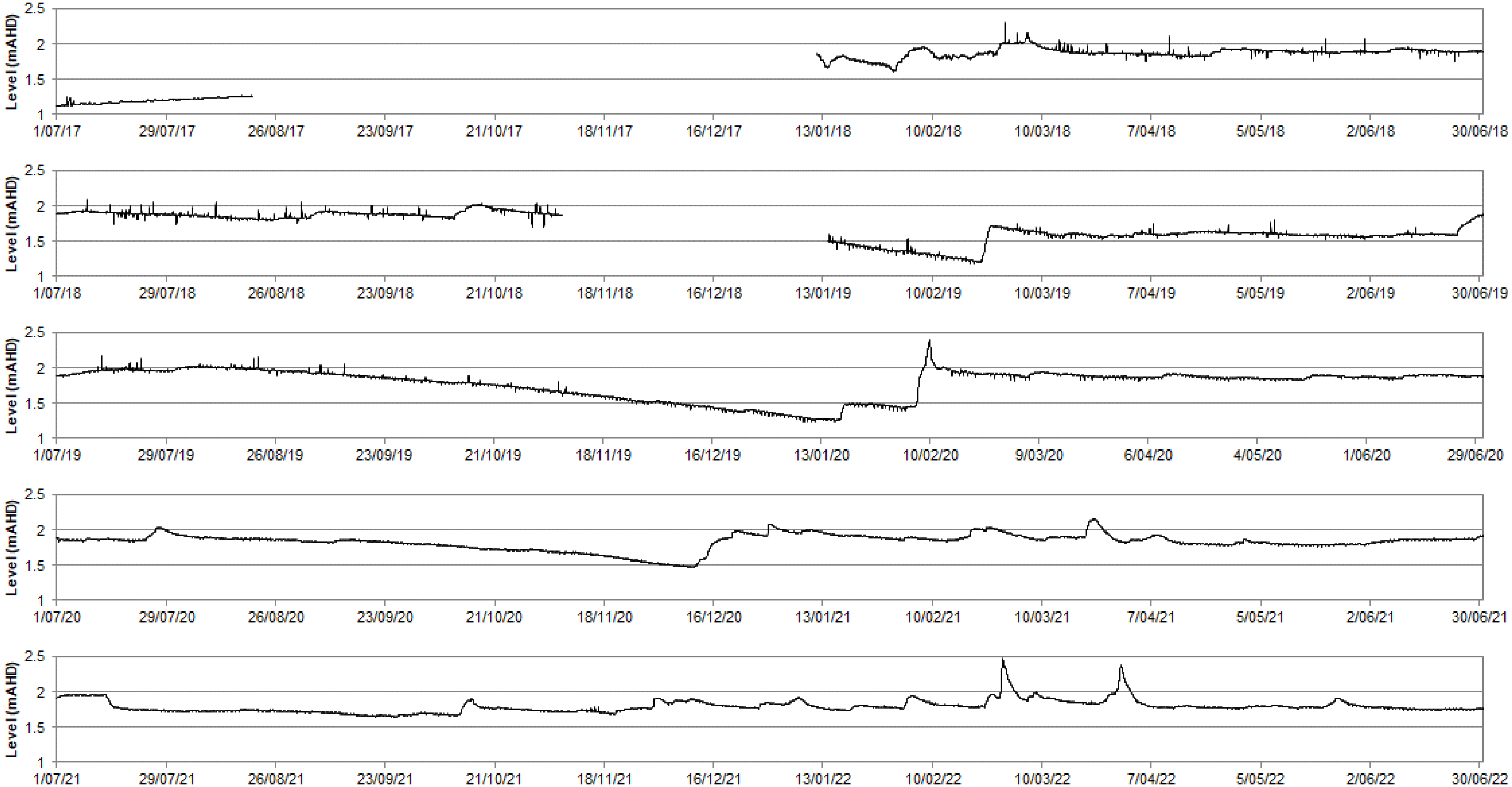


Figure B6 Level measurements from the Salty Lagoon PWQMS for the duration of the PCM

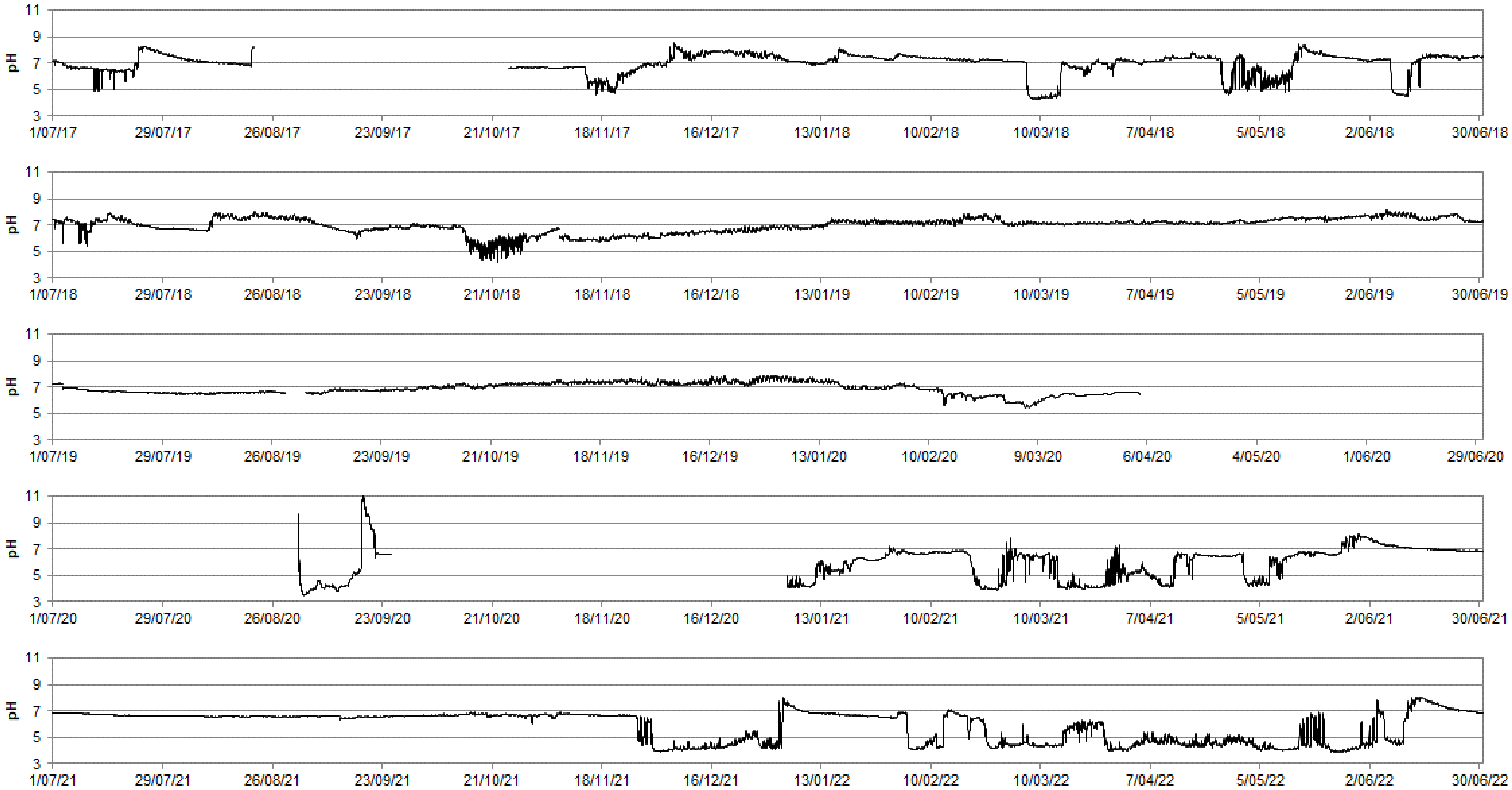


Figure B7 pH measurements from the Salty Creek PWQMS for the duration of the PCM

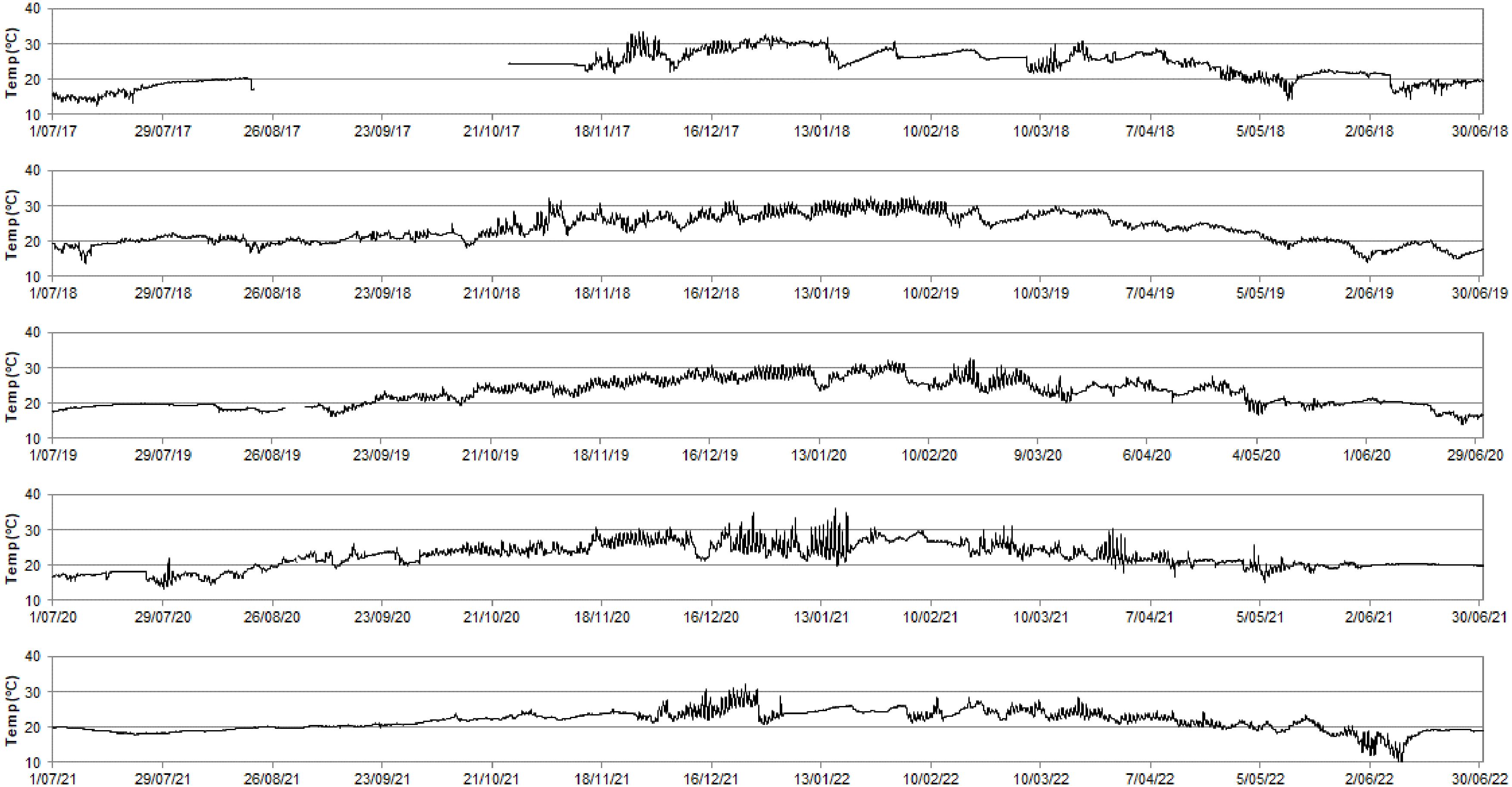


Figure B8 Temperature measurements from the Salty Creek PWQMS for the duration of the PCM

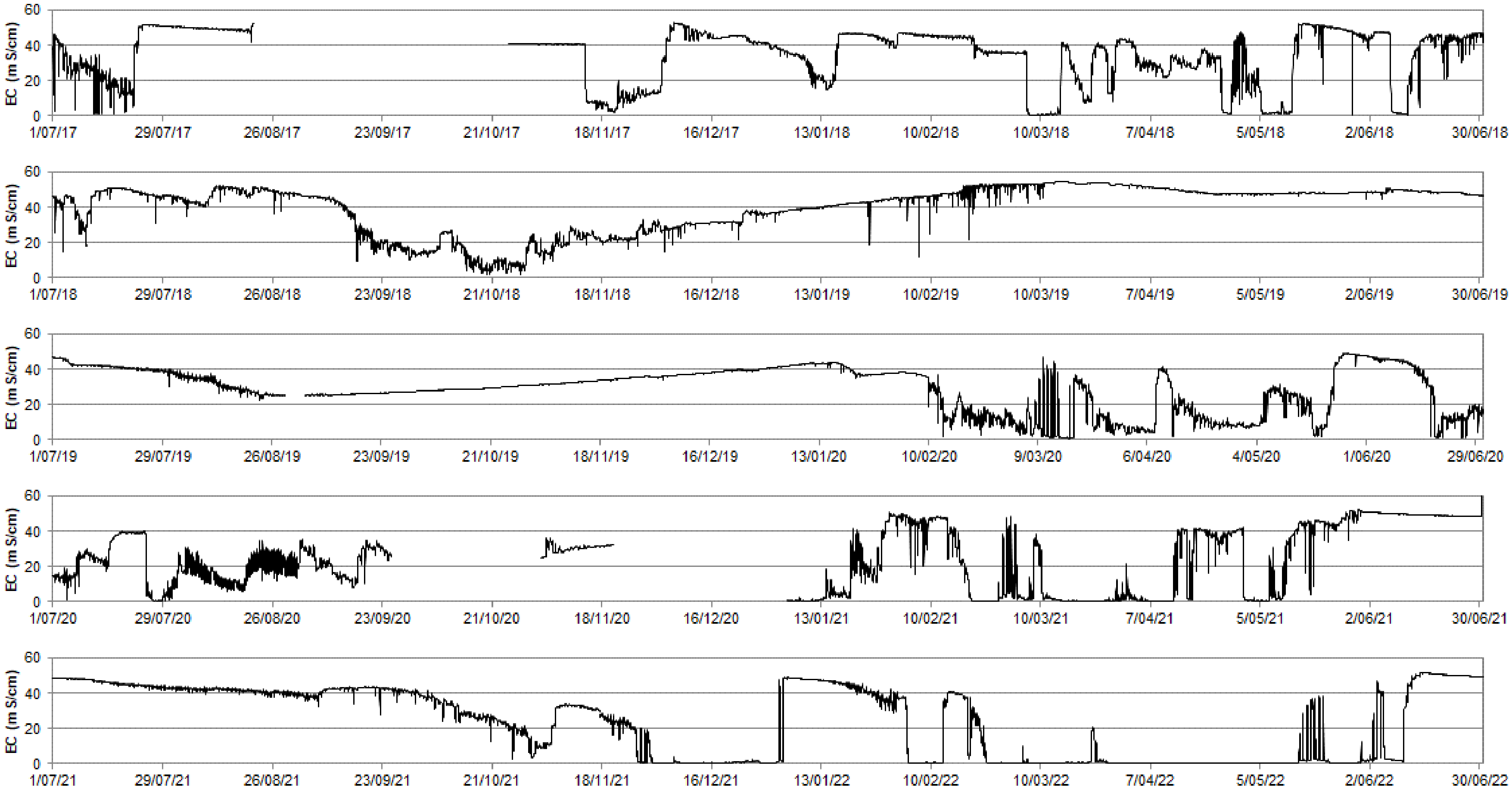


Figure B9 Electrical conductivity measurements from the Salty Creek PWQMS for the duration of the PCM

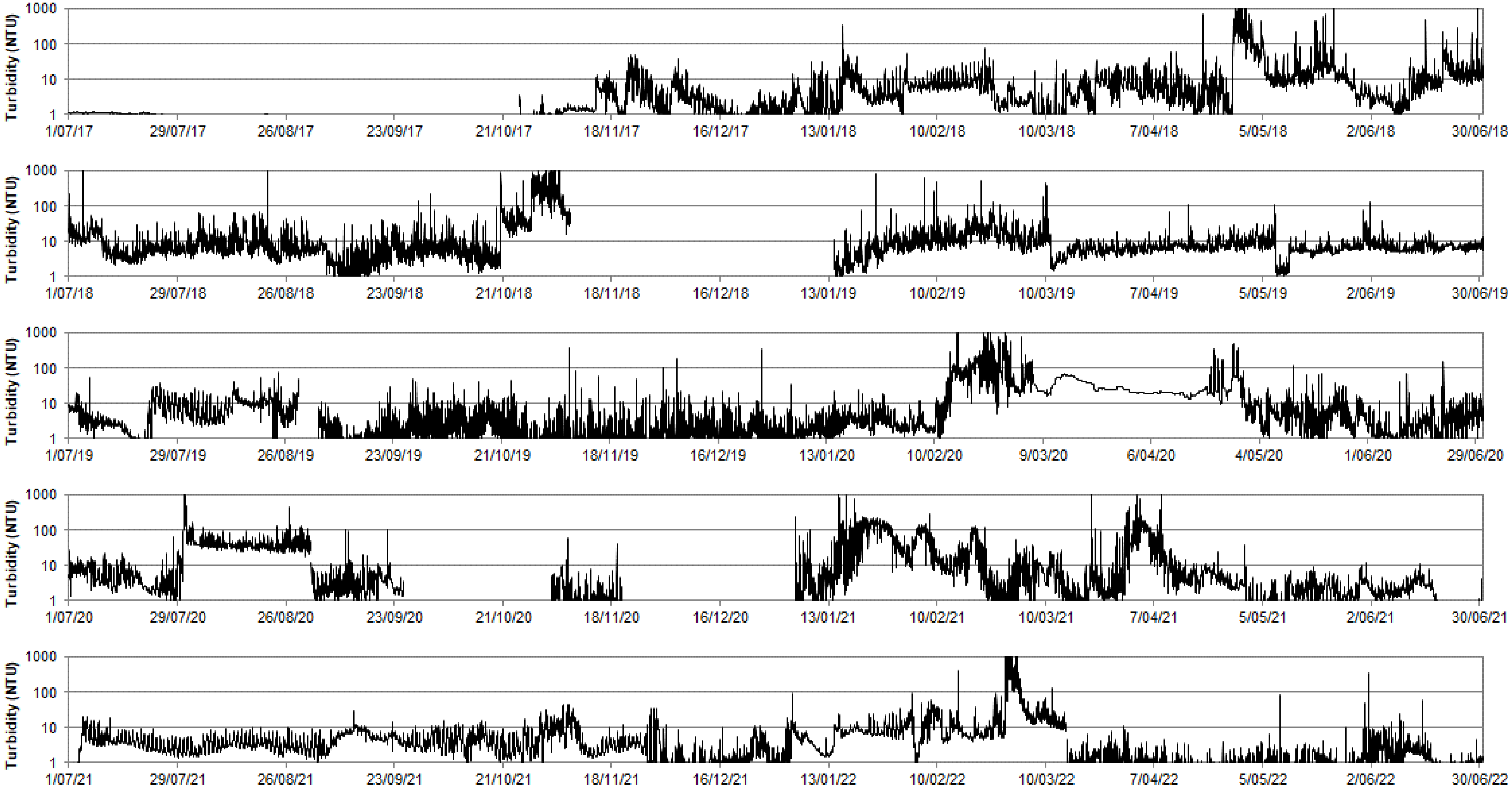


Figure B10 Turbidity measurements from the Salty Creek PWQMS for the duration of the PCM (log$_{10}$ scale)

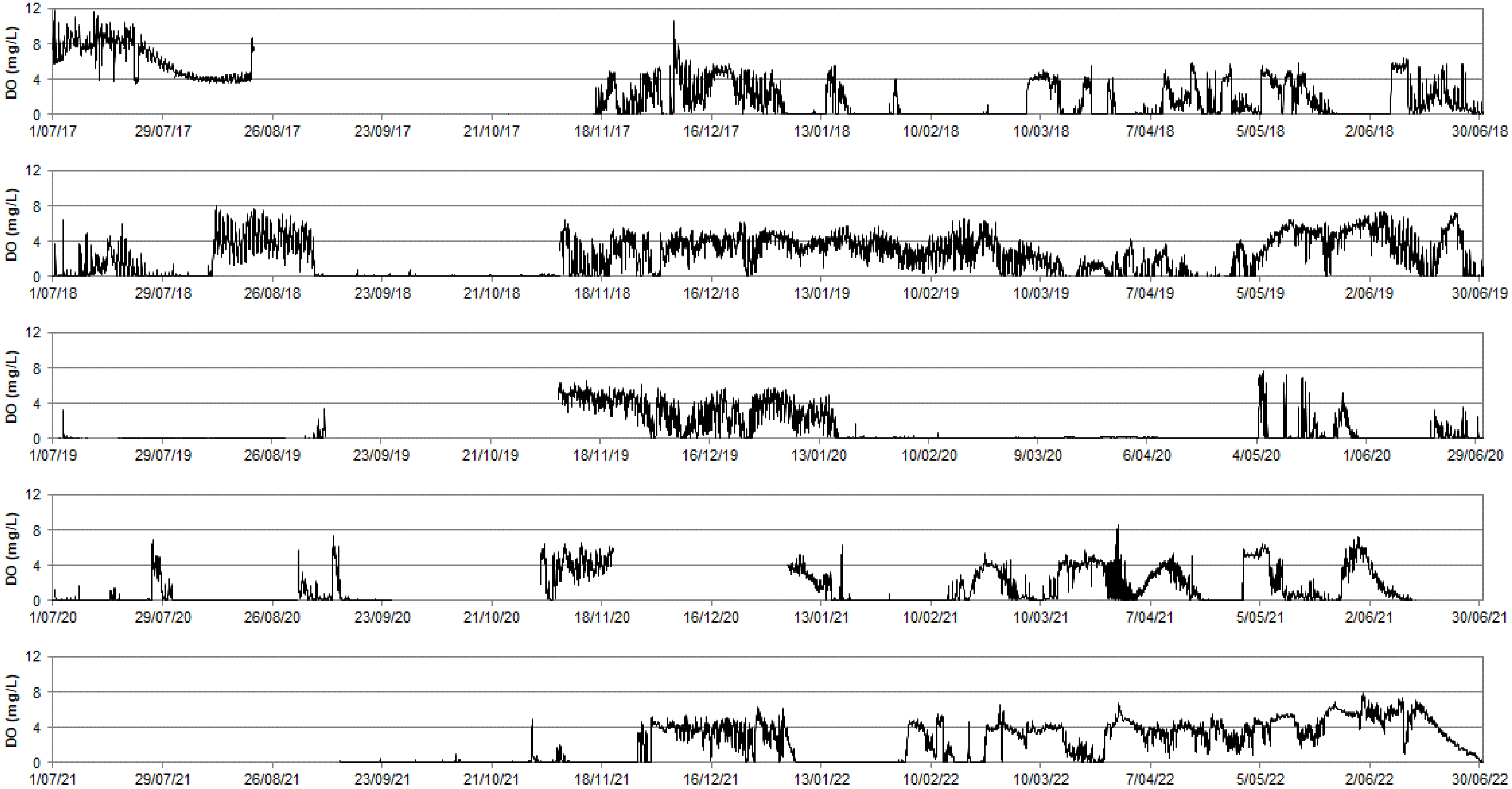


Figure B11 Dissolved oxygen measurements from the Salty Creek PWQMS for the duration of the PCM

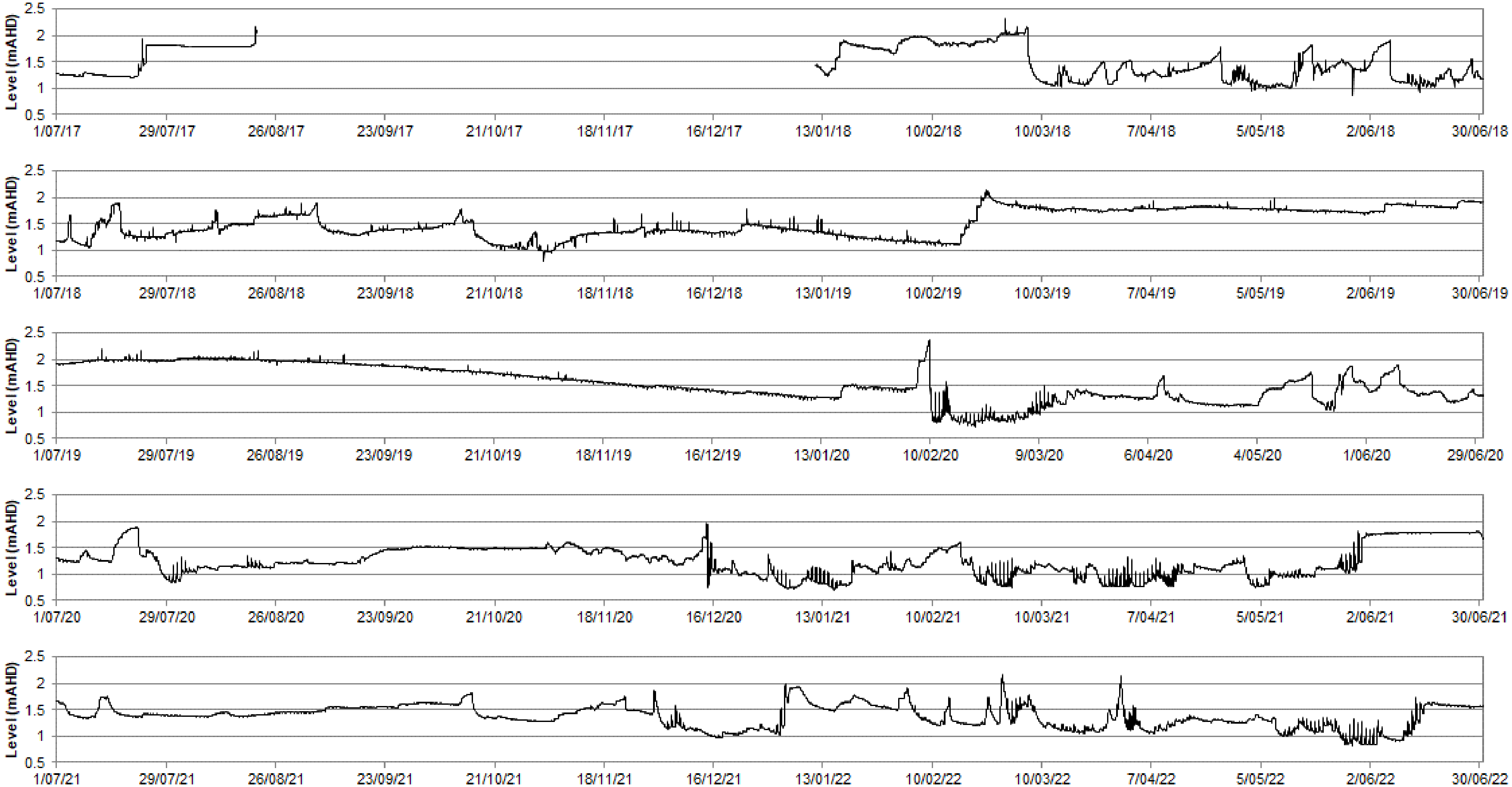


Figure B12 Level measurements from the Salty Creek PWQMS for the duration of the PCM

Appendix C

Summary of Discrete Water Quality Sample Data

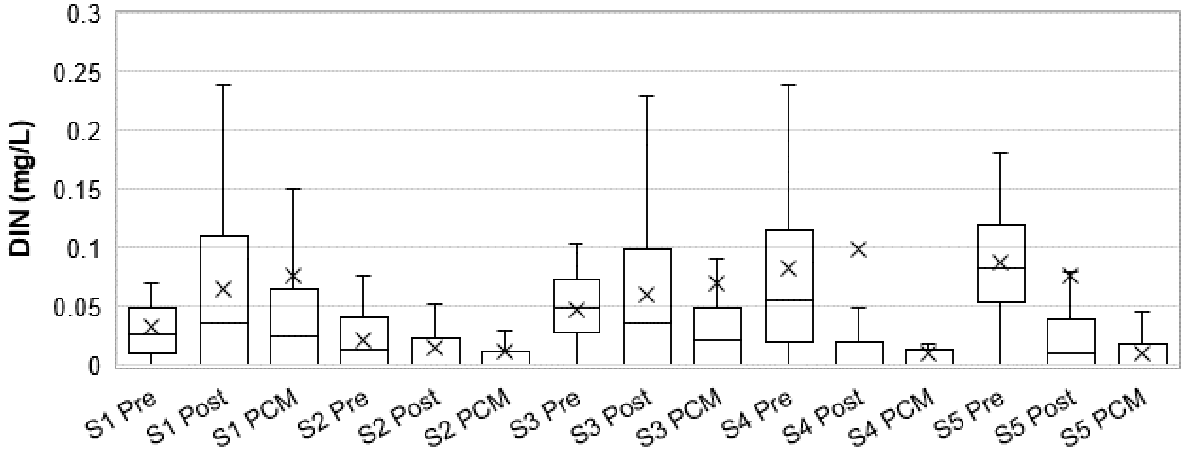


Figure C.1 Summary of DIN results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

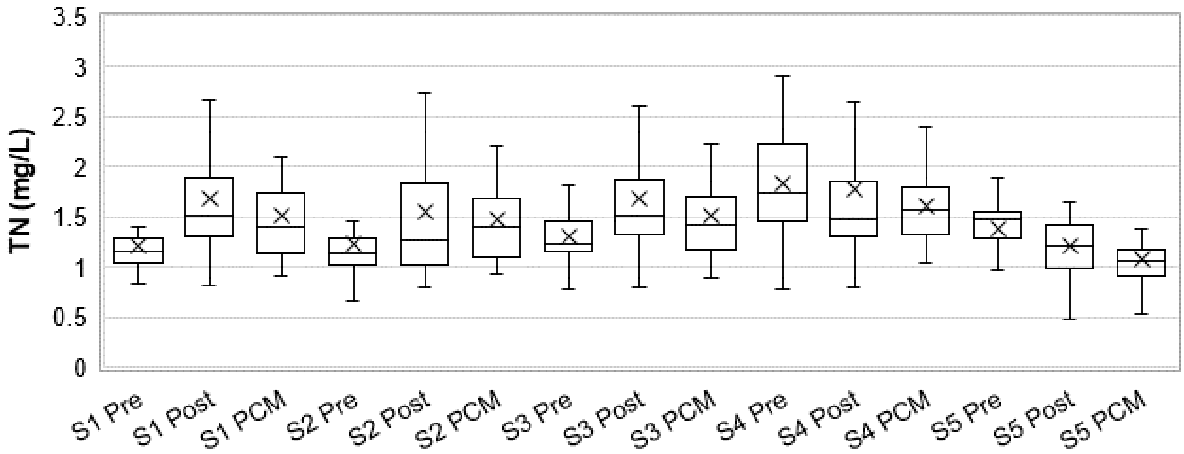


Figure C.2 Summary of TN results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

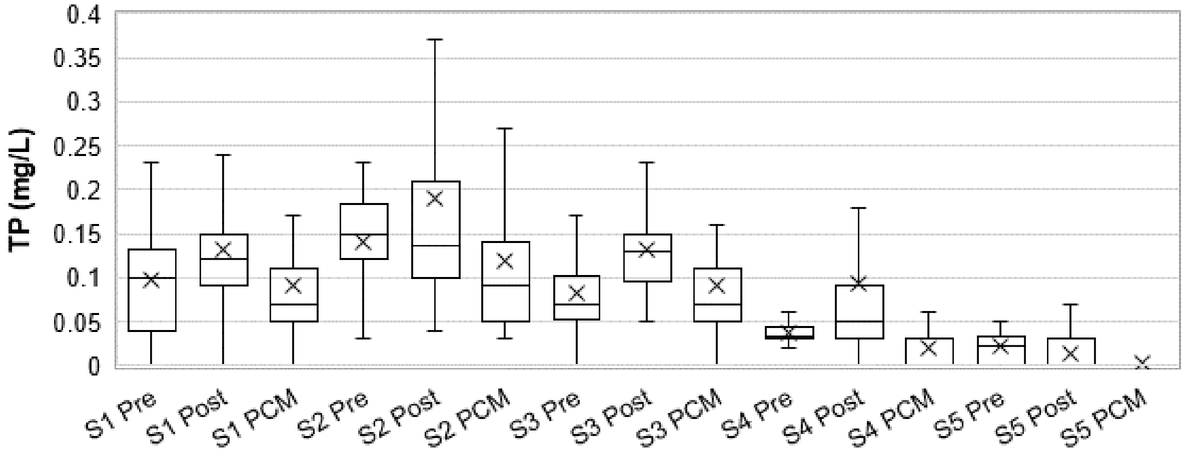


Figure C.3 Summary of TP results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

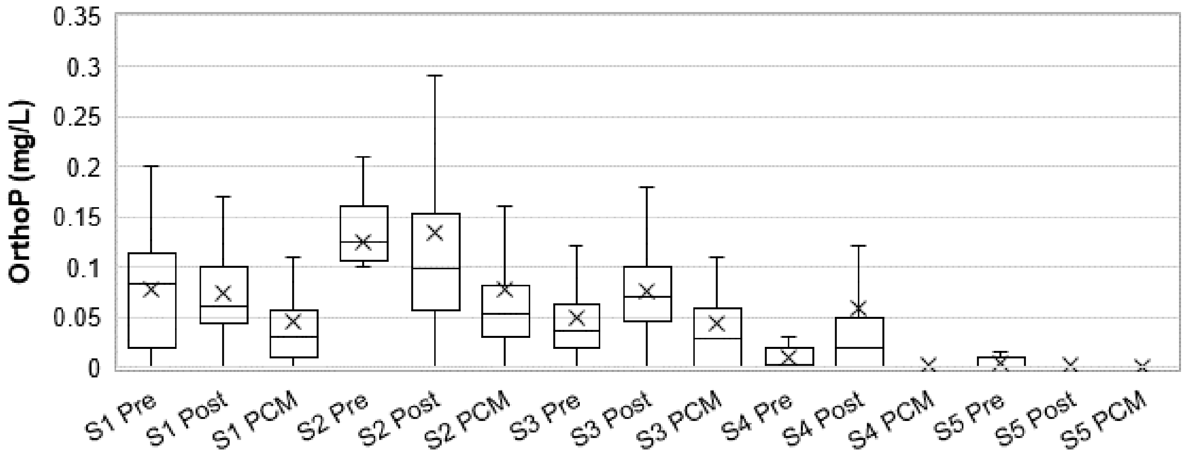


Figure C.4 Summary of orthophosphate results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

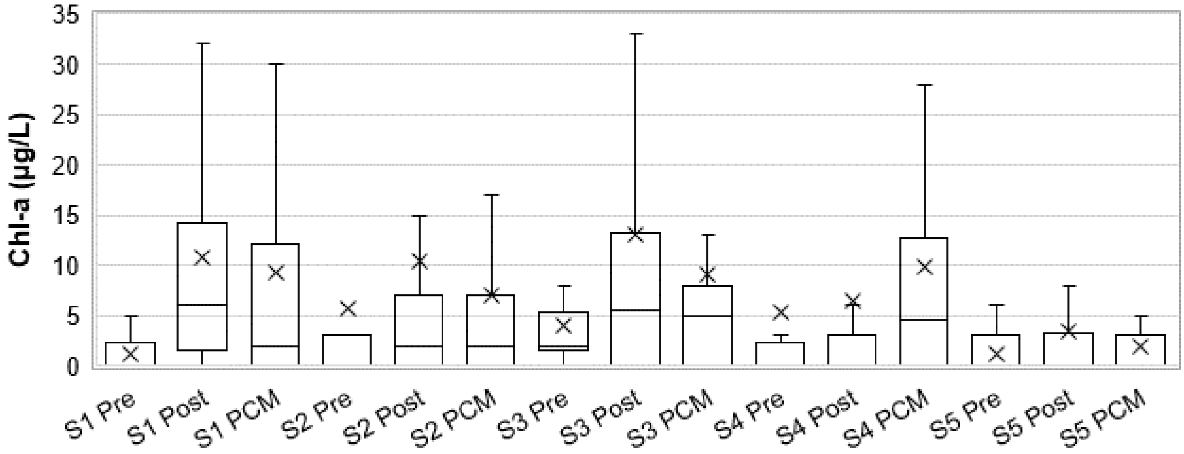


Figure C.5 Summary of chlorophyll-a results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

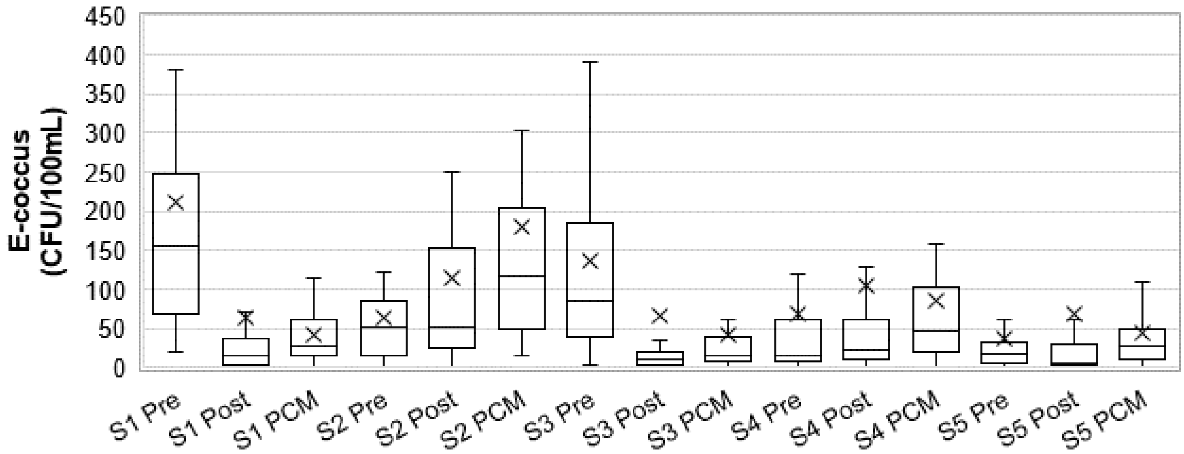


Figure C.6 Summary of enterococcus results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

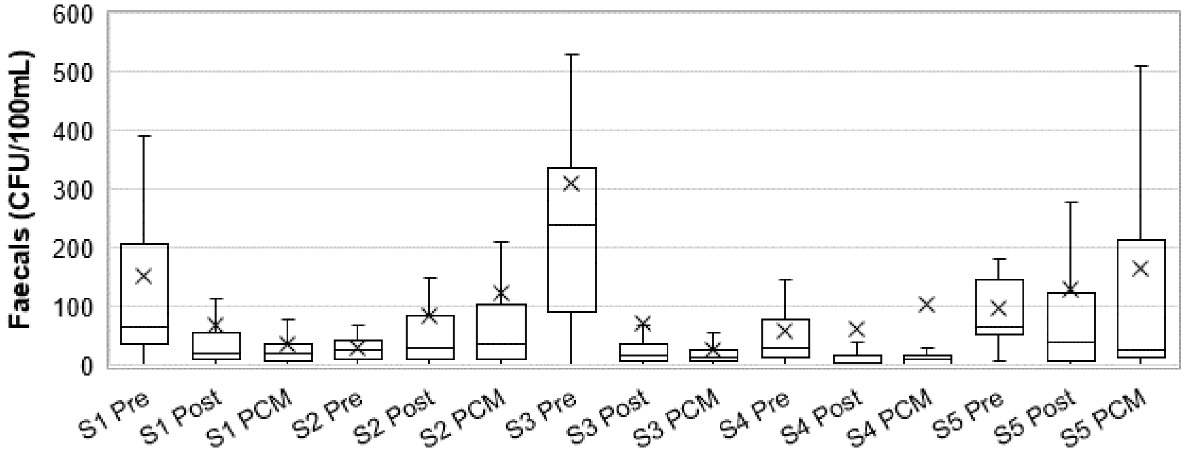


Figure C.7 Summary of faecal coliform results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

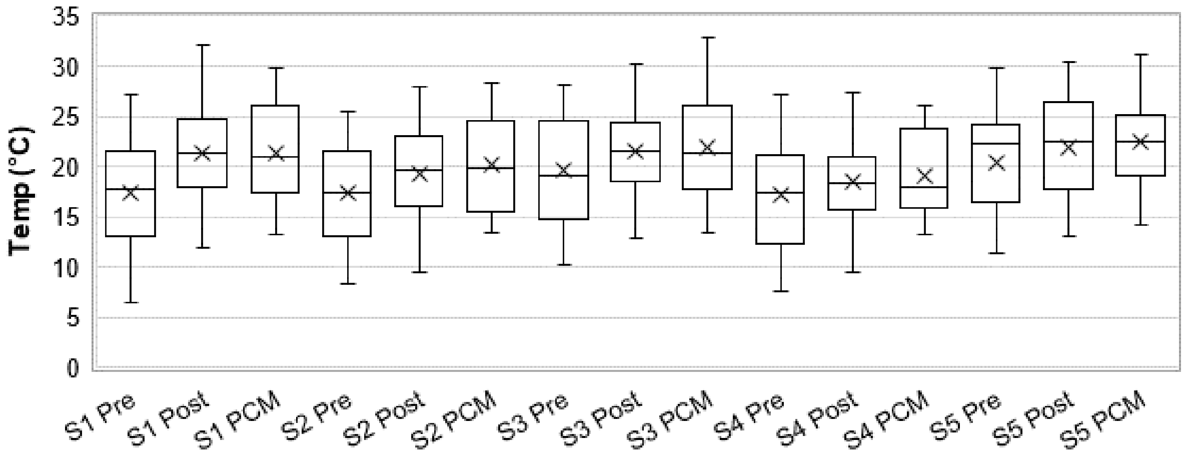


Figure C.8 Summary of temperature results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

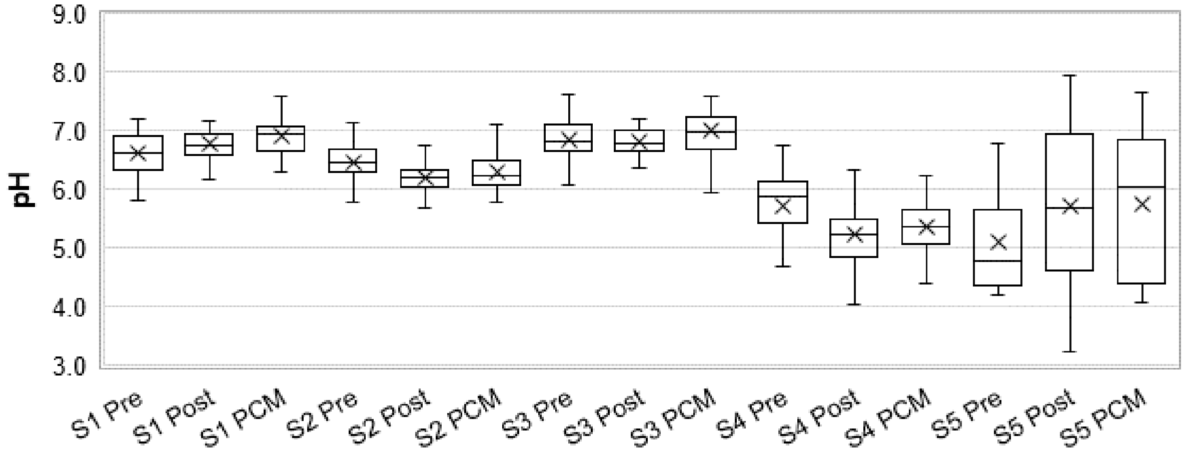


Figure C.9 Summary of pH results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

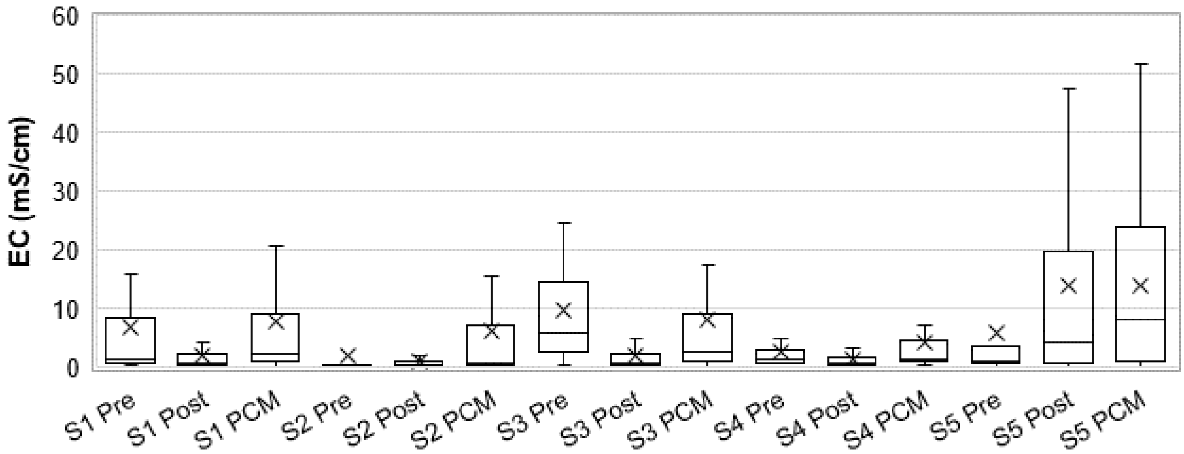


Figure C.10 Summary of conductivity results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

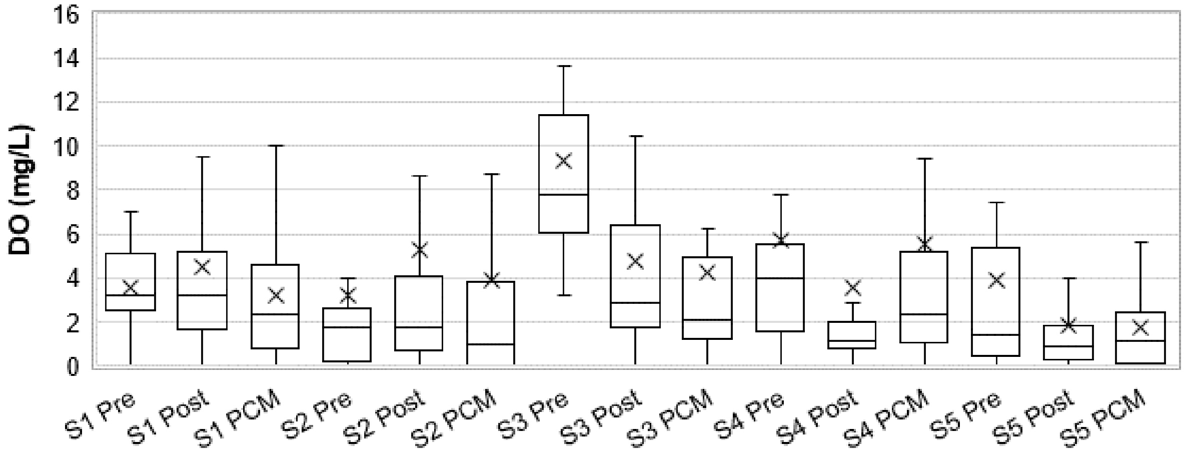


Figure C.11 Summary of DO results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive medians)

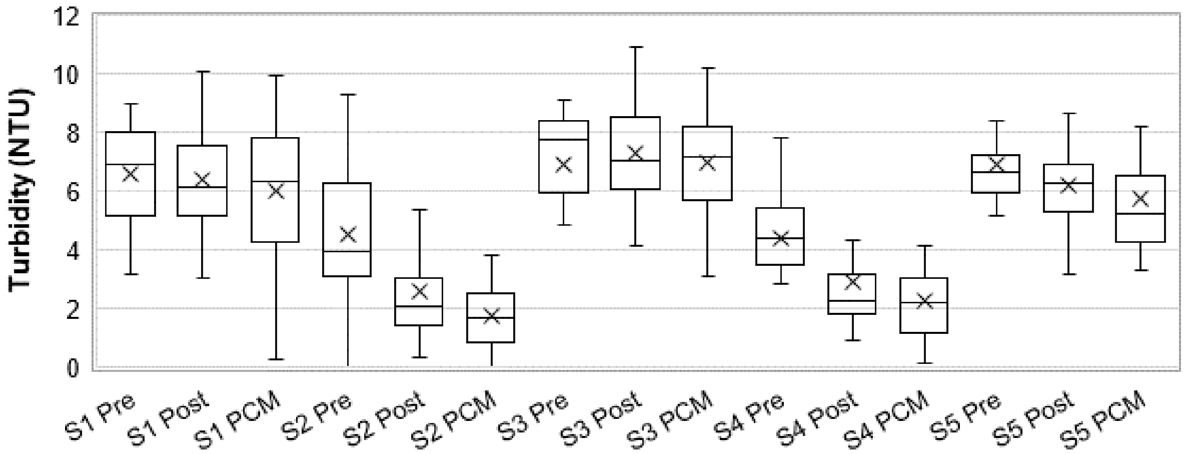


Figure C.12 Summary of turbidity results from the MPPC pre closure and post closure, and PCM periods (outliers removed, inclusive median