Department of Climate Change, Energy, the Environment and Water

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Estuary Report Card 2024-2025 Central Coast Lagoons

July 2025

Acknowledgement of Country

The Department of Climate Change, Energy, the Environment and Water acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders past and present through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

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Table of Contents

1 Introduction

1.1 Background

The Central Coast Council (CCC) engaged the Estuaries and Catchments Team within the Science and Insights Division of the Department of Climate Change, Energy, the Environment and Water (DCCEEW) to assess the water quality in Wamberal Lagoon, Terrigal Lagoon, Avoca Lagoon and Cockrone Lagoon over the 2024-2025 financial year and provide Council with an estuary report card. The monitoring program was first implemented in 2018 as a 6-month program and was expanded to a 12-month program in October 2021 at the request of CCC. This change coincided with the Avoca Lagoon Processes Study (DCCEEW 2024) and the decision to address a knowledge gap by collecting data across all seasons from each lagoon which have variable entrance opening regimes. CCC recognises that long-term monitoring programs are essential for tracking the ecological health of an estuary and to help identify potential areas of concern that may require additional management.

1.1.1 Location

Located on the Central Coast, NSW, Wamberal Lagoon, Terrigal Lagoon (Tarrygal), Avoca Lagoon (Bulbararong) and Cockrone Lagoon (Tudibaring) lie within a ten kilometre stretch of coastline to the north of Broken Bay, on the lands of the Darkinjung people. The four lagoons (Figure 1) are within the Central Coast Council (CCC) Local Government Area (LGA).

1.1.2 Program outline and scope

The Central Coast Lagoons water quality monitoring program was developed and implemented by DCCEEW in accordance with standardised sampling, data analysis and reporting protocols outlined in the NSW Natural Resources Monitoring, Evaluation and Reporting (MER) program for assessing estuary health (OEH, 2016). The project monitored water quality at the four Central Coast Lagoons from July 2024 through to June 2025, building on the long-term data set.

1.1.3 Aims and objectives of the program

The monitoring program aims to assess water quality in the Lagoons through the implementation of a monthly monitoring program to:

- Track change in condition and continue to build a long-term dataset to support management decisions by CCC
- Provide CCC and the community with an annual report on estuary health.

2 Methodology

2.1 Monitoring zones & frequency

The spatial scale of interest for the state-wide MER program is whole-of-estuary condition. As such, the state-wide program targets the assumed chlorophyll-a and turbidity maxima (OEH 2016), which is the central basin in lagoons. To ensure representative spatial coverage, the estuary is divided into zones, typically 500-700m in diameter in lakes and lagoons (OEH 2016). However, localised sampling programs such as Council MER programs, often need to consider condition at spatial scales that are smaller than the whole estuary. Localised issues may also require assessment of indicators in areas other than the theoretical chlorophyll-a and turbidity maxima. In these instances, sampling zones may be smaller in size and additional zones may be added, in tributaries for example (OEH 2016).

Sampling zones were established in the four Central Coast Lagoons (Figure 1) based on sampling protocols outlined for the MER estuary health assessments (OEH 2016), giving consideration to:

- estuary type, size and morphology,
- access and WHS issues,
- location of established or historical monitoring sites,
- location of tributaries or other major inputs,
- local knowledge of current water quality issues.

Over a 12-month period, monthly water quality sampling was carried out at nine zones throughout the study area: two each in Wamberal Lagoon, Terrigal Lagoon, and Cockrone Lagoon and three zones at Avoca Lagoon (Figure 1). Sampling at this frequency allows both monthly and seasonal variability in water quality to be assessed.

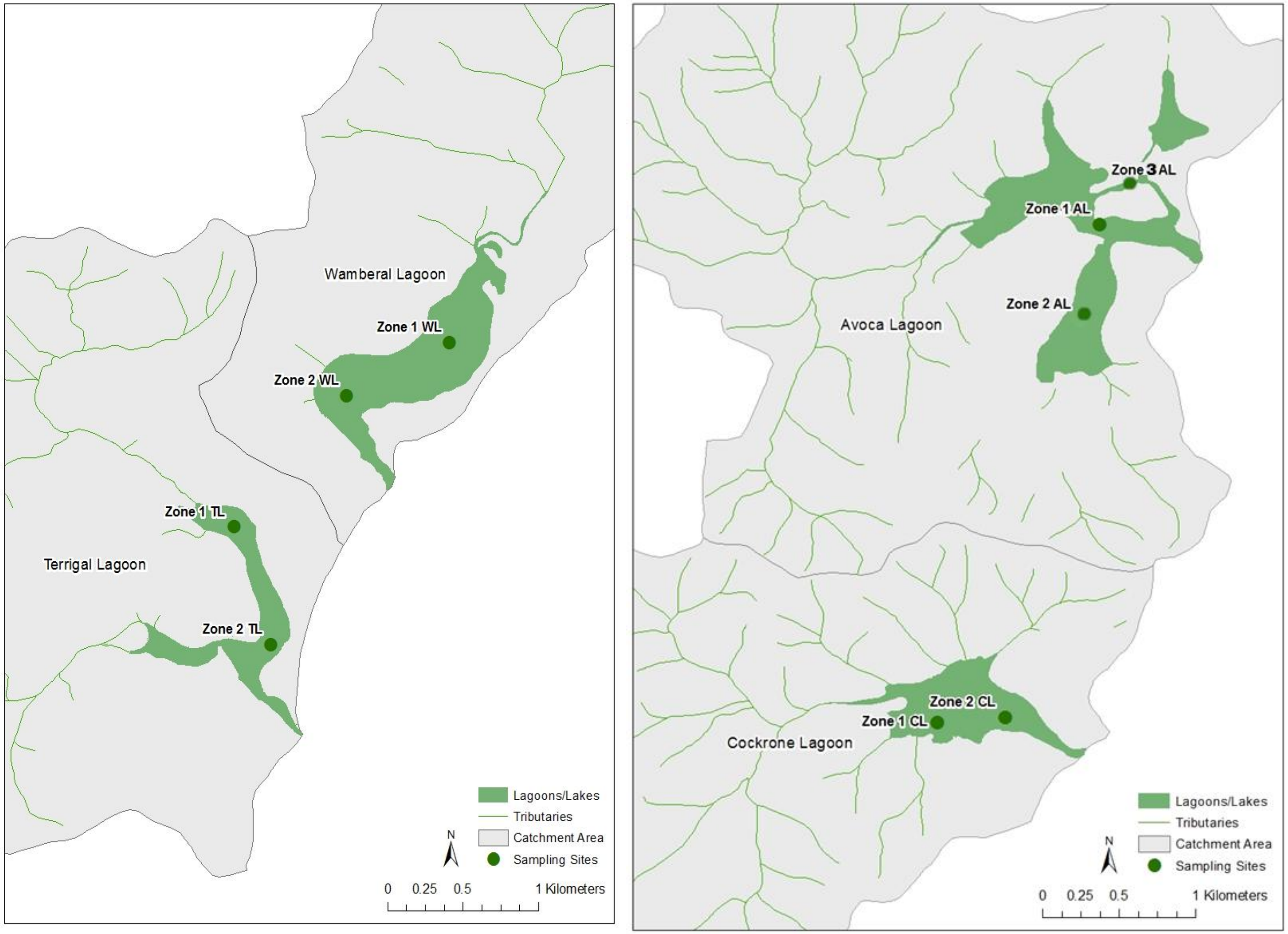

Figure 1 Sampling locations in Wamberal and Terrigal Lagoons (left map) and Avoca and Cockrone Lagoons (right map) during the 2024-2025 monitoring program. The green dots indicate the centre of the sampling zone, which vary in shape/size due to lagoon morphology.

2.1.1 Sampling methods

Water quality

All sampling was conducted from a motorised canoe. Using a Xylem EXO-2 multiparameter water quality sonde (WQ sonde) lowered to 0.3-0.5 m below surface, physicochemical water quality parameters were recorded, including:

- turbidity
- temperature
- salinity
- pH
- electrical conductivity and specific conductivity
- chlorophyll-a (by in-situ fluorometry)
- dissolved oxygen
- fluorescent Dissolved Organic Matter (fDOM)

Data was logged on the handheld device of the WQ sonde at a maximum depth of 0.5 m at one second intervals for a total of three minutes at each site. Meanwhile, the vessel used for sampling freely drifted, following the method outlined in MER sampling protocols (OEH 2016). Water quality data was downloaded from the device upon return to the office and laboratory.

A clean bucket was filled with approximately 10 litres of estuary water, collected from within 0.5 m of the surface using an integrated sampling pole, while drifting for 3 minutes in the sampling zone. The water in the bucket was used to collect samples for the analysis of chlorophyll-a, total suspended solids (TSS) and a suite of nutrients (total nitrogen, total dissolved nitrogen, ammonium, nitrate/nitrite, total phosphorous, total dissolved phosphorous and free reactive phosphorous). Total nutrient samples were directly transferred from the bucket to 30 ml vials using a clean 50 ml syringe barrel. All other nutrient samples were filtered immediately with 0.45 µm syringe-filters into two 30 ml vials. Nutrient samples were kept cool and frozen as soon as possible, in a portable freezer unit in the DCCEEW vehicle or, upon return to the laboratory.

Plastic bottles (111 ml) were filled with water from the bucket for chlorophyll-a analyses, taking care to exclude air bubbles. Chlorophyll-a samples were kept cool in an esky away from light until returning to the laboratory. One litre plastic bottles were filled with water from the bucket for TSS analysis, after mixing the water with the bottle to resuspend any solids. TSS samples were kept cool in an esky and stored in a cold room at 1-4 °C until analysis.

2.2 Laboratory analysis

Nutrient samples (frozen) were sent to Yanco Soil Laboratory or Sydney Water for analysis. Chlorophyll-a samples, kept cool in an esky and away from light, were filtered upon return to the laboratory, through 0.45 µm glass fibre filter papers under vacuum. Filter papers were frozen in labelled 50 ml vials until analysis. TSS samples were kept at 1-4 °C until analysis. Chlorophyll and TSS analyses were done in-house using American Public Health Association (APHA) methods. Chlorophyll-a concentrations were determined by UV fluorometry following extraction with 95 % acetone solution using method APHA 10200H (APHA, 2012). TSS samples were analysed using APHA methods 2130B and 2540D (APHA 2012).

2.3 Indicators/parameters

Turbidity and chlorophyll-a are considered appropriate measures of estuarine ecological health as they are short-term indicators of ecosystem performance in response to catchment pressure. Using turbidity and chlorophyll-a as the primary indicators to assess whole-of-estuary condition is consistent with the state-wide MER program protocols (OEH 2016). Data for other standard physicochemical parameters are also collected in the monitoring program, to provide context for the primary indicators and more information about water quality.

- **Chlorophyll-a** concentrations in the water column is used as a proxy for phytoplankton biomass and typically reflects the nutrient load into the system. Algae grow rapidly in response to inorganic nutrients; ammonia, nitrate and phosphate, which can lead to algal blooms if nutrients are present in excess.
- **Turbidity** measurements reflect water clarity and may reflect the sediment load to the estuary, including resuspension of catchment-derived fines from bed sediments. High turbidity can result in a reduction of light available for photosynthesis, limiting algal and seagrass growth. Thus, turbidity can be viewed as a surrogate for potential seagrass distribution.
- **Dissolved oxygen** is important for survival of most animals in aquatic systems and shows considerable variation during the daily cycle due to plant photosynthesis and respiration. Very high or very low concentrations of dissolved oxygen can indicate poor estuary condition. Sampling and assessment of dissolved oxygen presents many challenges as instantaneous dissolved oxygen levels depend on a few factors including salinity, temperature, time of day, cloud cover extent etc. when the sampling occurred. Surface water dissolved oxygen, as monitored in the MER program, is only useful for determining whether the entire water column is deoxygenated which occurs in severe situations. To gain a more wholistic

understanding of oxygen demand and production in the area of interest, dissolved oxygen should be measured across the complete diurnal cycle by data loggers deployed near the estuary floor.

- Salinity is a measure of the dissolved salts in the water. Salinity and temperature are measured to provide context for the other indicators.
- pH reflects the amount of hydrogen ions in lake water and is reported in pH units. Estuarine waters are typically slightly alkaline pH 7.5-8.0
- Electrical conductivity measures the ability of water to conduct an electrical current which depends on the concentration of dissolved salts (i.e., the salinity). Electrical conductivity increases with increasing water temperature. Specific conductivity is calculated (by the WQ sonde software) from electrical conductivity corrected to a standardised temperature, usually 25°C.
- Fluorescent Dissolved Organic Matter (fDOM) refers to the fraction of coloured dissolved organic matter (CDOM) that fluoresces. fDOM is a surrogate for CDOM and a fast and easy means of tracking DOM in waterbodies. DOM is a heterogenous mixture derived primarily from the decomposition products of terrestrial plant material, bacteria and algae.

Turbidity and chlorophyll-a data collected from NSW estuaries by DCCEEW as part of the state-wide estuarine MER Program have been used to develop trigger values specific to NSW estuaries (OEH 2016). Trigger values are derived from the 80th percentile values for variables measured in estuaries at seaward end of low disturbance catchments, for each estuary type (e.g., lake, lagoon, back dune lagoon etc). Compliance against a guideline or trigger value is commonly used to assess the status of a condition indicator. Exceeding the trigger value frequently, or by a large extent, should prompt further investigation or management action. Table 1 shows updated trigger values established for NSW lagoons and back dune lagoons that were generated from the state-wide estuarine water quality dataset (OEH 2018) and were used for grade calculations in this report.

Table 1 Trigger values for indicators in NSW Lagoons and Back Dune Lagoons (OEH 2018)

Indicator	Lagoons*	Back Dune Lagoons*
Turbidity NTU	4.4	4.2
Chlorophyll-a µg/L	3.9	5.3
Ammonia µg/L	22	222
NOx µg/L	10	23
TDN µg/L	560	1250
TN µg/L	625	1380
Phosphate µg/L	5	2
TDP µg/L	10	13
TP µg/L	25	32

*Terrigal Lagoon is a lagoon. Wamberal, Avoca and Cockrone Lagoons are back dune lagoons.

2.4 Data analysis

Estuary report card grades for the Central Coast Lagoons were calculated using salinity, turbidity and chlorophyll-a data collected during the water quality monitoring program. The estuary report cards for the lagoons now includes some analysis of water quality data in the context of lagoon entrance conditions, as well as some discussion of nutrient concentrations in the lagoons. All data collected in the program is compiled and sent to CCC in Microsoft Excel format each year. The data compilation includes all water quality parameters, total suspended solids (TSS), chlorophyll-a and nutrient concentration data.

2.4.1 Calculation of water quality grades

Water quality grades were calculated using a subset of turbidity and chlorophyll-a data from the 2024-2025 sampling period, only using data collected over the warmer months from October 2024 to April 2025 consistent with MER sampling protocols (OEH 2016). Grades for water quality were calculated based on how often and to what extent the values for turbidity and chlorophyll-a exceed the state-wide 80th percentile trigger values. Data collected in Wamberal Lagoon, Avoca Lagoon and Cockrone Lagoon were compared to the NSW Trigger Values for Back Dune Lagoons while data from Terrigal Lagoon were compared to NSW Trigger Values for Lagoons (Table 1). Chlorophyll-a and turbidity scores (which determine the grade) are averaged to get the overall water quality grade.

Grades assigned to turbidity, chlorophyll-a and overall water quality (A – very good, B – good, C – fair, D – poor and F – very poor) are determined by the zone score (0 - 1.0, Figure 2). The grade reflects the condition of a zone in comparison to the overall condition across all NSW estuaries with cut-off values for each grade defined by the percentage of estuaries in the state that received a score in that range (Figure 2). For example, a zone score of less than 0.07 is equivalent to the best 20% of scores in the state and receives an A (very good) grade (Figure 2, OEH 2016).

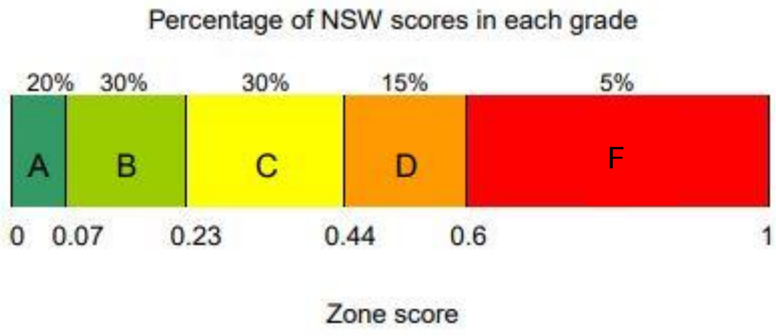

Figure 2 Relationship between distribution of NSW scores, grades and zone scores (OEH 2016)

In addition to the overall estuary grades, separate grading for each sampling zone in the lagoons has been provided for further insight into water quality in each region of the estuary. For example, in Avoca Lagoon it has been noted that water quality is continually poor at Zone 2, skewing the overall water quality grade for the estuary. These additional analyses may help prioritise management actions.

An additional metric is provided in the sliding scale diagram of the turbidity and chlorophyll-a grades shown below each table of grades for the whole estuary (Tables 2, 4, 6, 8). A percentage value is shown for each indicator based on the score received in the grade calculation. The percentage grade reflects the number of exceedances and the extent of exceedance of the respective trigger values and is calculated using the equation below. If there were no exceedances of the trigger value, a percentage grade of 100% is awarded. Lower percentages indicate that one or more samples exceeded the trigger value, with extent of exceedance further lowering the percentage grade.

$$Percentage\ grade\ [turbidity]\ (\%) = 100 - ([turbidity\ score]) * 100)$$
$$Percentage\ grade\ [chlorophyll - a]\ (\%) = 100 - ([chlorophyll - a\ score]) * 100)$$

Provision of the percentage grade allows for a finer scale assessment of change in chlorophyll-a and turbidity in the system, including occasions where the grade (A-F) remains the same.

A comprehensive description of how the water quality grades are calculated is available in *Assessing Estuary Ecosystem Health: Sampling, data analysis and reporting protocols*, NSW Natural Resources Monitoring, Evaluation and Reporting Program (OEH 2016).

2.5 QA/QC

The following QA/QC protocols were adhered to as part of this study:

- Standard operating procedures, best practice methods and peer-reviewed methods for completion of all field sampling, equipment operation and laboratory analyses.
- Equipment was calibrated at an appropriate frequency and well maintained to ensure highest quality field data collection.
- Maintain a high level of quality control of data management and file sharing and its interaction with end users and other external parties.
- Adhere to the principles in the DCCEEW Scientific Rigour statement.

3 Results

3.1 Report Card Grades

3.1.1 Wamberal Lagoon

Overall water quality in Wamberal Lagoon improved to a C (fair) grade in 2024-2025 (Table 2). The turbidity grade improved to D (poor) with a percentage grade of 50 % resulting from two minor and three moderate exceedances of the trigger value (Table 2, Figure 3). Turbidity levels were poor in Zone 1, which received a D grade and percentage grade of 42 % for turbidity (Table 3). The chlorophyll-a grade for the estuary improved to B (good) in 2024-2025 (Table 2) receiving a percentage grade of 91 % (Figure 3), with similar chlorophyll-a grades for Zone 1 and Zone 2 (Table 3). Overall water quality in Zone 2 scored a B grade (Table 3).

Table 2 Calculated water quality grades for Wamberal Lagoon during 2024-2025 and past monitoring periods for comparison.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality
2018 – 2019	D	B	C
2019 – 2020	D	B	C
2020 – 2021	D	B	C
2021 – 2022	B	A	B
2022 – 2023	D	B	B
2023 – 2024	F	C	D
2024 – 2025	**D**	**B**	**C**

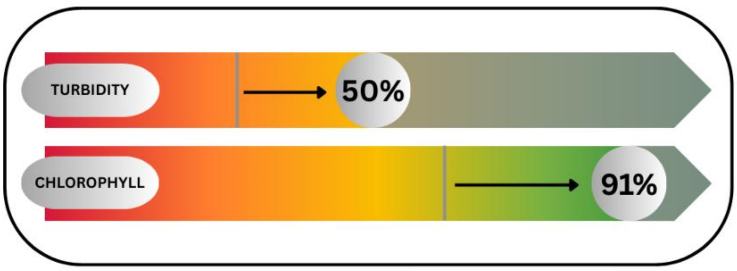

Figure 3 A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a in Wamberal Lagoon. Arrows indicate change from last year's percentage grades.

Table 3 Calculated water quality grades and percentage grades for each monitoring zone in Wamberal Lagoon for 2024-2025

Site	Turbidity	Turbidity % score	Chlorophyll-a	Chlorophyll-a % score	Overall Water Quality
WBL-Z-1	D	42	B	90	C
WBL-Z-2	C	57	B	92	B

3.1.2 Terrigal Lagoon

Water quality in Terrigal Lagoon declined in 2024-2025, receiving D (poor) grades for turbidity, chlorophyll-a and overall water quality (Table 4). The percentage grades for turbidity and chlorophyll-a declined to 50 % and 48 %, respectively (Figure 3). The poor grades for the estuary were driven by poor water quality in Zone 1 which received D grades for turbidity and chlorophyll-a, and percentage grades of 39 % and 41 %, respectively (Table 5). Turbidity in Zone 1 exceeded the trigger value on all sampling trips, three of which were moderate exceedances (2-3 times the trigger value) with one major exceedance (> 3 times the trigger value). Chlorophyll-a in Zone 1 exceeded the trigger value on four sampling trips, with two very large exceedances (47 & 35 μg/L) on March 21 and April 8, 2025. Water quality in Zone 2 was better, receiving a B grade for turbidity and 73 % for the percentage grade, and a C grade for chlorophyll-a and 70 % for the percentage grade (Table 5).

Table 4 Calculated water quality grades for Terrigal Lagoon during 2024-2025 and past monitoring periods for comparison.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality
2018 – 2019	D	B	C
2019 – 2020	D	B	C
2020 – 2021	C	B	C
2021 – 2022	D	C	C
2022 – 2023	C	C	C
2023 – 2024	C	C	C
2024 – 2025	**D**	**D**	**D**

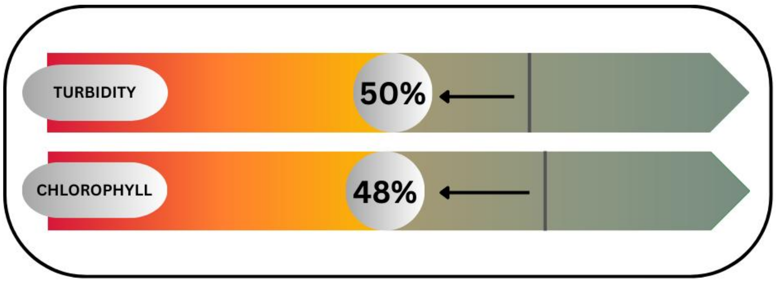

Figure 4 A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a in Terrigal Lagoon. Arrows indicate change from last year's percentage grades.

Table 5 Calculated water quality grades and percentage grades for monitoring zones in Terrigal Lagoon for 2024-2025

Site	Turbidity	Turbidity % score	Chlorophyll-a	Chlorophyll-a % score	Overall Water Quality
TGL-Z-1	D	39	D	41	D
TGL-Z-2	B	73	C	70	C

3.1.3 Avoca Lagoon

Water quality improved significantly in Avoca Lagoon in 2024-2025, with B (good) grades awarded for turbidity, chlorophyll-a and overall water quality (Table 6). The percentage grades for turbidity and chlorophyll-a improved to 83 % and 86 %, respectively (Figure 4). Zone 2 had the worst water quality, which is typical for this estuary, where turbidity received a C (fair) grade for turbidity, and 60 % for the percentage grade (Table 7). Turbidity in Zone 2 exceeded the trigger value on all sampling trips, most were minor except for April which was a major exceedance. All 3 zones received a B (good) grade for chlorophyll-a and percentage grades of 81-91 % (Table 7). It is the first time since 2020-2021 that Avoca Lagoon has scored a B (good) for overall water quality.

Table 6 Calculated water quality grades for Avoca Lagoon during 2024-2025 past monitoring periods for comparison.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality
2018 – 2019	F	D	F
2019 – 2020	F	D	F
2020 – 2021	C	B	B
2021 – 2022	C	B	C
2022 – 2023*	D	C	D
2023 – 2024*	D	C	D
2024 – 2025*	**B**	**B**	**B**

* Grades since 2022-2023 include three monitoring zones, while earlier years only include two monitoring zones.

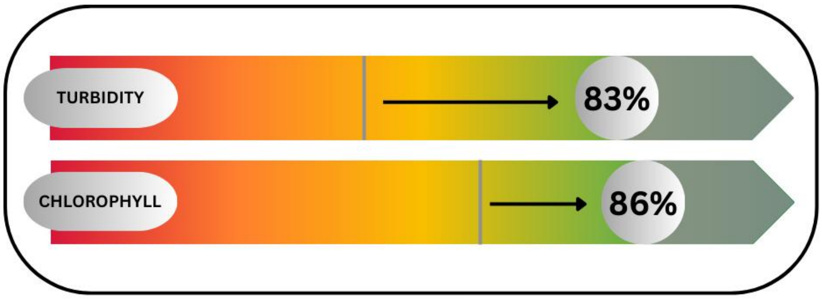

Figure 5 A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a in Avoca Lagoon. Arrows indicate change from last year's percentage grades.

Table 7 Calculated water quality grades and percentage grades for each monitoring zone in Avoca Lagoon for 2024-2025

Site	Turbidity	Turbidity % score	Chlorophyll-a	Chlorophyll-a % score	Overall Water Quality
AVO-Z-1	A	100	B	91	A
AVO-Z-2	C	60	B	89	B
AVO-Z-3	A	96	B	81	B

3.1.4 Cockrone Lagoon

Overall water quality in Cockrone Lagoon was very good again in 2024-2025, receiving A (very good) grades for turbidity, chlorophyll-a and overall water quality (Table 8). There were no exceedances of the turbidity trigger value in Zone 1 and 2 and only one minor exceedance of the chlorophyll-a trigger value in Zone 2, resulting in percentage grades of 100 % for the estuary (Figure 5, Table 9).

Table 8 Calculated water quality grades for Cockrone Lagoon during 2024-2025 and past monitoring periods for comparison.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality
2018 – 2019	C	A	B
2019 – 2020	A	A	A
2020 – 2021	B	A	A
2021 – 2022	B	B	B
2022 – 2023	B	A	B
2023 – 2024	B	A	A
2024 – 2025	A	A	A

Figure 6 A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a in Cockrone Lagoon. Arrows indicate change from last year's percentage grades.

Table 9 Calculated water quality grades and percentage grades for monitoring zones in Cockrone Lagoon for 2024-2025

Site	Turbidity	Turbidity % score	Chlorophyll-a	Chlorophyll-a % score	Overall Water Quality
CKR-Z-1	A	100	A	100	A
CKR-Z-2	A	100	A	97	A

3.2 Water quality data summary

Average salinity (psu), turbidity (NTU) and chlorophyll-a (µg/L) in the Central Coast Lagoons over the 12-month sampling periods of 2023-2024 and 2024-2025 are shown in Table 10. Salinity (psu), turbidity (NTU) and chlorophyll-a (µg/L) in the lagoons on the sampling dates in 2024-2025 are shown in Figures 6 – 8, relative to lagoon water height. Water level (m) data for each lagoon standardised to Australian Height Datum (AHD) were obtained from Manly Hydraulics Laboratory's Kister web portal (https://mhl.nsw.gov.au). Salinity (psu), turbidity (NTU) and chlorophyll-a (µg/L) in the lagoons are influenced by rainfall and entrance conditions, including the frequency and duration of opening events. These data are presented below in context of entrance conditions at the time of sampling.

3.2.1 Salinity

Wamberal Lagoon had the lowest average salinity of 15.5 psu which was in the range of 14.5 – 17.3 psu from August 2024 to June 2025, except for May 9 (21 psu, Figure 6). Terrigal and Cockrone Lagoons had the highest average salinities of 24.0 psu and 24.7 psu (Table 10). Salinity at Cockrone Lagoon was relatively stable from August 2024 to April 2025, ranging from of 23-25 psu when the entrance was closed (Figure 6). Salinity in Terrigal Lagoon was more variable over 2024-2025 due to frequent opening and closing events, ranging from 28-32 psu during ocean exchange, and 10-20 psu when closed (Figure 6). Salinity in Avoca Lagoon dropped gradually from ~25 psu in August 2024 to 16 psu in March 2025 while the entrance was closed, increasing to ~28-32 psu in April/May 2025 when the entrance was opened (Figure 6).

Table 10 Averaged salinity (psu), turbidity (NTU) and chlorophyll-a (µg/L) across the four Central Coast Lagoons over the 12-month sampling periods in 2023-2024 and 2024-2025.

	2023-2024 Salinity (psu)	2023-2024 Turbidity (NTU)	2023-2024 Chlorophyll-a (µg/L)	2024-2025 Salinity (psu)	2024-2025 Turbidity (NTU)	2024-2025 Chlorophyll-a (µg/L)
Wamberal	22.9	11.2	8.5	15.5	7.3	3.5
Terrigal	11.5	6.1	7.3	24.0	7.0	8.0
Avoca	19.0	9.2	9.7	20.6	3.7	3.0
Cockrone	15.6	3.0	1.9	24.7	2.1	2.1

3.2.2 Chlorophyll-a

Average chlorophyll-a concentrations in Wamberal and Avoca Lagoons in 2024-2025 were 60-70 % lower compared to 2023-2024 (Table 10). Average chlorophyll-a concentrations in 2024-2025 in Terrigal and Cockrone Lagoons were slightly higher compared to 2023-2024 (Table 10). Chlorophyll-a concentrations were very high (25-26 µg/L) in Terrigal in March and April 2025 when lagoon water level was 2.1-2.5 m, before entrance breakout on 23 April 2025 following 300 mm of rainfall in March-April 2025 (Figure 7, Table 11). Chlorophyll-a concentrations were generally below 4 µg/L in Wamberal, Avoca and Cockrone Lagoons for most of 2024-2025 (Figure 7).

3.2.3 Turbidity

Average turbidity in Wamberal, Avoca and Cockrone Lagoons was 30-40 % lower in 2024-2025 compared to 2023-2024 (Table 10). Average turbidity in Terrigal Lagoon was slightly higher in 2024-2025 compared to 2023-2024 (Table 10). Turbidity in Avoca lagoon was typically below 4 NTU and was always below 3.3 NTU in Cockrone Lagoon (Figure 8). Turbidity increased to ~11 NTU in Wamberal in January and February 2025 following partial entrance opening and reclosure, peaking at 16.5 NTU before entrance breakout on 23 April 2025 (Figure 8). Turbidity was more variable in Terrigal due to more frequent opening and closing of the entrance, however no clear pattern was discernible (Figure 8). Turbidity ranged from 3-16.5 NTU in Terrigal while the lagoon was open and 3.4-6.8 NTU while the lagoon was closed (Figure 8).

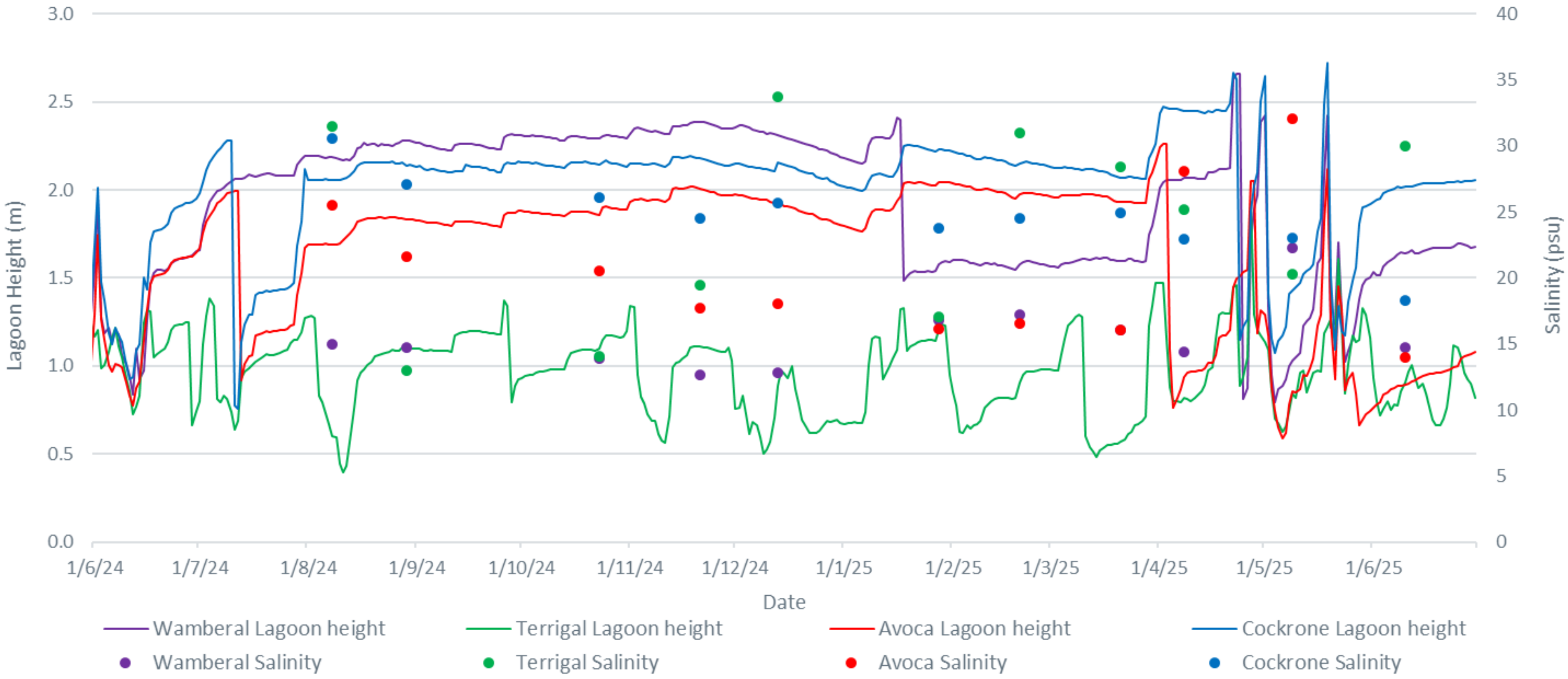

Figure 7 Salinity (psu, right axis) in the Central Coast Lagoons on sampling dates from July 2024 to June 30 2025, relative to lagoon water level (mAHD, left axis). Water level is shown from June 1, 2024, to June 30, 2025.

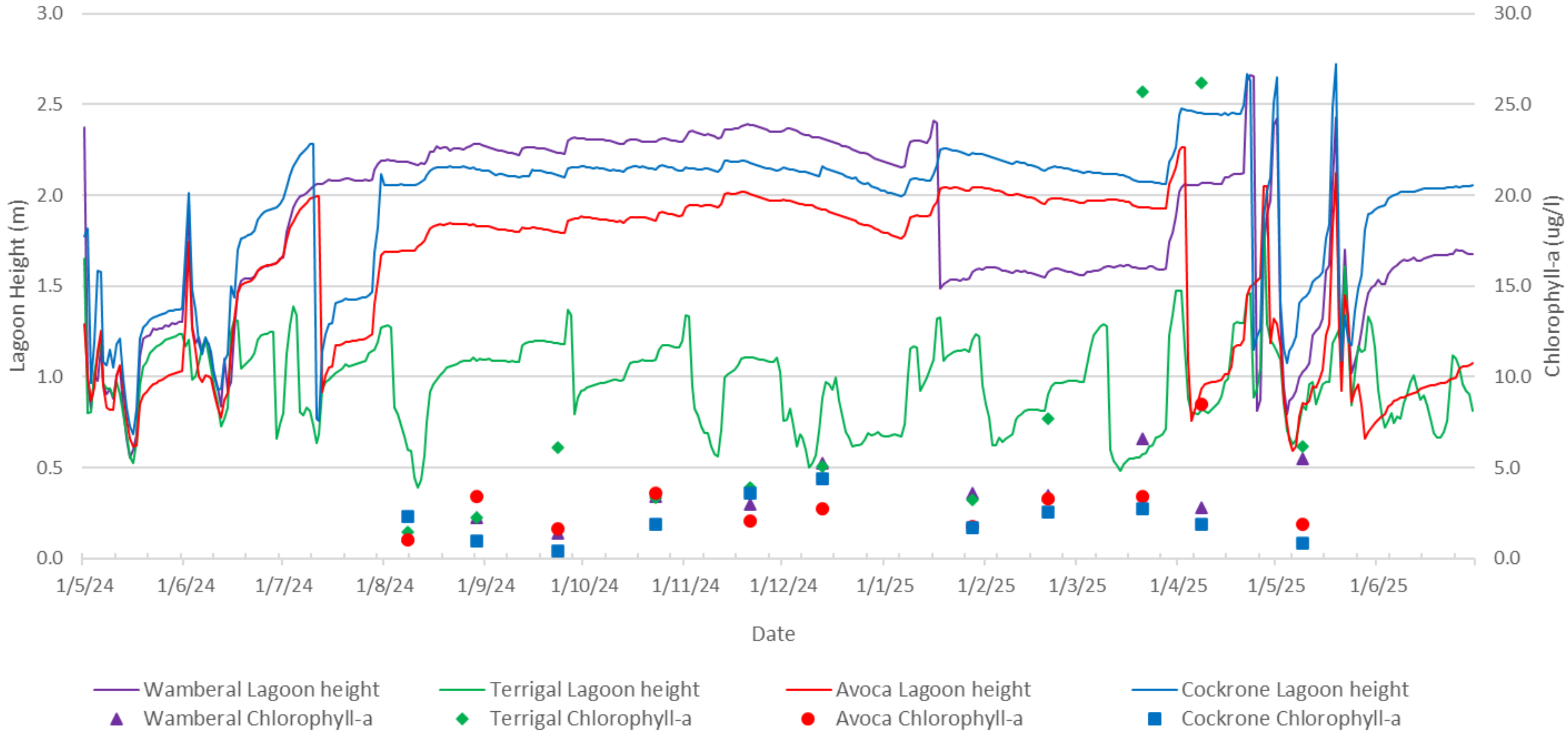

Figure 8 Chlorophyll-a concentrations (µg/L, right axis) in the Central Coast Lagoons on sampling dates from June 2024 to June 2025, relative to lagoon water level (mAHD, left axis). Water level is shown from June 1, 2024, to June 30, 2025

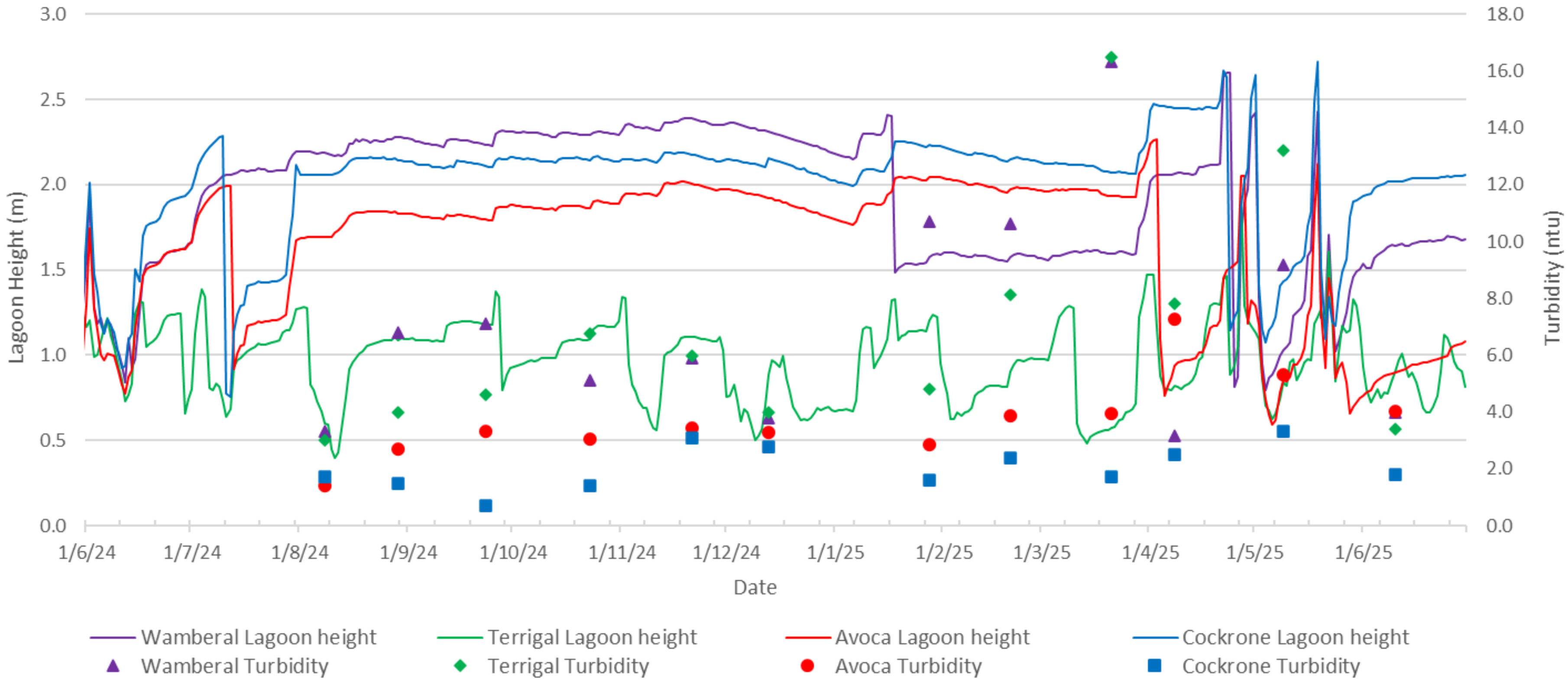

Figure 9 Turbidity (NTU, right axis) in the Central Coast Lagoons on sampling dates from June 2024 to June 2025, relative to lagoon water level (mAHD, left axis). Water level is shown from June 1, 2024, to June 30, 2025.

4 Summary and discussion

DCCEEW have observed and reported improved water quality across most of the Central Coast estuaries in 2024-2025, which was also the case for Lake Macquarie and estuaries on the mid coast of NSW. Water quality remained very good in both zones of Cockrone Lagoon but declined in Terrigal Lagoon in 2024-2025 due to poor (D) grades for both turbidity and chlorophyll-a. Avoca Lagoon had the greatest improvement in water quality, achieving the best results since the monitoring program began in 2018-2019 (Table 6). Turbidity, chlorophyll-a and overall water quality in Avoca Lagoon all received good (B) grades in 2024-2025.

The improvement in turbidity and chlorophyll-a grades (and the overall water quality grades) in 2024-2025 is likely to be linked to lower rainfall overall (compared to previous years), as well as low level of rainfall in the days prior to most sampling dates (Table 10, Table 11). Total monthly rainfall at Gosford (AWS 61425) over the MER sampling period, October 2024 to April 2025, was 735 mm, well below the 8-year average for this period (916 mm, Table 11) but on par with the 15-year average for this period (725 mm). In October 2024, December 2024 and February 2025, monthly rainfall was less than half the long-term average, whereas higher-than-average rainfall was recorded in January 2025 and April 2025 (Table 10). Chlorophyll-a concentrations in estuary waters can increase following rainfall as dissolved organic nutrients (ammonium, nitrate, phosphates) in catchment runoff fuel algal (phytoplankton) growth. This year, however, chlorophyll-a concentrations remained relatively low for most of the year across the lagoons (Figure 7). There was only one spike in chlorophyll-a concentration in Avoca in April 2025 (8.5 μg/L), and two very large spikes in chlorophyll-a in Terrigal in March-April 2025 (25-26 μg/L). Turbidity was the variable which performed more poorly in 2024-2025 in Terrigal and Wamberal Lagoons.

The water quality within the lagoons varied between zones at Avoca, Wamberal and Terrigal. Wamberal Zone 1 and Avoca Zone 2 had the poorer water quality within each estuary, which is typical result for these lagoons. Turbidity in the lagoon is influenced by catchment runoff, however, frequent resuspension of bottom sediments by wind-waves is the dominant process affecting turbidity in the shallow regions of the back dune lagoons (BDLs). Wamberal Lagoon is a shallow system with Zone 1 located in the large basin that is oriented north. These factors make it vulnerable to high turbidity and chlorophyll-a, especially during summer when prevailing north-easterly winds continually resuspend bed sediments and benthic microalgae. Characteristics of Avoca Zone 2 are like those described above for Wamberal Zone 1. This year, the poor results in Wamberal Zone 1 and Avoca Zone 2 were driven by poor turbidity but chlorophyll-a levels were good.

Back dune lagoons such as Avoca and Wamberal Lagoons are typically predominantly closed for more than 80 % of the time and two features distinguish BDLs from lagoons (DPIE 2021). BDL entrances tend to close rapidly after breakout due to small freshwater inputs relative to onshore sand supply (DPIE 2021). Significant groundwater inputs are also likely to influence water quality in BDLs (DPIE 2021). If BDLs are left to open naturally in response to high rainfall, it is more likely that continued rainfall will refill the lagoon upon closure. This greater water volume allows for better scouring to take place during an opening event, removing the fine sediment, and excess nutrients that directly impact the systems water quality.

Avoca Lagoon was closed from July 2024 to March 31, 2025, and was opened manually by Council twice in April for flood mitigation (Figure 6). Avoca Lagoon then opened naturally in May 2025 following very high rainfall and big swells associated with an East Coast low pressure event (Figure 6). Wamberal Lagoon was opened manually in mid-January, but only partially with the lagoon retaining an intermediate water level height of 1.5 m until end of March 2025. Water level increased rapidly to 2.0 m in early April followed by another rapid increase to just over 2.5 m on April 21, 2025, in response to heavy rainfall. Wamberal Lagoon was opened manually by Council on April 24 and May 1, 2025, for flood mitigation followed by a natural opening event in mid-May 2025.

Improved water quality in Avoca and Wamberal Lagoons in 2024-2025 is likely to be due to the lagoons being closed from October 2024 to April 2025, the period for which grades are calculated, with minimal catchment inputs occurring in the days prior to sampling. Following the natural opening events in May-June 2024 in response to very high rainfall, both BDLs refilled throughout June – July 2024 to a relatively stable water level throughout spring and summer months (Figure 6). Higher water levels benefit lagoon water quality by reducing the extent and magnitude of resuspension of sediments and benthic microalgae. Chlorophyll-a levels were generally below 5 µg/L in Avoca, Wamberal and Cockrone while the lagoons were closed (Figure 7). Turbidity was more variable in Wamberal and Terrigal but generally below 4 NTU in Avoca and Cockrone (Figure 8).

Water quality in Zone 1 at Terrigal was much worse than in Zone 2, which led to poor (D) grades for turbidity, chlorophyll-a and overall water quality for the estuary in 2024-2025. Algal biomass in Terrigal Lagoon peaked in March and April (~25 µg/L) following above average rainfall (Figure 7, Table 11). Terrigal Lagoon is the only Central Coast Lagoon that is classed as a lagoon. Terrigal Lagoon was open/partially open on approximately ten occasions this sampling season, with the majority being manual openings by Council. Water residence times were therefore less than the other lagoons with salinity in the lagoon increasing to 28-34 psu while open, indicating a good degree of exchange with oceanic water (Figure 6). However, like the other Central Coast lagoons, large parts of Terrigal are very shallow and prone to resuspension of sediments which affects the turbidity and chlorophyll-a levels and thus the water quality grades, particularly during frequent opening and closing of the entrance which disturbs bottom sediments. The highest turbidity and chlorophyll-a concentrations occurred following manual opening events in March-May 2025, however, catchment inputs would have also contributed to poor water quality in Terrigal Lagoon (Figure 7, Figure 8).

Water quality was very good in both zones in Cockrone Lagoon. Cockrone Lagoon's very good (A) water quality grades also show that long residence times brought about by limited opening events can have a positive impact water quality. Estuary water in Cockrone Lagoon had the longest residence time of all the systems, only seeing its first flush in April 2025 following manual opening by Council on April 22 and May 1, 2025, and a natural opening event in mid-May (Figure 6). Several factors contribute to Cockrone Lagoon having very good water quality, including its orientation, less developed catchment, and wetlands and riparian vegetation around the perimeter. The basin's orientation is east to west, with surrounding hills on the northern side that buffer prevailing winds from the nor-east throughout summer. Approximately half the catchment is residential while the rest of the catchment is less modified and well forested. Wetlands and riparian vegetation act as a buffer that filter sediments and nutrients from surface runoff. Cockrone Lagoon was the only lagoon to receive a very good grade for chlorophyll-a due to no exceedance of the chlorophyll-a trigger value. Macroalgae present in Cockrone Lagoon utilise excess nutrients limiting nutrient availability to suspended and benthic microalgae in the water column.

Nutrient data are only currently available from August 2024 to February-March 2025 with remaining samples awaiting laboratory analysis. Concentrations of ammonium (NH_4^+) and nitrate/nitrite (NO_x) were generally high in all lagoons, while phosphate concentrations were low, indicating that phytoplankton growth in the lagoons is limited by phosphorous. NSW trigger values for ammonium (NH_4^+), nitrate/nitrite (NO_x) and phosphates (PO_4^{3-}) are substantially higher for the estuary types - back dune lagoons (Avoca, Wamberal and Cockrone) and to a lesser degree for lagoons (Terrigal, Table 1 OEH 2018). NH_4^+ and NO_x concentrations in Terrigal Lagoon exceeded the respective NSW trigger values for NSW lagoons of 22 µg/L and 10 µg/L on 3-4 sampling trips from August 2024 to March 2025. In Terrigal Lagoon Zones 1-2, NH_4^+ concentrations ranged from 3-68 µg/L and NO_x concentrations ranged from 1-26 µg/L, while PO_4^{3-} concentrations ranged from 1-4 µg/L, below the NSW trigger value of 5 µg/L (Table 1, OEH 2018).

NH_4^+ concentrations in Wamberal Lagoon from August 2024 to March 2024-25 were at times very high, ranging from 10-240 µg/L, exceeding the NSW trigger value of 222 µg/L in August-September 2024. NO_x concentrations were also high in Wamberal Lagoon from August-October 2024 to March 2025, ranging from 26-70 µg/L and exceeding the NSW trigger value of 23 µg/L. PO_4^{3-} concentrations ranged from 1-2 µg/L, below the NSW trigger value of 2 µg/L (Table 1, OEH 2018). Nutrient concentrations in Avoca and Cockrone Lagoons remained below the NSW trigger values from August 2024 to February 2025. NH_4^+ concentrations, however, were often quite high in these lagoons, with a maximum concentration of 62 and 150 µg/L in Avoca and Cockrone Lagoons, respectively. Ammonification of NOx occurs in the sediments during the breakdown of organic material, returning NH_4^+ to the water column. PO_4^{3-} concentrations were always below the NSW trigger value of 2 µg/L (Table 1, OEH 2018), again demonstrating that phytoplankton growth in the Central Coast lagoons is limited by phosphorous.

Table 11 Monthly rainfall totals (mm) from October 2017 to June 2025 at Gosford Australian Weather Station (AWS, 61425, Bureau of Meteorology). Monthly totals in green font are from Ourimbah AWS (61093) as data were not available from Gosford AWS. Long-term monthly average rainfall at Gosford AWS from 2013-2025 are shown. Total annual rainfall from 2017 to 2024 at Gosford AWS is shown, with values in green font being a combination of data from Gosford AWS and Ourimbah AWS.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2017	35.6	152.4	399.2	113.4	36	*173.2*	7.8	10.6	2.4	79.2	78	61.8	**1150**
2018	26.6	163.2	102.8	73	17.8	213.6	12	17.6	58.2	258	*131.4*	*68.6*	**1143**
2019	57	109	256.4	40.2	17.6	161.2	46	212.6	112.6	49.8	*21.8*	3	**1087**
2020	125.6	*538.6*	180.4	39.8	50.2	56.4	171.6	51.2	50.2	253.2	36.2	197.6	**1751**
2021	119.6	91.4	467.6	41.4	81.4	67.6	44.8	72.2	46.2	55.6	190.2	150.6	**1429**
2022	116	*340.2*	579	225.2	129.8	14	448.8	30.2	149.4	160.6	25.2	49	**2267**
2023	88	173.4	74.6	133.2	46.8	21.2	*22.2*	*57.4*	16.8	58.8	135	66	**893**
2024	85.4	121.6	22.4	305.6	245.2	196	68.6	39.4	74.2	46.6	81	16.8	**1303**
2025	197.4	51.4	137.4	204.6	367.2	7.4							
Monthly and annual means (2013-2025)	**118.9**	**115.5**	**214.9**	**153**	**100.5**	**118.6**	**87.4**	**76.7**	**64**	**97.6**	**91.4**	**75.7**	**1314**

Table 11. A. Total rainfall (mm) recorded from October to April for each monitoring season (2017/18 to 2024/25) at Gosford/Ourimbah AWS are shown. Water quality data collected in this period are used to calculate the water quality grades. B. Rainfall recorded at Gosford AWS in the 3-days and 7-days prior to water quality sampling are shown as recent rainfall can affect water quality.

A.

Sampling period	Total rainfall (mm)
Oct 2017 - Apr 2018	585
Oct 2018 - Apr 2019	859
Oct 2019 - Apr 2020	677
Oct 2020 - Apr 2021	1207
Oct 2021 - Apr 2022	1763
Oct 2022 - Apr 2023	704
Oct 2023 - Apr 2024	795
Oct 2024 - Apr 2025	735
8-year average	916

B.

Sampling date	Rainfall mm 3-days prior	Rainfall mm 7-days prior
8/08/2024	0.6	2.0
29/08/2024	0	0.8
23/9/2024	0	0
23/10/2024	0	2.6
21/11/2024	0.8	12.8
13/12/2024	0	1.6
28/01/2025	1.4	1.4
20/02/2025	0	5.8
21/03/2025	0	0
8/04/2025	6.2	6.2
9/05/2025	3.8	10
10/06/2025	0.6	5.2

5 References

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