Department of Climate Change, Energy, the Environment and Water

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Estuary Report Card 2023-2024 Lake Macquarie

June 2024

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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Acknowledgements

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Contents

1 Introduction

1.1 Background

The Lake Macquarie City Council (LMCC) engaged the Estuaries and Catchments Team of the Department of Climate Change, Energy, the Environment and Water (DCCEEW) to monitor water quality and ecological health in Lake Macquarie over the 2023-2024 financial year and provide Council with an estuary report card. The monitoring program in Lake Macquarie has been ongoing since 2011. LMCC recognises that long-term monitoring programs are essential for tracking estuary ecological health over time and help to identify potential areas requiring further management actions.

1.1.1 Location

Lake Macquarie (Awaba) is the largest coastal saltwater lake in New South Wales, located in the Lower Hunter region on the lands of the Awabakal First Nations people. The Lake has a permanent entrance to the Tasman Sea at Swansea channel, approximately 20 kilometres south-west of Newcastle. All of Lake Macquarie and most of the catchment fall within the LMCC Local Government Area (LGA).

1.1.2 Program outline and scope

LMCC engaged the Estuaries and Catchments Team of DCCEEW to monitor water quality and ecological health in Lake Macquarie over the 2023-2024 financial year and provide Council with an estuary report card. The Lake Macquarie Water Quality Monitoring Program was designed by DCCEEW following 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 each month at thirteen zones and seagrass depth range was surveyed annually at five sites (Figure 1). The majority of the catchments for the southern bays (Crangan Bay, Chain Valley Bay and Wyee Bay) lay in the Central Coast Council (CCC) LGA thus CCC funds the monitoring of zones in those bays (Figure 1).

1.1.3 Aims and objectives of the program

The aim of The Lake Macquarie Water Quality Monitoring Program is to assess the ecological health of Lake Macquarie using methods that are scientifically valid and standardised. The objectives are to:

- Track change in condition and continue to build a long-term dataset to support management decisions by LMCC
- Collect data for potential use in future hydrodynamic and ecological response models
- Provide LMCC 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 lakes. To ensure representative spatial coverage, the estuary is divided into zones typically 500-700m in diameter in lakes (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 Lake Macquarie and its tributaries (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.

Lake Macquarie is a vast lake over 20 kilometres long and up to 11 kilometres wide, with a surface area of 110 square kilometres. The Lake has multiple basins and bays, isolated embayments and two major tributaries (Figure 1). Its size and complex lake morphology require monitoring zones to be spread across the lake and in Cockle Creek and Dora Creek, rather than just monitoring the central basins of the lake (OEH 2016).

Over a 12-month period, water quality sampling was carried out at 10 monitoring zones throughout the lake (Figure 1) for LMCC: one zone in each lake basin (B1-north, B6-south basin), four zones in bays throughout the lake (L1, L2, L4, L5), one zone in the isolated embayment of Fennell Bay (L6), one zone in Swansea channel (B4), and one zone in each of the two major inflowing tributaries to the lake – Cockle Creek (E3) and Dora Creek (E1, Figure 1). Sampling at this frequency allows both monthly and seasonal variability in water quality to be assessed. Note that water quality is also monitored at three additional zones (CC1, CCC2, CCC3) in the southern bays of Lake Macquarie which fall in the CCC LGA (Figure 1). CCC funds that component of the Program however the data collected in the southern bays is incorporated into the analysis presented in this report.

Seagrass depth range was surveyed at five monitoring sites in April 2024: M5 (Wangi Wangi), M7 (Point Wolstoncroft), M8 (Valentine), M11 (Fennell Bay) and M12 (Mannering Park).

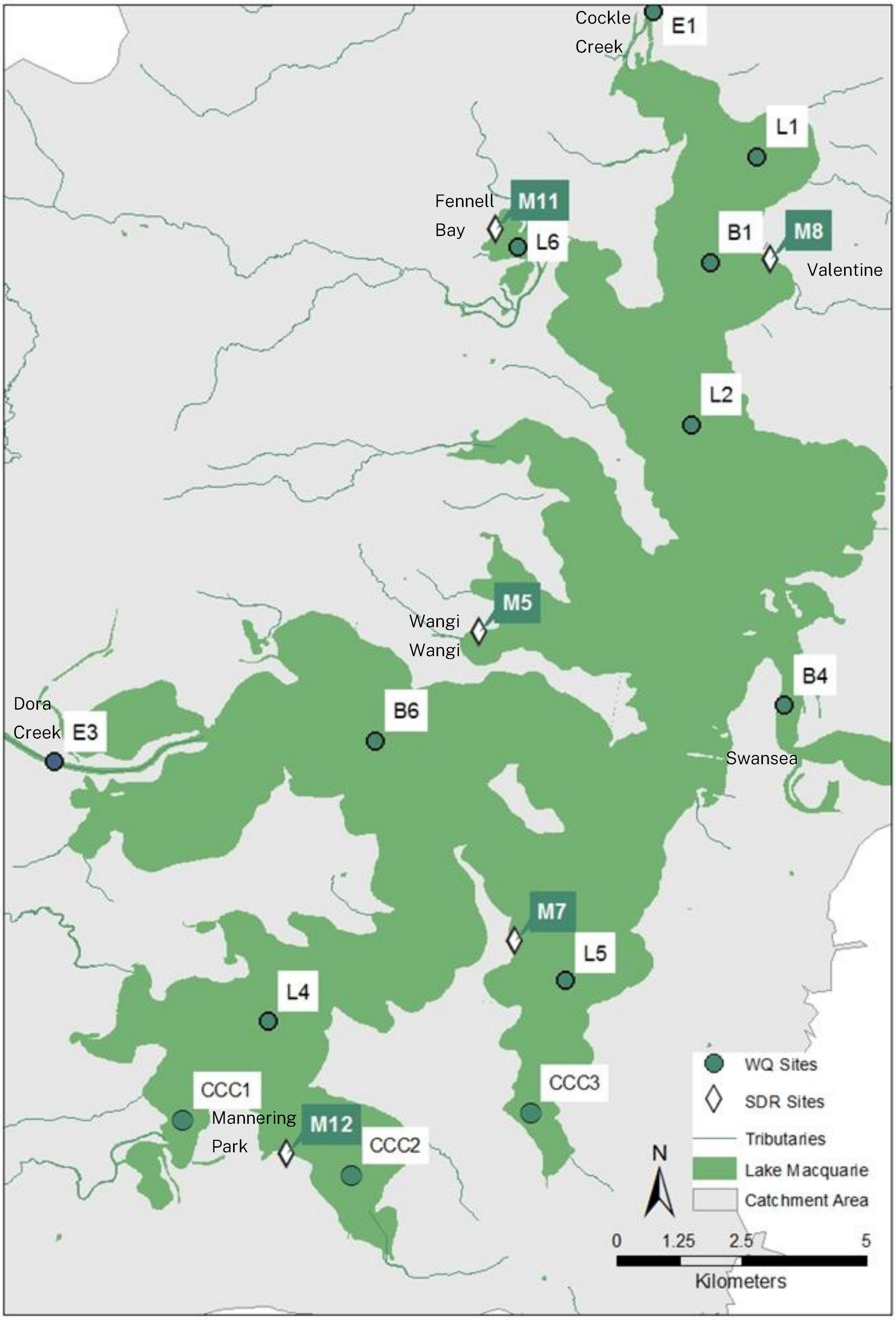


Figure 1 Sampling locations in Lake Macquarie for water quality monitoring and seagrass depth range assessments for 2023-2024. Note: CCC1, CCC2 and CCC3 monitoring zones in the southern bays form part of the CCC estuary monitoring program.

2.1.1 Sampling methods

Water quality

All sampling was conducted from a 4.5m research vessel. Using a Xylem EXO-2 multiparameter water quality sonde (WQ sonde) lowered to 0.3-0.5m below surface, physicochemical water quality parameters were recorded, including:

- turbidity,
- temperature,
- salinity,
- 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 0.5m 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 0.5m 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 30ml vials using a clean 50-ml syringe barrel. All other nutrient samples were filtered immediately with 0.45 µm syringe-filters into two 30ml 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 (111ml) 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.

Seagrass depth range

Seagrass depth range (SDR) was calculated from the minimum and maximum water depth for seagrass cover at the site. Water depth was measured at the shallow limit and deep limit of seagrass *Zostera capricorni* cover across three transects at each monitoring site. One transect is a routine transect used in the survey each year. The remaining two transects are randomly located within 50 m each side of the routine transect. All depths were standardised to a number of standard height markers within the lake to remove potential errors from changing water levels

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 50ml vials until analysis. TSS samples were kept at 1-4° 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, chlorophyll-a and change in seagrass extent are considered appropriate measures of estuarine ecological health as they are short-term (turbidity, chlorophyll-a) and long-term (seagrasses) indicators of ecosystem performance in response to catchment pressure. There are extensive seagrass beds present in the main basin of Brisbane Water and annual change in seagrass depth range has been included as an additional indicator of ecological health since the monitoring program commenced. Monitoring seagrass depth range helps track their health and resilience.

Using turbidity, chlorophyll-a and change in seagrass extent 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.
- **Seagrasses** reflect changes in water quality as their high light requirements make them sensitive to turbidity, salinity, and other environmental conditions.
- **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.
- **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, river, 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 lakes and rivers that were generated from the state-wide estuarine water quality dataset (OEH 2018) and are used for grade calculations in this report.

Table 1 Trigger Values for water quality indicators in NSW Lakes and Rivers (OEH 2018).

Indicators	Lakes	Rivers Lower (>25psu)	Rivers Mid (10-25psu)	Rivers Upper (<10psu)
Turbidity NTU	5.5	3	3.1	6
Chlorophyll-a µg/L	5.3	2.7	4.3	4.8
Ammonia µg/L	14	10	29	52
NOx µg/L	3	5	40	34
TDN µg/L	670	270	320	550
TN µg/L	750	270	420	670
Phosphate µg/L	1	2	2	5
TDP µg/L	9	6	6	6
TP µg/L	24	12	14	16

2.4 Data analysis

Estuary report card grades for Lake Macquarie were calculated using salinity, turbidity, chlorophyll-a and seagrass depth range data collected during the water quality monitoring program. Since program inception, there has been no further analysis of any additional water quality data (outlined in Section 2.3), however, all data from the program is compiled and sent to LMCC 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 Water Quality Grades

Water quality grades were calculated using a subset of turbidity and chlorophyll-a data from the 2023-2024 sampling period, collected over the warmer months from October 2023 to April 2024, consistent with MER sampling protocols (OEH 2016). Grades for water quality are calculated by looking at how often and to what extent the values for turbidity and chlorophyll-a exceed the state-wide 80th percentile trigger values. Data from lake basin/bay sites were compared to the NSW Trigger Values for Lakes while data collected in the tributaries were compared to NSW Trigger

Values for Rivers (Table 1). Chlorophyll-a and turbidity scores determine the grades for these indicators, which are then averaged to get the overall water quality grade.

For Fennell Bay (L6) and the tributary monitoring sites (E1, E3), report card grades for turbidity and chlorophyll-a were calculated and turbidity and chlorophyll-a scores were averaged to get the overall water quality grade. Other sites in the lake and bays were grouped into broad zones (Northern, Southeast, Southwest), and grades for turbidity and chlorophyll were calculated for the zone by averaging the turbidity and chlorophyll scores from each site within that zone. Zone scores for turbidity and chlorophyll were averaged to get the overall water quality grade for the zone.

An additional metric is provided in the sliding scale diagram of the turbidity and chlorophyll-a grades shown below each table of grades (Tables 1-8). 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.

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

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

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).

2.4.2 Seagrass depth range grade

Seagrass depth range (SDR) is calculated by measuring water depth at the shallow limit and deep limit of seagrass *Zostera muelleri* cover across three transects at each monitoring site. The mean shallow limit is subtracted from the mean deep limit to give the depth range for that site. All depths are standardised to a number of standard height markers within the lake to remove potential errors from changing water levels. There are two components used to calculate the SDR grade, a depth grade and a trend grade. The depth grade compares the measured depth range to an expected depth range based on the physical attributes of the site if conditions were optimal. The trend grade compares the recorded depth range that year with the depth range from the previous year and reflects how seagrass has progressed, recovered, or regressed over time.

A percentage value is shown on the sliding scale depiction of the SDR grade that reflects the points awarded in the grade calculation, with 100% reflecting the maximum points assigned.

2.4.3 Overall ecological health grade

The overall ecological health grade is calculated by combining the average scores for turbidity and chlorophyll-a (70% weighting) with the score for seagrass depth range (30% weighting) for those zones where seagrass depth range is monitored. For those zones where only water quality is monitored, the overall grade is equivalent to the overall water quality grade.

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 the 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

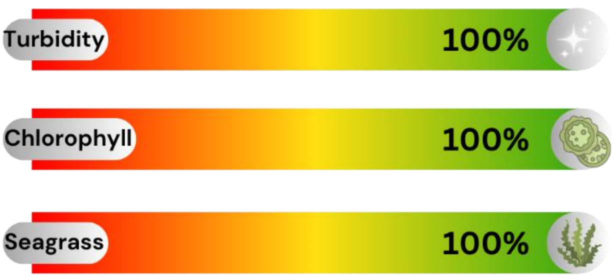
3.1.1 Northern Zone (L1, L2, B1, M5, M8)

The Northern Zone of Lake Macquarie scored A (very good) grades for overall water quality and ecological health for the twelfth consecutive year (Table 2). There were no exceedances of the 80th percentile trigger values for turbidity or chlorophyll-a resulting in an A (very good) grade and a percentage grade of 100% for each indicator. Similarly, sea grass depth range (SDR) at M5 and M8 received an A grade and a percentage grade of 100% (Table 2). SDR increased by 0.14m to 3.13m, averaged across the two sites (Table 9).

Table 2 Report card grades for the Northern Zone during 2023-2024 and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range is shown below the table.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Ecological Health
2011 - 2012	C	B	C	A	B
2012 - 2013	A	B	A	A	A
2013 - 2014	A	A(*B)	A(*B)	A	A
2014 - 2015	A	A(*B)	A	A	A
2015 - 2016	A	A	A	B	A
2016 - 2017	A	A(*B)	A(*B)	A	A
2017 - 2018	A	A	A	A	A
2018 - 2019	A	A	A	A	A
2019 - 2020	A	A	A	A	A
2020 - 2021	A	A	A	A	A
2021 - 2022	A	B	A	A	A
2022 - 2023	A	A	A	A	A
2023 - 2024	**A**	**A**	**A**	**A**	**A**

(*) previous grade reported using old trigger values



3.1.2 Swansea Channel (B4)

Swansea channel scored an A (very good) grade for overall water quality for the twelfth consecutive year (Table 3). There were no exceedances of the 80th percentile trigger values for turbidity or chlorophyll-a, resulting in an A (very good) grade for turbidity and an improved grade for chlorophyll (A-very good) for 2023-24 (Table 3). Both indicators received a percentage grade of 100%.

Table 3 Report card grades for Swansea channel during 2023-2024 and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a is shown below the table.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Grade
2011 - 2012	C	A	B		B
2012 - 2013	A	B	A		A
2013 - 2014	A	A(*B)	A(*B)		A(*B)
2014 - 2015	A	A(*B)	A		A
2015 - 2016	A	A(*B)	A		A
2016 - 2017	A	A(*B)	A		A
2017 - 2018	A	A	A		A
2018 - 2019	A	A	A		A
2019 – 2020	A	A	A		A
2020 – 2021	A	A	A		A
2021 – 2022	A	A	A		A
2022 – 2023	A	B	A		A
2023 - 2024	**A**	**A**	**A**		**A**

(*) previous grade reported using old trigger values

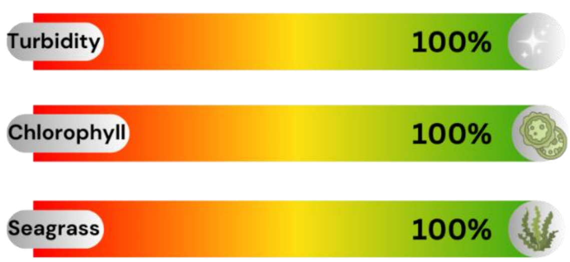
3.1.3 Southeast Zone (L5, CCC3, M7)

The Southeast Zone of Lake Macquarie scored A (very good) grades for overall water quality and ecological health for the twelfth consecutive year (Table 4). There were no exceedances of the 80^{th} percentile trigger values for turbidity or chlorophyll-a: A (very good) grades were retained in 2023-2024 (Table 4). The seagrass depth range at the M7 site in the Southeast Zone increased by 0.48m to 4.29m (Table 9) and an A grade this year (Table 4). All indicators received a percentage grade of 100%.

Table 4 Report card grades for the Southeast Zone during 2023-2024 and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range is shown below the table.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Ecological Health
2011 - 2012	B	A(*B)	B	A	A
2012 - 2013	A	A	A	A	A
2013 - 2014	A	A(*B)	A	A	A
2014 - 2015	A	A	A	A	A
2015 - 2016	A	A(*B)	A	A	A
2016 - 2017	A	A(*B)	A	A	A
2017 - 2018	A	A	A	A	A
2018 - 2019	A	A	A	A	A
2019 - 2020	A	A	A	A	A
2020 - 2021	A	A	A	A	A
2021 - 2022	A	A	A	A	A
2022 - 2023	A	A	A	A	A
2023 - 2024	**A**	**A**	**A**	**A**	**A**

(*) previous grade reported using old trigger values



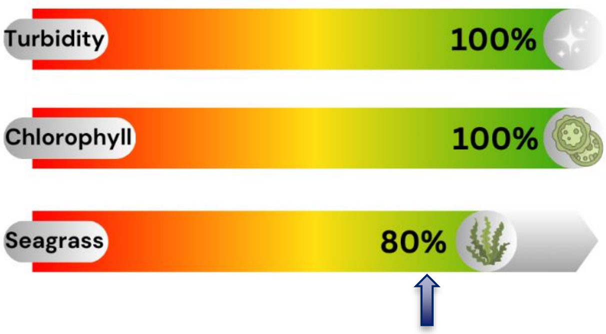
3.1.4 Southwest Zone (L4, B6, CCC1, CCC2, M12)

The Southwest Zone of Lake Macquarie scored A (very good) grades for overall water quality and ecological health for the twelfth consecutive year (Table 5). There were no exceedances of the 80^{th} percentile trigger values for turbidity or chlorophyll-a: A (very good) grades were retained in 2023-2024 (Table 5). Seagrass depth range at M12 in the Southwest Zone increased by 0.37m to 1.74m (Table 9) in 2023-2024 resulting in an improved percentage grade of 80% (from 70% in 2022-2023) and an improved grade to B (good, Table 5).

Table 5 Report card grades for the Southwest Zone during 2023-2024 and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range (relative to 2022-23 percentage grades, arrow) is shown below the table.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Ecological Health
2011 - 2012	B	A(*B)	B	D	C
2012 - 2013	A	A	A	B	A
2013 - 2014	A	A(*B)	A(*B)	C	A(*B)
2014 - 2015	A	A(*B)	A	C	A
2015 - 2016	A	A(*B)	A(*B)	C	A(*B)
2016 - 2017	A	A(*B)	A(*B)	C	A(*B)
2017 - 2018	A	A	A	C	A
2018 - 2019	A	A	A	C	A
2019- 2020	A	A	A	C	A
2020 - 2021	A	B	A	C	A
2021 - 2022	A	A	A	C	A
2022 - 2023	A	A	A	C	A
2023 - 2024	**A**	**A**	**A**	**B**	**A**

(*) previous grade reported using old trigger values



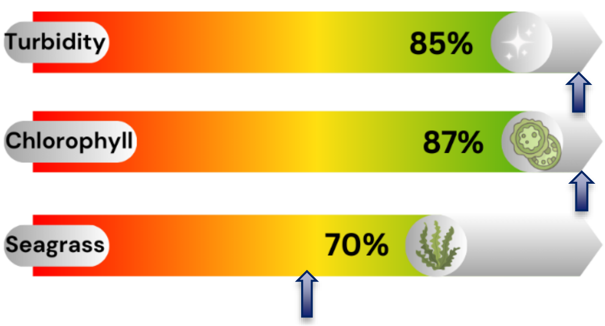
3.1.5 Fennell Bay (L6, M11)

Overall water quality, turbidity and chlorophyll-a grades in Fennell Bay all dropped a grade from A (very good) to B (good) in 2023-2024 (Table 6). The drop in grades was driven by one exceedance of the turbidity trigger value in February 2024, and one exceedance of chlorophyll-a trigger value in March 2024, which lowered the percentage grades to 85% and 87% respectively (Table 6). Seagrass depth range at M11 improved a grade to C (fair), increasing the percentage grade from 50% to 70% for 2023-24 (Table 6).

Table 6 Report card grades for Fennell Bay during the 2023-2024 monitoring period and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range (relative to 2022-23 percentage grades, arrow) is shown below the table.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Ecological Health
2011 - 2012	C	B	B	D	C
2012 - 2013	A(*B)	A(*B)	A(*B)	C	A(*B)
2013 - 2014	B(*C)	B(*C)	B(*C)	F	C(*D)
2014 - 2015	B(*C)	B	B	C	B(*C)
2015 - 2016	A(*B)	B	A(*B)	C	B(*C)
2016 - 2017	A(*B)	B	B	C	B
2017 - 2018	A	A	A	C	A
2018 - 2019	A	A	A	C	A
2019 - 2020	A	A	A	D	B
2020 - 2021	A	A	A	C	A
2021 - 2022	A	B	B	D	C
2022 - 2023	A	A	A	D	B
2023 - 2024	**B**	**B**	**B**	**C**	**B**

(*) previous grade reported using old trigger values



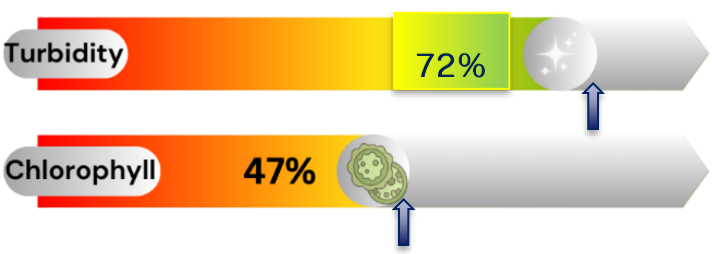
3.1.6 Cockle Creek Estuary (E1)

Cockle Creek estuary retained a C (fair) grade for overall water quality in 2023-2024 despite both turbidity and chlorophyll-a dropping a grade (Table 7). Chlorophyll-a concentrations in the estuary exceeded the 80th percentile trigger values on all sampling trips, with extent of exceedance large enough to result in a drop in grade to D (poor) and a percentage grade of 47%. Turbidity dropped a grade to C (good) as all samples exceeded the 80th percentile trigger values but exceedances were relatively minor resulting in a percentage grade of 72% (Table 7).

Table 7 Report card grades for Cockle Creek during 2023-2024 and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a (relative to 2022-2023 percentage grades, arrow) is shown below the table.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Grade
2011 - 2012	F	F	F		F
2012 - 2013	B	B	B		B
2013 - 2014	D(*C)	B	C		C
2014 - 2015	D(*C)	C	C		C
2015 - 2016	C(*B)	C	C(*B)		C(*B)
2016 - 2017	C(*B)	C	C(*B)		C(*B)
2017 - 2018	B	B	B		B
2018 - 2019	B	C	C		C
2019 – 2020	B	C	C		C
2020 - 2021	C (B)	C	C (B)		C (B)
2021 - 2022	B (A)	D	C (B)		C (B)
2022 - 2023	B	C	C		C
2023 - 2024	**C**	**D**	**C**		**C**

(*) previous grade reported using old trigger values



Note: errors in reported turbidity and overall water quality grades for 2020-21 and 2021-22 have been updated with correct grades (erroneous grade in brackets, red font).

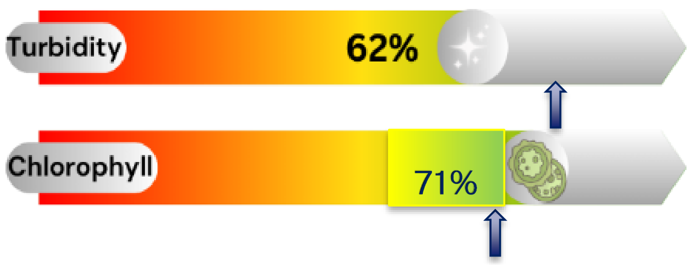
3.1.7 Dora Creek Estuary (E3)

The Dora Creek Estuary saw a decline in the overall water quality grade to C (fair) in 2023-24 due to a drop in the turbidity grade to C (fair), (Table 8). There were three exceedances of the 80th percentile trigger value for turbidity in October, December, and February and a percentage grade of 62% (Table 8). The exceedance in February was over eight times the turbidity trigger value leading to the drop in grade. Chlorophyll-a concentrations exceeded the 80th percentile trigger value on all sampling occasions but exceedances were relatively minor, resulting in a percentage grade of 71% and a C (fair) grade (Table 8).

Table 8 Report card grades for Dora Creek during 2023-2024 and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a (relative to 2022-23 percentage grades, arrow) is shown below the table.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Grade
2011 - 2012	D	B(*C)	C		C
2012 - 2013	C(*B)	B	B		B
2013 - 2014	F(*D)	B	C		C
2014 - 2015	C(*B)	C	C		C
2015 - 2016	B	B	B		B
2016 - 2017	B	B	B		B
2017 - 2018	A	A	A		A
2018 - 2019	B	B	B		B
2019 – 2020	A	B	A		A
2020 – 2021	C	B	B		B
2021 – 2022	C	B	B		B
2022 – 2023	B	C	B		B
2023 - 2024	**C**	**C**	**C**		**C**

(*) previous grade reported using old trigger values



3.2 Seagrass Depth Range

Lake Macquarie seagrass beds recorded an increase in depth range across all sites in the 2023-24 summer sampling season. Seagrass depth range (SDR) expanded at the two sites (M5, M8) in the Northern Zone for a third consecutive season recording 0.14m (4.7%) increase to 3.13m this year (Table 9). M7 in the Southeast Zone similarly recorded an increase in SDR for the second consecutive year to 4.29 m, a 0.48m (13%) increase from 2022-23 and the largest range recorded at the site since monitoring began in 2011 (Table 9). SDR at M12 in the Southwest Zone increased for the first time since 2020 to 1.74m, an increase of 21% and the second largest range recorded at this site since monitoring began in 2011 (Table 9). SDR at M11 in Fennell Bay increased by 0.2m to 0.68m, a 42% improvement on last year's range (Table 9).

Table 9 Observed seagrass depth range (metres) at monitoring sites for 2023-2024 and past monitoring periods for comparison. Note that data for the Northern Zone is the average of SDR at M5, M8.

Year	Northern (M5, M8)	Southeast (M7)	Southwest (M12)	Fennell Bay (M11)
2011	2.50	2.90	1.40	0.90
2012	2.53	2.90	1.40	0.39
2013	2.50	3.11	1.99	0.54
2014	2.39	3.42	1.49	0.00
2015	2.91	3.58	1.56	0.28
2016	2.49	3.75	1.48	0.30
2017	2.96	4.14	1.56	0.56
2018	2.51	3.70	1.37	0.67
2019	3.13	3.43	1.50	1.01
2020	2.78	3.54	1.55	0.73
2021	2.76	3.99	1.53	0.82
2022	2.80	3.14	1.43	0.68
2023	2.99	3.81	1.37	0.48
2024	**3.13**	**4.29**	**1.74**	**0.68**

4 Summary and discussion

Lake Macquarie's basin and bay sites continued to have *very good* water quality and ecological health in 2023-24, while Fennell Bay had *good* water quality and ecological health. Lake Macquarie is a relatively deep lake compared to other coastal systems and is vast in size. Nutrient and sediment inputs from the tributaries following heavy rainfall, and from industry, have few negative effects on water quality in the main lake due to dilution of inputs across the lake. Sediment inputs can settle from the water column to the lakebed and are not resuspended in the deeper sections of the lake, despite the large wind fetch. Lake Macquarie is also permanently open to the ocean through the Swansea channel allowing for constant exchange of lake water with oceanic water, resulting in very good water quality in the channel.

Conversely, both Dora Creek and Cockle Creek estuaries received a *fair* water quality grade, exceeding NSW trigger values for turbidity and chlorophyll-a over the peak of summer. Chlorophyll-a is used as a proxy for algal biomass which can reach high levels when excessive nutrients are in the system. Algal abundance is consistently high in Cockle Creek during the warmer months when higher water temperatures and light levels promote algal growth, resulting in C or D grades for chlorophyll-a for the past six sampling seasons. Algal growth is amplified by nutrients in surface runoff from the highly urbanised and industrial catchment of Cockle Creek flowing into the shallow receiving waters (1.3 – 2.2m) and resuspension of creek sediments which are heavily enriched by historical pollution (DPIE 2021). Turbidity can be an issue in Dora Creek (C-fair) which has the largest (sub)catchment in Lake Macquarie with mixed land use (urban, industrial and agricultural; DPIE 2021). The higher proportion of agriculture (associated with high sediment run-off due to land practices) in this catchment is likely to be the main driver of turbidity in Dora Creek, particularly after heavy rainfall.

Seagrass beds increased in depth range at all sites monitored in Lake Macquarie. High turbidity levels can impact seagrass growth by reducing light available for photosynthesis and is one reason why turbidity is used as an indicator of estuary health. All Zones (Northern, Southwest, Southeast) received A grades for turbidity, a likely contributing factor to the expansion of seagrass depth range (SDR) at sites across the main lake. Fennell Bay received a B (good) grade for turbidity and a C (fair) grade for SDR in 2024, improving from D (poor) grade for the previous two years. The seagrass site in Fennell Bay has not scored an A or B grade since monitoring began, despite consistently receiving A and B grades for water quality, suggesting other factors are impacting seagrass health. Fennel Bay is an isolated bay end with minimal flushing making it one of the more sensitive areas in Lake Macquarie, prone to enrichment. Nutrient and sediment inputs from the urban and industrial catchment have likely impacted sediment quality which could be one factor in the limited expansion of seagrass at this site. Another factor is boat mooring and boating activity which occur at this monitoring site.

The exotic green alga *Caulerpa taxifolia* was observed at Wangi (M5) and Valentine (M8) in the Northern Zone and Point Wolstoncroft (M7) in the Southeast Zone (Figure 1). *Caulerpa* is a marine pest in NSW due to its robust nature and ease of translocation, which can rapidly colonise areas, displacing native species and reducing biodiversity and abundance of flora and fauna. *Caulerpa* also reduces habitat complexity compared to the habitat forming native seagrasses *Zostera* spp. and *Posidonia australis*. This is the first time that *Caulerpa* has been observed at these sites which may spread throughout the lake if management actions are not put in place to limit its expansion.

It is recommended that additional monitoring is undertaken to monitor the presence of *Caulerpa* within the lake.

Table 10 Rainfall totals (mm) recorded at Australian Weather Station 61282 at Dora St (Dora Creek, Bureau of Meteorology). Monthly, annual total from 2011-2024 are shown as well as long-term monthly averages. Rainfall was also summed from October to April for each monitoring season as this is the time period from which grades are calculated.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Sum Oct to Apr
2011	38.4	64.4	75.2	174.6	123.4	220.0	188.9	59.0	130.6	111.8	200.6	146.0	**1532.9**	
2012	98.0	191.8	135.0	143.6	24.6	189.2	55.2	29.2	25.2	9.8	83.2	105.8	**1090.6**	1026.8
2013	216.4	187.4	183.0	113.2	85.6	114.4	13.4	16.4	21.8	57.0	298.8	29.2	**1336.6**	898.8
2014	28.2	349.8	116.8	160.8	50.4	62.8	18	189.8	43.8	68.2	24.0	139.6	**1252.2**	1040.6
2015	213.8	89.6	139.8	481.8	136.6	75.8	14	24.2	83.4	88.6	104.6	120.8	**1573.0**	1156.8
2016	351.6	21.7	59.8	33.6	12.4	235.2	63.6	87.8	60.1	61.4	44.4	92.2	**1123.8**	780.7
2017	69.8	128.8	254.6	82.4	23.0	113.6	2.0	11.6	15.0	144.0	64.6	58.8	**968.2**	733.6
2018	18.8	135.4	96.2	52.4	17.4	195.7	0.0	9.0	72.4	189.8	112.7	77.4	**977.2**	570.2
2019	63.4	100.2	197.6	34.2	13.8	137.8	51.8	142.6	97.2	30.4	23.4	2.8	**895.2**	775.3
2020	62.8	335.2	168.2	78.2	82.8	72.8	230.2	54.0	33.8	169.2	61.8	233.4	**1582.4**	701.0
2021	109.4	182.4	503.4	42.8	28.8	55.4	31.0	67.6	42.8	78.8	236.4	131.0	**1509.8**	1302.4
2022	140.4	145	428.9	162.8	124.6	20.0	417.8	34.6	144.5	191.6	40.2	35.8	**1886.2**	1323.3
2023	129.6	94.4	148.2	106.8	37.6	8.8	28	58.6	59	97.2	124.4	134.2	**1026.8**	746.6
2024	57.8	167	32.2	306.2									*563.2*	919
Mean (1907-2022)	114.2	156.7	181.4	141.0	58.5	115.5	85.7	60.3	63.8	99.8	109.2	100.5	1289	903

5 References

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