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Estuary Report Card 2024-2025 Lake Macquarie

June 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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Estury Report Card 2024-2025 Lake Macquarie

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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 2024-2025 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 2024-2025 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
- 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 500-700 m 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 assumed 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 2025: M5 (Wangi), M7 (Point Wolstoncroft), M8 (Valentine), M11 (Fennell Bay) and M12 (Chain Valley Bay).

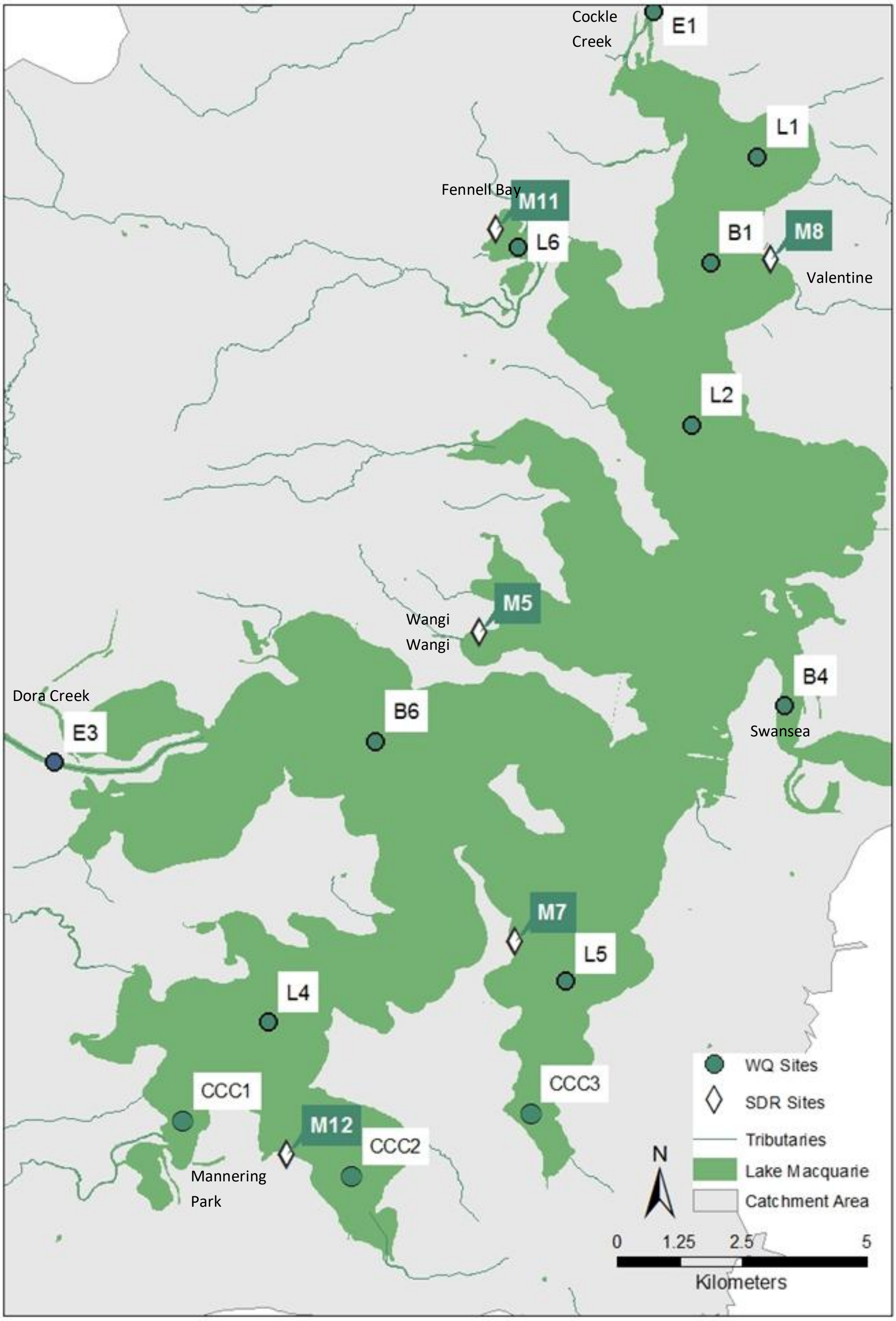

Figure 1 Sampling locations in Lake Macquarie for water quality monitoring (WQ sites) and seagrass depth range (SDR sites) assessments for 2024-2025. Note: CCC1, CCC2 and CCC3 monitoring zones in the southern bays form part of the CCC estuary monitoring program.

2.1.1 Sampling methods

Water quality

All sampling was conducted from a 4.5 m research vessel. 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.

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 metres - AHD (Australian Height Datum) using 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 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, 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 seagrass 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 and in-water nutrient concentrations 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 as a matter of course 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, 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 2024-2025 sampling period, collected over the warmer months from October 2024 to April 2025, 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.

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).

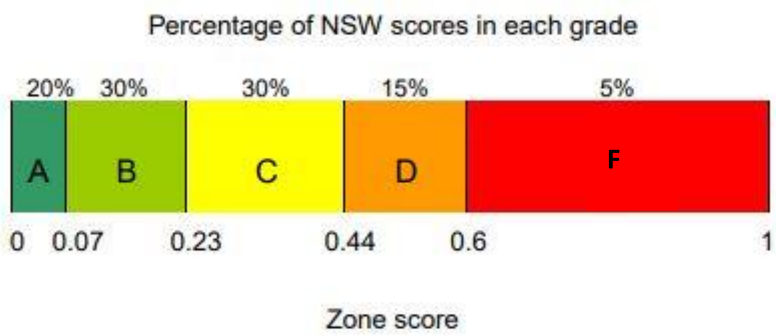

Figure 2 Relationship between distribution of NSW scores, grades and zone scores (OEH 2016)

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 2-8). 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.

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

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

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).

2.4.2 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.

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. Therefore, the SDR grade reflects how seagrass has progressed, recovered, or regressed over time.

A percentage value is shown on the sliding scale for the SDR grade that is based on the points awarded for the depth grade and trend grade, 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 thirteenth 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 percentage grades of 100 % for each indicator (Figure 3). Similarly, seagrass depth range (SDR) at M5 and M8 received an A grade and a percentage grade of 100 % (Table 2, Figure 3). SDR remained at 3.13 m averaged across the two sites, with a decrease of 0.21 m at Wangi (M5) and an increase of 0.21 m at Valentine (M8, Table 9).

Table 2 Report card grades for the Northern Zone during 2024-2025 and past monitoring periods for comparison.

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
2024 - 2025	**A**	**A**	**A**	**A**	**A**

(*) previous grade reported using old trigger values

Figure 3 A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range for the Northern Zone (no change from last year's percentage grades)

3.1.2 Swansea Channel (B4)

Swansea Channel scored an A (very good) grade for overall water quality for the thirteenth consecutive year (Table 3). There were no exceedances of the 80th percentile trigger values for turbidity or chlorophyll-a recorded in 2024-25, resulting in A (very good) grades and 100 % for the percentage grades (Table 3, Figure 4).

Table 3 Report card grades for Swansea Channel during 2024-2025 and past monitoring periods for comparison.

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
2024 - 2025	**A**	**A**	**A**		**A**

(*) previous grade reported using old trigger values

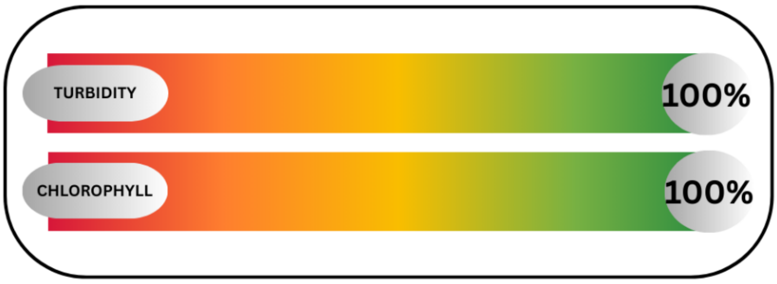

Figure 4 A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a for Swansea Channel (no change from last year's percentage grades).

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 thirteenth consecutive year (Table 4). There were no exceedances of the 80th percentile trigger values for turbidity or chlorophyll-a recorded in 2024-25, with both indicators receiving an A (very good) grade and 100 % for the percentage grade (Table 4). The seagrass depth range at the M7 site (Wolstoncroft) in the Southeast Zone decreased by 0.97 m to 3.32 m (Table 9) in 2024-25, resulting in a drop in SDR grade to B (good) and 90 % for the percentage grade (Table 4, Figure 5).

Table 4 Report card grades for the Southeast Zone during 2024-2025 and past monitoring periods for comparison.

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
2024 - 2025	**A**	**A**	**A**	**A**	**A**

(*) previous grade reported using old trigger values

Figure 5 A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range in the Southeast Zone. Arrows indicate change from last year's percentage grades.

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 thirteenth consecutive year (Table 5). There were no exceedances of the 80th percentile trigger values for turbidity or chlorophyll-a: A (very good) grades and percentage grades of 100% were retained in 2024-2025 (Figure 6). Seagrass depth range at M12 in the Southwest Zone decreased by 0.12m to 1.63m (Table 9) in 2024-2025, resulting in a drop in grade to C (fair) and a lower percentage grade of 70% (Table 5, Figure 6).

Table 5 Report card grades for the Southwest Zone during 2024-2025 and past monitoring periods for comparison.

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
2024 - 2025	**A**	**A**	**A**	**C**	**A**

(*) previous grade reported using old trigger values

Figure 6 A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range in the Southwest Zone. Arrows indicate change from last year's percentage grades

3.1.5 Fennell Bay (L6, M11)

Overall water quality, turbidity and chlorophyll-a grades in Fennell Bay all improved a grade to A (very good) in 2024-2025 (Table 6). There were no exceedances of the turbidity and chlorophyll-a trigger values in 2024-2025, resulting in percentage grades of 100 % for these indicators (Figure 7). Seagrass depth range at M11 decreased by 0.13 m to 0.55 m in 2024-2025 and dropped a grade to D (poor) with a lower percentage grade of 40 % (Table 6, Figure 7).

Table 6 Report card grades for Fennell Bay during the 2024-2025 monitoring period and past monitoring periods for comparison.

Sampling Period	Turbidity	Chlorophyll-a	Overall Water Quality	Seagrass Depth Range	Overall Ecological Health
2011 - 2012	C	B	B	D	C
2012 - 2013	A	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
2024 - 2025	**A**	**A**	**A**	**D**	**B**

(*) previous grade reported using old trigger values

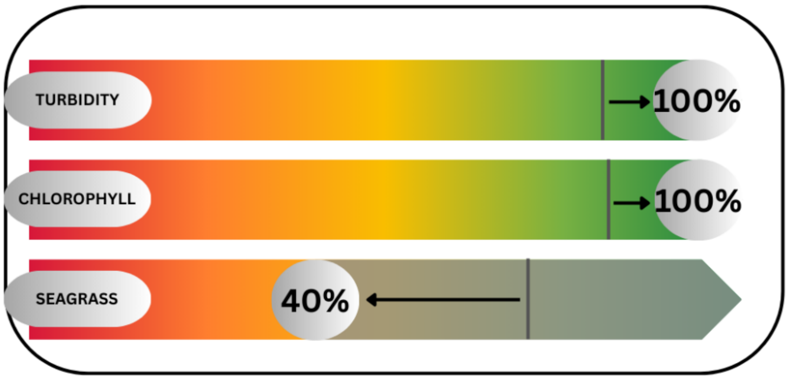

Figure 7 A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range in Fennell Bay. Arrows indicate change from last year's percentage grades

3.1.6 Cockle Creek Estuary (E1)

Water quality in Cockle Creek estuary improved a grade across the board, receiving a B (good) grade for both turbidity and overall water quality, and a C (fair) grade for chlorophyll-a in 2024-2025 (Table 7). Chlorophyll-a concentrations in the estuary exceeded the 80th percentile trigger values on all sampling trips, with only minor exceedance on 3 trips, improving the percentage grade to 70 % (Figure 8). Turbidity only exceeded the 80th percentile trigger values on 3 sampling trips resulting in a percentage grade of 82 % (Figure 8).

Table 7 Report card grades for Cockle Creek during 2024-2025 and past monitoring periods for comparison.

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	C	C		C
2021 - 2022	B	D	C		C
2022 - 2023	B	C	C		C
2023 - 2024	C	D	C		C
2024 - 2025	**B**	**C**	**B**		**B**

(*) previous grade reported using old trigger values

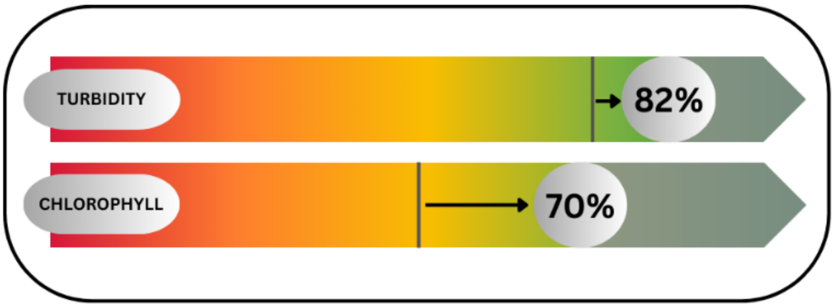

Figure 8 A sliding scale diagram of the percentage grades for turbidity, chlorophyll-a and seagrass depth range in the Southwest Zone. Arrows indicate change from last year's percentage grades

3.1.7 Dora Creek Estuary (E3)

Water quality in the Dora Creek Estuary improved a grade across the board, receiving a B (good) grade for turbidity, chlorophyll-a and overall water quality in 2024-2025 (Table 8). There were only three minor exceedances of the 80th percentile trigger value for turbidity resulting in a percentage grade of 88 % (Figure 9). Chlorophyll-a concentrations exceeded the 80th percentile trigger value on five sampling occasions but most exceedances were minor and scored a percentage grade of 82 % (Figure 9).

Table 8 Report card grades for Dora Creek during 2024-2025 and past monitoring periods for comparison. A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a is shown below the table (arrow indicates change from last year's percentage grades).

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
2024 - 2025	**B**	**B**	**B**		**B**

(*) previous grade reported using old trigger values

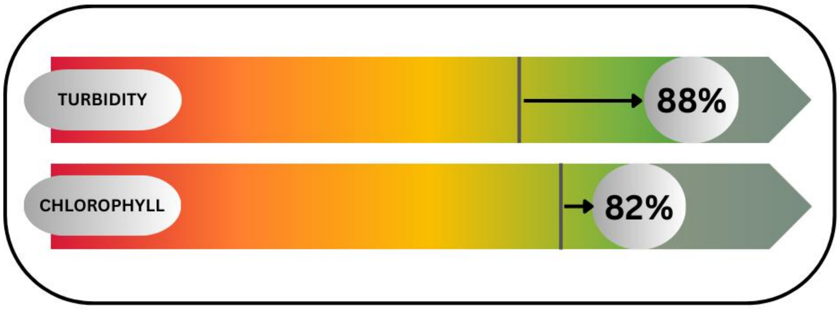

Figure 9 A sliding scale diagram of the percentage grades for turbidity and chlorophyll-a for Dora Creek Estuary. Arrows indicates change from last year's percentage grades.

3.2 Seagrass Depth Range

Seagrass depth range decreased at all monitoring sites in Lake Macquarie in 2024-2025, except for Valentine (M8) which recorded a small increase of 0.21 m for a third consecutive season (Table 9). Seagrass depth range (SDR) decreased at Wangi (M5), Wolstoncroft (M7), Fennell Bay (M11) and Chain Valley Bay (M12, Table 9). M7 in the Southeast Zone recorded the largest reduction in range of 0.97 m to 3.32 m (Table 9). The decrease in range at the other sites were comparatively minor (0.07 m-0.21 m, Table 9).

Table 9 Observed seagrass depth range (metres) at monitoring sites for 2024-2025 and past monitoring periods for comparison. Note that data for the Northern Zone is the average of SDR at M5, M8.

Year	M5	M8	Northern (M5, M8)	Southeast (M7)	Southwest (M12)	Fennell Bay (M11)
2011	2	2.99	2.50	2.90	1.40	0.90
2012	2.17	2.82	2.53	2.90	1.40	0.39
2013	2.35	2.59	2.50	3.11	1.99	0.54
2014	2.09	2.70	2.39	3.42	1.49	0.00
2015	2.84	2.89	2.91	3.58	1.56	0.28
2016	2.24	2.75	2.49	3.75	1.48	0.30
2017	2.41	2.72	2.96	4.14	1.56	0.56
2018	2.43	2.57	2.51	3.70	1.37	0.67
2019	2.92	3.19	3.13	3.43	1.50	1.01
2020	2.68	2.87	2.78	3.54	1.55	0.73
2021	2.50	3.02	2.76	3.99	1.53	0.82
2022	2.78	2.81	2.80	3.14	1.43	0.68
2023	2.96	3.02	2.99	3.81	1.37	0.48
2024	3.04	3.22	3.13	4.29	1.74	0.68
2025	**2.83**	**3.43**	**3.13**	**3.32**	**1.63**	**0.55**

4 Summary and discussion

Lake Macquarie's basin and bay sites continued to have *very good* (A) water quality and ecological health in 2024-2025, and Fennell Bay had *very good* water quality and *good* (B) 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 lake wide.

Dissolved inorganic nutrients like nitrate, ammonium (DIN) and phosphate (DIP) are readily bio-available and rapidly assimilated by microalgae (phytoplankton). Chlorophyll-a is used as a proxy for algal biomass which can reach high levels when excess nutrients are in the system. Only nutrient data from sampling dates in July 2024 through to February 2025 are available currently. Ammonium (NH_4^+) and nitrate/nitrite (NO_x) concentrations in the bays and basins of Lake Macquarie rarely exceeded the NSW trigger values of 14 µg/L for NH_4^+ and 3 µg/L for NO_x (Table 1, OEH 2018). Conversely, phosphate (PO_4^{3-}) exceeded the NSW trigger value of 1 µg/L in 98 % of samples, with an average concentration of 3.8 µg/L. Surface runoff from urban and agricultural land use, industrial wastewater discharges and stormwater overflows from the sewage network are sources of PO_4^{3-} to the lake. An analysis of nutrient data collected for the Lake Macquarie Water Quality Monitoring Programs from 2013 to 2020, found a significant downward trend in PO_4^{3-} concentrations, decreasing by 0.4-0.65 µg/L per annum at Bardens Bay (L4), Speers Point (L1) and Eleebana (B1, DPIE 2021). All other sites showed a decreasing trend in PO_4^{3-} concentrations over this period; however, these were statistically insignificant (DPIE 2021).

Water quality in the Dora Creek and Cockle Creek estuaries improved to *good* (B) in 2024-25 due to improved grades for both turbidity and chlorophyll-a. Turbidity can be an issue in Dora Creek which has the largest subcatchment in Lake Macquarie comprised of mixed land use (urban, industrial and agricultural; DPIE 2021). This year, however, turbidity was *good* in Dora Creek, only exceeding the trigger value marginally on three occasions. Concentrations of chlorophyll-a exceeded the NSW trigger value on all sampling trips. 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 seven sampling seasons. Algal growth is amplified by nutrients in surface runoff from the highly urbanised catchment of Cockle Creek flowing into the shallow receiving waters (1.3 – 2.2 m). The highest chlorophyll-a concentrations in Dora and Cockle Creeks occurred in January 2025 following 50 mm of rainfall in the 5-days prior to sampling. The highest concentrations of NH_4^+ (23-32 µg/L) and NOx (8-15 µg/L) in the program dataset were recorded in the January samples, however, this was the only instance where concentrations of NH_4^+ and NO_x exceeded the NSW trigger values of 10 µg/L of NH_4^+ and NO_x of 5 µg/L (Table 1, OEH 2018). Conversely, PO_4^{3-} concentrations in Cockle Creek exceeded the NSW trigger value of 2 µg/L on all sampling trips, while Dora Creek samples exceeded the trigger value on five sampling trips.

The nutrient data collected in Lake Macquarie and tributaries show that nitrogen is likely to be limiting phytoplankton growth in the estuary. The Redfield ratio of 16:1 is the consistent atomic proportions of nitrogen

(N) to phosphorous (P) in marine phytoplankton. Molar ratios of DIN:DIP in the environment that deviate from 16:1 indicate nutrient limitation, with ratios less than 16 indicating the system is N-limited, and ratios above 16 indicating the system is P-limited. For this dataset, median DIN:DIP was 1.3 for lake sites, 1.4 for Cockle Creek, 3.0 for Fennell Bay and 3.9 for Dora Creek, indicating nitrogen is limited phytoplankton growth in Lake Macquarie.

This year, seagrass depth range decreased at all monitored sites in Lake Macquarie except for Valentine (M8) in the Northern Zone, which increased by 0.21 m for the third consecutive year. The decrease in seagrass depth range at Chain Valley Bay (M12 – Southwest Zone) and Fennell Bay led to a drop in the seagrass depth range grade to *fair* (C) for M12 and *poor* (D) at M11. 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. Turbidity was graded as *very good* or *good* at M12 and M11, respectively, based on turbidity at the time of sampling. However, seagrass growth and expansion or retraction in range are dependent on turbidity and light levels experienced over the entire growing season from mid-spring to early summer. November 2024 and January 2025 were wetter than average months, with 135 mm and 223 mm monthly totals (Table 10) and the resultant increase in turbidity during these months of the growing season may have affected seagrass growth and distributions at the monitoring sites.

The seagrass site in Fennell Bay has not scored an A or B grade for seagrass depth range since monitoring began, despite consistently receiving A and B grades for water quality, suggesting other factors may also be impacting seagrass distributions in the bay. Fennell 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. *Halophila* was the dominant seagrass species in one of the transects, which is known to tolerate and colonise enriched sediments of poor quality. Other factors that may be impacting seagrass depth range at Fennell Bay are boat mooring and boating activity in the bay.

The exotic green alga *Caulerpa taxifolia* was again observed at Wangi (M5) where dense coverage was observed in the shallows. *Caulerpa* was observed in one transect at Fennell Bay (M11) this year. Last year, *Caulerpa* was observed at Valentine (M8), but it was not observed this year, possibly outcompeted by *Zostera* spp. as dense seagrass beds were observed at the site. *Caulerpa* was observed at Point Wolstoncroft (M7) last year but was not observed this year. *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 second year that *Caulerpa* has been observed at Wangi where it has established and it may continue to 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 (mm) recorded at Bureau of Meteorology (BOM) Australian Weather Station (AWS) 61282 at Dora St (Dora Creek) showing monthly and annual totals from 2011-2024 and long-term monthly averages. Rainfall data for March – May 2025 is from BOM AWS 61376 (Eraring, 3.8 kilometres from 61282) as data were not available for 61282. Neither station had data for June 2025. * Annual total for 2025 only includes rainfall from January to May.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total (mm)
2011	38.4	64.4	75.2	174.6	123.4	220	188.9	59	130.6	111.8	200.6	146	1533
2012	98	191.8	135	143.6	24.6	189.2	55.2	29.2	25.2	9.8	83.2	105.8	1091
2013	216.4	187.4	183	113.2	85.6	114.4	13.4	16.4	21.8	57	298.8	29.2	1337
2014	28.2	349.8	116.8	160.8	50.4	62.8	18	189.8	43.8	68.2	24	139.6	1252
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
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	1124
2017	69.8	128.8	254.6	82.4	23	113.6	2	11.6	15	144	64.6	58.8	968
2018	18.8	135.4	96.2	52.4	17.4	195.7	0	9	72.4	189.8	112.7	77.4	977
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
2020	62.8	335.2	168.2	78.2	82.8	72.8	230.2	54	33.8	169.2	61.8	233.4	1582
2021	109.4	182.4	503.4	42.8	28.8	55.4	31	67.6	42.8	78.8	236.4	131	1510
2022	140.4	145	428.9	162.8	124.6	20	417.8	34.6	144.5	191.6	40.2	35.8	1886
2023	129.6	94.4	148.2	106.8	37.6	8.8	28	58.6	59	97.2	124.4	134.2	1027
2024	57.8	167	32.2	307.4	209.4	123.8	79.2	47.8	85.8	107	134.6	43.3	1395
2025	222.8	41.2	165.4	230.8	383.6								*1044**
Monthly mean **(1907-1912, 1988-2025)**	**103.4**	**148.5**	**153.4**	**123.8**	**80.9**	**100.2**	**83.6**	**57.1**	**59.9**	**77.8**	**97.2**	**82.5**	**1289**

Table 11. A. Rainfall (mm) recorded from October to April for each monitoring season are shown as data collected in this period are used to calculate water quality grades. B. Rainfall recorded in the 3-days and 5-days before water quality sampling are shown as recent rainfall can affect water quality.

A.

Sampling period	Total rainfall (mm)
Oct 2011 - Apr 2012	1027
Oct 2012 - Apr 2013	899
Oct 2013 - Apr 2014	1041
Oct 2014 - Apr 2015	1157
Oct 2015 - Apr 2016	781
Oct 2016 - Apr 2017	734
Oct 2017 - Apr 2018	570
Oct 2018 - Apr 2019	775
Oct 2019 - Apr 2020	701
Oct 2020 - Apr 2021	1302
Oct 2021 - Apr 2022	1323
Oct 2022 - Apr 2023	747
Oct 2023 - Apr 2024	920
Oct 2024 - Apr 2025	945
14-year average	**923**

B.

Sampling date	mm 3-days prior	mm 5-days prior
24/07/2024	0	0
27/08/2024	1.0	3
24/09/2025	0	0
29/10/2024	0	48
27/11/2024	0	0
11/12/2024	7.2	15
22/01/2025	0	50
18/02/2025	0	0.8
19/03/2025	0	0
9/04/2025	4.4	4.4
29/05/2025	13.6	13.6

5 References

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