Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols

NSW Natural Resources Monitoring, Evaluation and Reporting Program

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1 Introduction

A healthy estuary is an ecosystem with its various components (biological, physical and chemical) operating effectively to maintain a functioning system within the limits of natural variability. It should also be resilient to some level of stress (Rapport et al. 1998).

Assessing estuary ecosystem health (or condition) requires a framework for setting the objectives of the assessment, and selecting, monitoring and reporting on appropriate indicators that measure components of an estuary's ecosystem that contribute to its overall health.

These protocols provide a standardised approach to estuary ecosystem health monitoring, analysis and reporting in NSW. Standardising monitoring, analysis and reporting based on best practice provides consistency at a range of scales (local, regional and state), allows for the comparison of assessments and ensures scientific validity in reporting products and information provided to the community.

The benefits of implementing a well designed estuary ecosystem health monitoring program include providing a basis upon which to determine appropriate management actions, monitoring the effectiveness of management and contributing to the ongoing adaptive management of estuaries and their catchments.

These protocols can be used for monitoring all estuary types in NSW including intermittently closed and open lakes and lagoons (ICOLLs). Methodologies for monitoring freshwater systems are available from a number of sources, for example Muschal et al. (2010) and ANZECC and ARMCANZ (2000), and AUSRIVAS protocols for freshwater macroinvertebrates.[1]

These protocols do not address matters that reflect broader estuary uses, human health and community values such as the assessment of recreational water quality (see Beachwatch protocols), or the status of shellfish harvesting areas (see NSW Shellfish Program protocols). However, there may be opportunities to include additional indicators or utilise monitoring information from those programs when reporting on estuary health or water quality more broadly.

2 NSW Estuary Management Program

The NSW Estuary Management Program, coordinated by the NSW Office of Environment and Heritage (OEH), provides technical and financial assistance to local councils in the management of coastal hazards, estuary health and community uses. This is generally through the development and implementation of coastal zone management plans.

Guidance for the preparation of coastal zone management plans is available (DECCW 2010a). An integrated approach to managing estuary ecosystem health and community values is recommended and this includes:

- estuary ecosystem health assessment
- understanding pressures on estuary ecosystem health
- managing threats to estuary ecosystem health
- estuary ecosystem health monitoring.

[1] http://ausrivas.canberra.edu.au/

These protocols provide practical advice on estuary ecosystem health monitoring including sampling, data analysis and reporting. In particular, the protocols should, where relevant, be used by councils receiving grants from the Estuary Management Program to carry out estuary ecosystem health assessments.

3 NSW Natural Resources Monitoring, Evaluation and Reporting Program

The NSW Natural Resources Monitoring Evaluation and Reporting (MER) Strategy 2010–2015 (DECCW 2010b) and Program supports continuous improvement in policy and investment decision-making, and tracks progress against the statewide resource condition targets set by the Natural Resources Commission (NRC 2005). The program reported on resource condition in 2010 through State of the Catchments (SoC) reports (DECCW 2010c, 2010d, 2010e, 2010f).

Statewide resource condition target for estuaries and coastal lakes:

By 2015 there is an improvement in the condition of estuaries and coastal lake ecosystems.

The content of these protocols is informed by work undertaken as part of implementing the MER Program (see Roper et al. 2011), including the selection of indicators, design of monitoring and analysis of monitoring data.

Monitoring as part of the estuaries theme of the MER Program focuses on estuarine biology to determine condition in preference to the stressors and pressures which are the external factors that cause changes in condition (see Scanes et al. 2007). Under the program, pressure assessments have also been completed, based on a range of indicators where statewide datasets were available or could be compiled (for example through modelling).

Results from estuary ecosystem health monitoring programs can also be used to assess progress against the community's long-term goals for estuaries as outlined in the NSW Water Quality and River Flow Objectives (NSW Government 1999).

4 Local-scale monitoring

The MER Program indicators and the way in which they are monitored for ecosystem health reporting provide a focus on statewide issues and hence not all indicators will necessarily be applicable to all estuaries (Scanes et al. 2009). However, where the indicators are applicable, the protocols provide a standardised method that is also valid for sampling at the local scale.

At the local scale, estuary ecosystem health monitoring by councils and other bodies may include additional condition indicators that reflect the specific estuary, its uses and the pressures present (see Section 10). Local managers may also wish to increase the locations and frequency of sampling to better understand variability in condition over time (for example seasonally or after large rainfall events), increase reliability of results or gain a better understanding of the condition of specific locations such as tributaries.

The following sections provide guidance on replication in space and time, field collection and quality assurance and quality control (QA/QC) procedures, data management and analysis including relevant trigger values, and reporting.

Reporting on monitoring programs may be done in a number of ways, depending on the intended audience for the information. Summarised information in the form of a report card might be a useful way to communicate information to a non-technical audience. Where simplified reporting products are used, they should always be accompanied by adequate technical information outlining the monitoring and analysis methodology used. For example, programs such as the Northern Rivers EcoHealth Program have provided advice and support for local-scale ecosystem health monitoring. While the overall approach taken as part of that program is consistent with these protocols, there may be some localised differences. Supporting technical reports should be used to outline sampling and analysis procedures used (see Ryder 2011).

5 Goals and objectives

In any monitoring program it is critical to establish the goals and objectives at the start of the design process so that any subsequent data collection and analysis meets requirements. The overall goal of monitoring under these protocols is to accurately assess estuary ecosystem health.

The reasons why monitoring is being conducted can be expressed in the objectives of the program. These might include providing one or more of the following:

- a general overview of an ecosystem's health
- baseline assessment against which future change can be measured
- a change or trend in condition through time
- an early warning of any impending future change
- an evaluation of the effect of management actions
- reporting progress towards targets (for example the NSW statewide NRM targets) or values (for example the NSW Water Quality and River Flow Objectives – NSW Government 1999)
- reporting compliance with regulatory standards or licences.

Setting objectives ensures subsequent steps of the monitoring design process are soundly based. These steps should include the specific questions to be answered, conceptual model development, spatial and temporal scale, experimental design framework, indicator selection, statistical power and implementation.

6 Condition indicators

As part of the MER Program core estuary condition indicators are monitored (see Scanes et al. 2009 and Roper et al. 2011 for monitoring locations and frequency). The mix of indicator groups adopted represents elements of the structure, function and composition of estuarine ecosystems and includes:

Eutrophication –

- microalgal abundance as pelagic chlorophyll *a*
- macroalgal abundance

Habitat availability –

- extent of seagrass
- extent of mangroves
- extent of saltmarsh
- water clarity indicated by turbidity

Fish assemblages –

- species diversity and composition
- species abundance
- nursery function

- trophic integrity.

While macroalgal abundance is a favoured indicator, method development at a statewide scale has proven problematic and is still underway (discussed further in Section 10.1).

The MER Program, based on the findings of Scanes et al. (2007), concluded that measurement of chlorophyll *a* and turbidity would provide an effective measure of the short-term response of estuary ecosystem health in response to a range of likely pressures and their management. Estuarine macrophytes and fish assemblages provide a longer-term integration of estuary ecosystem health status.

The MER Program has established a list of 184 estuaries for NSW (Appendix 1). These estuaries have a distinct waterway area shown in the 1:25,000 topographic map series published by Land and Property Information. While the condition of all estuaries could not be determined for the first round of SoC reporting, the longer-term aim is for the condition of all to be assessed. Initial pressure assessments have been carried out for all 184 estuaries (DECCW 2010c, 2010d, 2010e, 2010f).

Accompanying the SoC reports is technical documentation (Roper et al. 2011) that outlines the methodology used to design, implement and report on the monitoring program, including the estuary classification schemes used, spatial and temporal scales of data collection, derivation of trigger values and indicator assessment.

7 Water quality indicators

While the measurement of chlorophyll *a* and turbidity is recommended as condition indicators, a number of other water quality indicators will provide useful contextual data to assist in interpreting results. Water quality multiprobes allow for the measurement of a number of parameters. Salinity and temperature should be measured as a matter of course. Dissolved oxygen is discussed in Section 10.2.

Traditionally, many water quality monitoring programs have included measuring the concentration of nutrients (nitrogen and phosphorus). While the concentration of nutrients may be of interest as a measure of the stressors present in an estuary, to monitor specific discharges or to better understand nutrient dynamics, it is usually difficult to directly relate nutrient concentrations to condition indicators (Scanes et al. 2007). As nutrient analysis can be costly, it is recommended not to proceed without a clear rationale for collection, analysis and interpretation.

7.1 Chlorophyll *a*

Chlorophyll *a* concentrations in waters are determined by two primary methods:

- chlorophyll a is filtered from water samples (0.45 micron filters) and extracted in solvent and measured in a laboratory by spectrometry or fluorometry – this is the preferred method
- in-situ fluorometry (which must be used with some caution – see below).

At first inspection, the use of an in-situ fluorometer probe for chlorophyll *a* determination has distinct attractions: easier logistics, lower costs and better spatial representation. OEH uses YSI Model 6820V2-S multiprobes fitted with a YSI 6025 fluorometric chlorophyll probe, although other probes may also be suitable. It should be noted that, even under the best conditions, the measurement of chlorophyll *a* by fluorometry is regarded as an approximation allowing rapid and low-cost comparisons between systems and times (Tamburri 2006), and therefore provides only approximate comparisons to trigger values (Section 7.9).

OEH has extensively tested the efficacy of fluorescence probes over the last few years and has found significant interference occurs from coloured dissolved organic matter (CDOM) in the water and from a range of other as yet undetermined factors. This causes the chlorophyll *a* concentrations to appear higher than they really are. It must be understood that the fluorometric methods were developed primarily for clear- water ocean studies, and interference by CDOM is well recognised by probe manufacturers and users.

OEH measures CDOM UV fluorescence with a CDOM fluorometer. Output in millivolts is converted by the probe to Relative Fluorescence Units (RFU). Water with no obvious tannin colouration should measure <50 RFU. Moderate to heavy colouration is between 100 and 200 RFU. Very dark staining measures about 300 RFU.

At present, OEH *cannot recommend fluorometry* as a routine method for chlorophyll *a* determination in estuaries, except under special circumstances. Those circumstances are an absence of any influence of CDOM (which is highly unlikely), or in cases where measurements are made at a small number of sites and there is a long history of calibration against analyses of chlorophyll *a* extracts from those sites. OEH is actively researching the topic, but it seems that unless concurrent measurements of CDOM are made, there is little likelihood that fluorometry data will be able to be used in most circumstances.

OEH therefore recommends that determination of chlorophyll *a* concentrations is based on the analysis of chlorophyll *a* filtered from water samples and extracted in a solvent (usually acetone). Chlorophyll analysis using this method is a standard and relatively cheap process and is available from many regional laboratories.

7.2 Water clarity and turbidity

Water clarity is measured by Secchi disk. The data is best interpreted as changes in mean depth over time at a location or in conjunction with supporting data (such as salinity) to document short-term changes.

Turbidity is measured as part of the MER Program using a calibrated probe. OEH uses YSI Model 6820V2-S multiprobes fitted with a YSI 6025 fluorometric chlorophyll probe and a turbidity probe, although other probes will also be suitable. Often turbidity in estuaries is low (<3 NTU) and most meters will not perform well in this range unless carefully calibrated.

7.3 Instrument calibration

Follow the instructions of the instrument manufacturer to calibrate instruments. Be aware, however, of the likely range of values being measured and calibrate accordingly. The instrument will perform much better if it is calibrated for the data ranges expected in the field. For example, it is counterproductive to calibrate a turbidity meter to a standard of 800 NTU when most of the data is in the range of 1 to 20 NTU.

For OEH sampling, prior to each field trip (or day of sampling) turbidity is calibrated to 0 and 50 NTU using milli-q filtered water and a formazin standard respectively.

Salinity is calibrated to a known seawater standard prior to every field trip.

The fluorometer is factory calibrated, but a standard solution of rhodamine is used prior to every field trip to check that the calibration remains constant over time and is consistent among probes.

7.4 MER Program sampling design

The estuary selection for monitoring of chlorophyll *a* and turbidity by OEH as part of the MER Program monitoring utilises a mixed model design, with seven fixed *sentinel* estuaries that are sampled every year to track inter-annual variability and a minimum of

27 stratified random *roving* estuaries sampled within a particular region each year. This mixed model design is based on that used by the Sustainable Rivers Audit (Davies et al. 2008) for macroinvertebrates and fish, established after considerable evaluation of a range of possible sampling strategies.

Roving estuaries are sampled on a three-year rolling basis, with a specific region sampled each year. The regions are based on five Catchment Management Authority (CMA) areas:

1. Northern Rivers
2. Hunter-Central Rivers, Hawkesbury-Nepean and Sydney Metropolitan
3. Southern Rivers.

Estuaries within each region were initially divided into disturbance classes based on the ratio of undisturbed past to present total nitrogen (TN) loads. Systems with a TN load ratio <1.5 were defined as relatively undisturbed, 1.5 to 2.5 as moderately disturbed and >2.5 as highly disturbed (see Appendix 1). Estuaries within each disturbance class were then subdivided into three estuary types: rivers, lakes and lagoons (within lagoons there is a further subdivision into lagoons and creeks), based on the estuarine response classification scheme developed as part of the MER Program (see Roper et al. 2011 and Appendix 1).

For each year's sampling program at least three examples of each disturbance class and estuary type are selected from the available systems at random (see Appendix 1 for estuaries sampled as part of the MER Program). Additional systems are selected as back-ups if access is not possible.

One example of high and low disturbance for each estuary type was selected as fixed sentinel sites (see Appendix 1). These are all in the central part of the NSW coast (but away from Sydney) for logistical reasons. Preference was given to systems with existing data sets.

7.5 Monitoring locations

The spatial scale of interest for the MER Program is whole-of-estuary condition. As such the program targets the assumed chlorophyll *a* and turbidity maxima. For lakes and lagoons this is the central basin, and for rivers, the mid to upper sections.

To facilitate representative spatial coverage, estuaries are divided into zones. For lakes and lagoons, a zone is an area of approximately 500–700 metres in diameter. Sufficient zones (up to four with a minimum of two) are designated within the central basin so that the majority of the lake or lagoon is represented (for example see Figure 1). This may mean small systems have only one zone; if this is the case at least two integrated samples (see Section 7.7) are collected from a transect within the zone.

Figure 1: Coastal lake or lagoon sampling strategy

If feasible, rivers are sampled using a longitudinal transect from the mid section to the upper section (Figure 2).

Figure 2: River sampling strategy

The sampling vessel is fitted with a water intake (see Photo 1) and data is continuously logged by the probe as the vessel moves along the river (Photo 2). Position (from a GPS) is logged simultaneously.

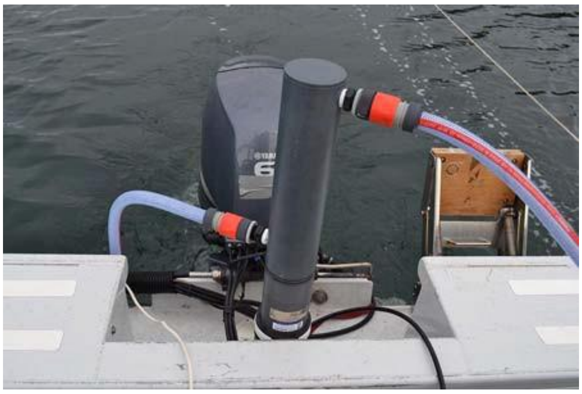

Photo 1

Photo 2

As part of the MER Program integrated samples are collected from sampling zones within the longitudinal transect, although integrated samples can be collected within the larger transect if preferred (see Section 7.7).

Integrated samples are taken from the surface water within 0.5 metres of the surface. For localised sampling programs there may be the need to consider condition at spatial scales smaller than the whole waterway or in areas other than the theoretical

chlorophyll *a* and turbidity maximum. In this case the sampling strategy should be to either designate smaller or additional zones (for example including tributaries) within the waterway.

Considerations in determining localised monitoring locations may include:

- access and WHS issues
- location of existing or historical monitoring sites (this may include council programs, MER Program, or monitoring by research institutions or water authorities)
- location of tributaries or other major inputs
- salinity, flushing characteristics or other environmental attributes.

7.6 Monitoring frequency

The relevant temporal scale for the MER Program is the annual seasonal chlorophyll *a* maxima. Sampling windows for NSW are:

1. Northern Rivers: mid September to end of January
2. Hunter-Central Rivers, Hawkesbury-Nepean and Sydney Metropolitan: mid September to end of March
3. Southern Rivers: mid November to end of March.

MER Program sampling is timed to fit six sampling occasions within the defined window (normally resulting in a three-week interval). Additional monitoring outside these windows is encouraged and will provide data for other times of the year. From a statistical perspective a minimum of at least six samples is recommended from within the chlorophyll *a* maxima period, with more samples providing greater confidence in analysis.

7.7 Field collection

Field data sheets

At the commencement of sampling in each estuary fill out field data sheets (an example is provided in Appendix 2). Information in the field data sheet can be used during data analysis and should include relevant items such as the entrance state, riparian condition, observations about macroalgae and other submerged aquatic vegetation (including dominant types), weather and state of the tide.

Lakes and lagoons

Determine zones for the estuary and locate them on a chart or photograph of the estuary. Since the start point and direction are random within the zone, this does not need to be accurately defined.

The collection strategy used for the MER Program includes integrated samples within zones. Integrated samples are preferred over grab samples as they reflect the concentration over large areas (estuary or zone), rather than at a discrete point (or series of points) within the waterway. As discussed in Section 7.5, where localised assessments are targeting condition at spatial scales smaller than the whole waterway (or riverine maximum), the sampling strategy should be to collect multiple integrated samples within the areas of interest in preference to multiple single samples (again to reduce the influence of small-scale variation).

It is recommended that where possible sampling is done by boat. For each zone:

- Travel to the upwind boundary.
- Record Secchi depth by lowering the disk until it is not visible and note the depth, then lower some more and raise until it is visible, noting the depth when it is just visible. Secchi depth is the average of these two depths. Be sure to take Secchi depth measurements where there are no shadows cast from the boat.
- OEH uses a water quality probe to measure fluorometric chlorophyll *a*, turbidity, salinity, temperature, depth and time. The probe is fixed in the water at a depth of approximately 400 millimetres (OEH uses a special cradle attached to the boat's gunwale). Set the probe to measure and record results every second. If the logging function is not available, write down the measurements every 30 seconds. This procedure captures data for a transect through the zone and allows the calculation of an average (or median) turbidity and fluorometric chlorophyll for the zone.
- Record the time at which the transect commences and allow the boat to drift for five minutes. If there is insufficient wind, the boat can be rowed or paddled for five minutes.
- While the boat moves along the transect, use a pole sampler to collect 10 x 1 metres integrated water samples approximately 30 seconds apart. A pole sampler is a length of (approximately) 40–50 millimetres of PVC water pipe with a valve at the lower end to retain the water when the pole is lifted from the water (OEH uses a flap valve available from plumbing specialists, but a rope operated ball valve or bung can also be used). It is plunged vertically into the water, capturing a vertical cross-section of the water column. These samples are all placed into a single clean bucket to provide an integrated sample. Two sub-samples are taken from the bucket for chlorophyll *a* analysis – this provides replication for the integrated sample, and the integrated sample provides generality for the zone. The volume of sample required depends on the methods used to determine the chlorophyll *a*; seek advice from the laboratory analysing the samples as to the volume required.
- At the end of the transect, repeat the Secchi depth measurement and then slowly lower the water quality probe to the bottom, recording a profile through the water column.

Rivers

When sampling rivers following longitudinal transects it is more efficient to carry out sampling while the boat is motoring. Where this is the case an additional apparatus is required to allow continuous sampling while underway. This involves using either a water pick-up that uses the boat's speed to force water up a hose into the boat or a submerged pump, and a receptacle in the boat to house the water quality probe in a way that allows continuous monitoring of the stream of water.

The pick-up is a cheap commercially available device used by fishers to provide a flow of water to on-board tanks and can be purchased at most boating shops. Contact OEH Coastal Waters Unit (9995 5515) for details of the rest of the system.

As part of the MER Program integrated samples are collected from sampling zones within the longitudinal transect; however, integrated samples (as described above) can be collected along the longitudinal transect if preferred.

If not using a longitudinal transect, sample randomly selected zones in the upper estuary as described above for lakes and lagoons.

Non-boat based monitoring

If the organisation doing the monitoring does not have access to a boat then careful thought needs to be given to issues arising from alternative methods. For example, a single 'spot' sample from a location may not be representative of a larger location, and sampling replication may be required due to the variability that can occur in water quality.

Collection of samples by wading can result in samples contaminated by re- suspended material and is not recommended for routine sampling. Samples from the fringes of lakes and lagoons with extensive macrophyte beds are often different from central basin samples and may strongly influence results and comparisons to other estuaries, and to trigger values (which are derived from central basin data). A better option may be to collect samples from bridges or jetties or to use kayaks or canoes to move away from the shore line.

7.8 Laboratory analysis

Prior to field sampling it will be necessary to engage a laboratory to analyse water samples for chlorophyll *a*. Use of laboratories accredited by the National Association of Testing Authorities (NATA) is preferable. Analytical methods should follow recognised techniques and appropriate QA/QC procedures.

Collection and storage of samples should be discussed with the laboratory to ensure adequate volumes are collected, storage is appropriate and adequate field and laboratory QA/QC procedures are in place.

7.9 Data analysis and reporting

Trigger values

To assess the health or condition of an estuary requires the determination of reference or baseline conditions against which data can be compared. Compliance against a guideline or trigger value is commonly used to assess the status of an indicator, in this case the condition indicators chlorophyll *a* and turbidity.

A trigger value is used comparatively to indicate when an indicator is outside the expected range. The MER Program has determined trigger values as a means to assess when estuarine condition may not be desirable for the continued health of the ecosystem. Trigger values were calculated based on the methodology recommended by ANZECC and ARMCANZ (2000), that is by calculating the 80th percentile of all data for reference estuaries in each estuary type (Roper et al. 2011): see Table 1. Reference estuaries were defined as those minimally impacted with respect to chlorophyll *a* and turbidity; the ratio of increase in TN loading was adopted as the measure of disturbance in recognition that estuaries are generally nitrogen-limited (see Roper et al. 2011).

Trigger values are likely to be recalculated periodically as additional data becomes available.

The level of compliance against a trigger value is commonly used for reporting purposes (including in report cards such as the SoC reports). Depending on the level and frequency of exceedance, exceeding the values should 'trigger' either further investigation or a management action.

Table 1: MER Program trigger values for chlorophyll a and turbidity. These values have been updated in 2015 from Roper et al. (2011) to utilise more data and allow the inclusion of the Back Dune Lagoon estuary type

	Trigger Values	
	Chlorophyll a (µg/L)	**Turbidity (ntu)**
Creeks	3.3	1.5
Lagoons	3.9	5.7
Lakes	5	6
Back Dune Lagoons	5.3	2.8
Rivers Lower (>25 psu)	2.3	2.8
Rivers Mid (10 – 25 psu)	4.3	2.6
Rivers Upper (< 10 psu)	4.8	6

* Trigger values have been revised from those in Roper et al. (2011).

Assigning grades

As discussed above, compliance against a guideline or trigger value is commonly used to assess the status of an indicator. Compliance is then generally summarised into a value that can be compared between different estuaries or reporting zones. Simply calculating compliance against a trigger value indicates whether a value is compliant or non-compliant but does not indicate the scale of compliance (how far away it is from the trigger value). Building on from work undertaken by OEH as part of the MER Program, additional work has been undertaken for Great Lakes Council[2] to determine a suitable methodology. It is recommended that a distance measure is used to provide greater sensitivity in determining condition along a scoring gradient from very good to very poor.

In summary, the process for calculating a condition score for an estuary or zone within an estuary involves six steps. Appendix 3 provides the formulae that can be used in Excel to calculate each step.

1. **Calculating the non-compliance (NC_i) score:** this is the proportion of time that the measured values of the indicator are outside the adopted trigger values (NC_i, the non-compliance score).

   NC_i = number of samples non-compliant with trigger value divided by the total number of samples (expressed as a value between 0 and 1, with 0 equal to all values being compliant and 1 equal to all values non-compliant).
2. **Calculating the Worst Expected Value (WEV)**: choice of a suitable WEV is critical. If the WEV is too high, the distance score will always be very low, diluting any difference between reporting zones and between years making comparison difficult. If the WEV is too low, the distance scores will be high, and poorly performing sites may not be identified. Ideally, the WEV will be just high enough that a large majority of the measured values for all of the reporting zones will fall beneath it.

   The WEVs provided in Table 2 have been derived by examination of the MER Program data set. The 98th percentile value was selected as the WEV. This provides values that should be close enough to measured values so that small changes in distance are not swamped by a very large WEV, but large enough that most values are less than the WEV. In the small number (2%) of circumstances where measured values are greater than the WEV, the measured value can be replaced with the WEV so that the distance measure becomes 1 (which is the highest possible value).

[2] www.greatlakes.nsw.gov.au/files/13e416da-b80a-4b21-85e5-9fa600a3de87/2011_GLC_SoE.pdf

Table 2: Worst Expected Values from the MER Program

	Worst Expected Value	
	Chlorophyll *a* (ug/L)	**Turbidity (NTU)**
Lake	30	20
Lagoon	30	20
River (lower)	30	30
River (mid)	30	30
River (upper)	30	60

3. **Calculating the distance (DS_i) from the trigger value:** a distance score is only calculated for data greater than the trigger; it is defined as the extent that the period of data extends past the trigger value and approaches the WEV. The distance from the benchmark score (DS_i) will be nearly 0 for slight exceedances of the trigger value and 1 when data equal the WEV for each of the indicators.

   DS_i = (value – trigger value) / (WEV – trigger value)

4. **Calculating an indicator score (IS_i) for each zone**: once the NC_i and DS_i have been calculated for each indicator, both scores need to be combined to arrive at a single score that can be used to assess the condition of the indicator in that zone. This is calculated as the geometric mean because the distance score is conditional on being above the guideline (non-compliant).

   $IS_i = \sqrt{(NC_i \times DS_i)}$

5. **Calculating the zone score (ZS):** the overall zone score (ZS) for each reporting zone is simply the average of the indicator scores for the relevant indicators (chlorophyll a, ISc and turbidity, ISt) for each zone.

   ZS = (ISc + ISt) / 2

6. **Grading the zone**: if reporting on condition through the use of report cards, it is common practice to assign a ‘grade’ to allow for easy comparisons between systems and through time. These may be on a gradation such as A (very good), B (good), C (fair), D (poor) and E (very poor).

   These values for each grade should reflect the condition of a zone in comparison to the overall condition across all NSW estuaries. Essentially, we want an A (very good) grade to really represent very good condition for a NSW estuary. As the grades are strongly affected by the specific trigger values and WEVs used in the calculations, grades should also be standardised.

7. The cut-off values for each grade are defined as the percentage of the scores for the state (Table 3). For example, a zone score less than 0.07 defines the 20% of best scores in the state and this is an A (very good) grade (see Table 3 and Figure 3 for other cut-offs). A score of zero is not used to define very good because, as a consequence of how the trigger values are calculated, it is expected that even reference sites will exceed trigger values 20% of the time.

   Report card grades and example definitions and descriptions of how the final scores might be categorised into each grade are provided in Table 4.

Table 3: Percentile values which define cut-offs for grade scores

Percentile	Cut-off zone score
95	0.60
80	0.44
50	0.23
20	0.07

Note: higher scores (those approaching 1) represent a worse condition than lower scores (those approaching 0).

Figure 3: Relationship between distribution of NSW scores, grades and zone scores

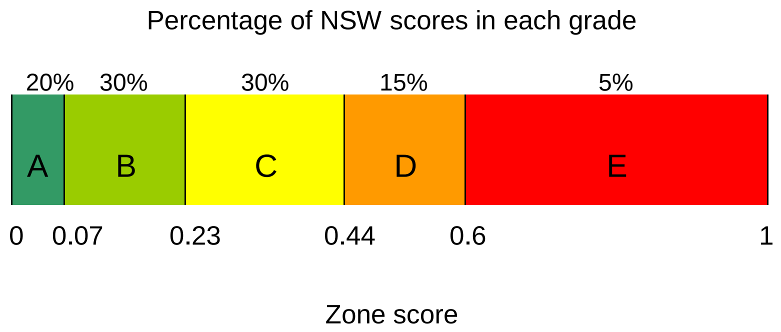

Table 4: Report card grades, definitions and descriptions

Grade	Result	Definition (example)	Description
A	Very good	The indicators measured meet all of the benchmark values for almost all of the time period.	Equivalent to the best 20% of scores in the state
B	Good	The indicators measured meet all of the benchmark values for most of the time period.	Equivalent to the next 30% of good scores
C	Fair	The indicators measured meet some of the benchmark values for some of the time period.	Equivalent to the middle 30% of scores
D	Poor	The indicators measured meet few of the benchmark values for some of the time period.	Equivalent to the next 15% of poorer scores
E	Very poor	The indicators measured meet none of the benchmark values for almost all of the time period.	Equivalent to the worst 5% of scores in the state

8 Estuarine macrophytes

Estuarine macrophytes, including seagrass, mangroves and saltmarsh, play an important ecological role in estuaries.

The first comprehensive mapping of estuarine macrophytes in NSW commenced in the early 1980s and included 133 estuaries (West et al. 1985). The status of estuarine macrophytes reported in the SoC reports (DECCW 2010c, 2010d, 2010e, 2010f) was determined by a combination of projects undertaken by DPI.[3] Extensive time series data are available for a small number of estuaries in NSW. This list expands as opportunities arise to map historical distributions of macrophytes at more locations or at other times.

8.1 MER Program mapping

The following standard is recommended for mapping seagrass, mangrove and saltmarsh distribution.

- All mapping is derived from air photo interpretation.
- All scanned photos have an output resolution of one metre.
- Images provided in digital format are kept at their original resolution.
- All images are orthorectified using:
  - NSW LPI 25 m Digital Elevation Model
  - NSW LPI Digital Cadastral Database
  - NSW LPI Digital Topographic Database.
- The rectification error is no greater than 15 metres, but can be as small as two metres.
- A preliminary map of all features for each estuary is mapped via on-screen digitising of macrophyte boundaries from the orthorectified images.
- All digitising is carried out at a scale of 1:1500.
- Digitising tolerances are:
  - snapping tolerance 0.75 map units (metres)
  - streaming tolerance 1.5 map units (metres).
- Preliminary maps for every estuary are validated by field investigation (see Creese et al. 2009) with as many polygons and boundaries between habitat types checked as time allows.
- Preliminary maps for every estuary are edited and amended where necessary based on the field validations.
- All polygons are attributed to one of the three macrophyte categories. For seagrass this is done on the basis of presence/absence – if any seagrass at all is present in a polygon it is classified as ‘seagrass’. Similarly a ‘mangrove’ classification is given to any polygon which contains mangroves, even if some saltmarsh plants are also present. A polygon is classified as saltmarsh only if it is the only macrophyte present.
- A final map is created and lodged in the NSW Estuarine Macrophyes database, a corporate geodatabase held by DPI Fisheries.

8.2 Data analysis and reporting

Research is being carried out into the factors controlling estuarine macrophyte distribution and extent so as to define an ‘ideal mix’ of seagrass, mangrove and saltmarsh in any given system (Roper et al. 2011). However, until this knowledge is

[3] www.dpi.nsw.gov.au/research/areas/aquatic-ecosystems/estuarine-habitats-maps

available the recommended approach is to report on the change in macrophyte extent based on consecutive surveys using consistent methodologies; the initial survey should be used as the baseline against which change should be assessed.

For seagrass and saltmarsh extent the grades in Table 5 are recommended.

Table 5: Scoring grades for seagrass and saltmarsh extent

Grade	Change in extent
Very good	≥10% gain
Good	<10% gain to –10% loss
Fair	>–10 to –40% loss
Poor	>–40 to –70% loss
Very poor	>–70 to 100% loss

Scoring of mangroves may be more problematic. Increasing mangrove extent could be due to a number of factors.

- Recolonisation of areas previously supporting mangroves would be viewed as a positive change.
- Colonisation upslope into areas occupied by saltmarsh might be viewed as a negative change.
- Marinisation (increasing salinity) of estuaries through entrance training, artificial entrance opening, water extraction and potentially climate change could be considered as negative.

Therefore it is recommended that a stable mangrove extent (change between –10% to +10%) over consecutive surveys is considered good. Any change outside that range will require further interpretation and investigation to determine the condition.

It should be noted that for some estuaries estuarine macrophytes may not always be a relevant condition indicator, for example estuaries that are intermittently closed for long periods are not conducive to mangrove colonisation. Where consecutive surveys indicate the absence of macrophytes this should be scored as ‘not applicable’ as it is possible macrophytes have never occurred in that estuary.

9 Fish assemblages

Fish assemblages are considered an appropriate indicator of estuarine condition as they represent a component of estuarine biology responsive to a range of pressures and stressors.

Past collection and analysis of fish community data in NSW estuaries has been for a variety of purposes, including stock assessment for commercially or recreationally important species, ecological studies of fish habitat use or biodiversity surveys.

In order to ensure long-term availability of estuarine fish data, a process was begun within DPI Fisheries as part of the MER Program to collate this data into a database known as the Estuarine Fish Ecology Database (EFED).

Additional data on estuarine fish in NSW can be accessed from the Australian Museum’s fish database. However, much of the data in this system comes from the projects that comprise the EFED system. Also, the focus of the Australian Museum is the taxonomy and distribution of individual species rather than fish community structure. Catch data from commercial fishers who operate in estuaries also provides information on the geographical occurrence of fish species.

Information from these databases, together with information published on the website FishBase, in books and in scientific papers, is used to generate lists of fish species that might be expected to occur in NSW estuaries and to classify those species according to attributes such as their geographical range or feeding mode.

9.1 Estuarine Fish Community Index

Traditionally, biotic measures of ecosystem condition have often included single indicators based on species diversity, dominance or presence/absence. Indices are being developed particularly for freshwater systems that capture information from individual, population and community levels to provide a more integrated assessment of biological integrity (Harrison and Whitfield 2006).

One such index is the multi-metric Estuarine Fish Community Index (EFCI), developed to describe the health of 190 South African estuaries spanning three biogeographic regions and three distinct estuary types (Harrison and Whitfield 2004, 2006). The EFCI combines four broad fish community attributes: species diversity and composition (four metrics), species abundance (two metrics), nursery function (four metrics) and trophic integrity (four metrics) (Table 6).

Table 6: Estuarine Fish Community Index metrics

EFCI metric	Rationale	Response to environmental stress
Species diversity and composition		
1. Total number of taxa	Simplest measure of diversity	Reduced
2. Rare or threatened species	Presence imparts additional conservation value	Absent
3. Exotic or introduced species	Potential threat to naturally occurring taxa	Present
4. Species composition (relative to reference assemblage)	Similarity is a measure of biological integrity	Reduced
Species abundance		
5. Species relative abundance	Captures change from many species in relatively low proportions to simple assemblages dominated by few communities	Reduced
6. Number of species that make up 90% of abundance	Dominance by fewer species	Reduced
Nursery function		
7. Number of estuarine-resident taxa	Estuaries are important habitat for resident taxa.	Reduced
8. Number of estuarine-dependent marine taxa	Estuaries fulfil role of nursery habitat for marine taxa as well as estuarine resident taxa.	Reduced
9. Relative abundance of estuarine-resident taxa	Between 9 and 10, quantitative and complementary measures of estuarine habitat quality and nursery function	Very low or very high
10. Relative abundance of estuarine-dependent marine taxa	See above	Very low or very high
Trophic integrity		
11. Number of benthic invertebrate feeding taxa	Indirect measure of the condition of the benthic invertebrate fauna	Reduced
12. Number of piscivorous taxa	Diverse and abundant top carnivores represent the broader trophic network in estuaries.	Reduced

EFCI metric	Rationale	Response to environmental stress
13. Relative abundance of benthic invertebrate feeding taxa	Between 13 and 14, quantitative and complementary analysis of trophic integrity	Reduced
14. Relative abundance of piscivorous taxa	See above	Reduced

The index was trialled for NSW estuaries for the SoC reports. Further details of how the data are used to generate the index and how this is then converted into scores of condition are provided in Roper et al. (2011).

For fish communities, earlier statistical analysis classified estuaries into three bioregions defined by latitude, and three types: permanently open riverine barrier estuaries and drowned river valleys, large barrier lagoons and predominantly open lakes and lagoons, and predominantly closed lakes and lagoons (Pease 1999). As might be expected, this classification is different from the chlorophyll *a* response- based classification that is discussed in Section 7.4.

9.2 Field collection

For the purpose of SoC reporting, sampling in all estuary types used seine netting, with a minimum of five replicate hauls done at all sites. For barrier estuaries and ICOLLs gill netting is also recommended. Sampling sites are situated within the central mud basin of estuaries (as defined by Roy et al. 2001).

For seine netting, six sites are randomly selected using a GIS procedure. First, a polygon is created for the central mud basin. Second, the shoreline contained within this polygon is divided into 100 m segments which are numbered consecutively. Third, a random number generator is used to select six segments from the available list. Fourth, the selection is checked to ensure that not all selected sites are clumped together in one place. Wherever possible, sites on either shoreline are included in the selection.

Samples are collected using a 12 millimetres stretched mesh seine net with a 20 metre headline, a two metre drop and a cod-end. This net is designed to catch only small or slow- moving fish, and therefore does not provide a measure of the total fish diversity at a site. Each replicate net haul is done during daylight hours to form a U-shape that covers approximately 100 m^2. The ends are drawn together so that the sample is collected in the cod-end.

In addition, for barrier estuaries and ICOLLs, three multi-panelled gill nets (total length of 25 metres) are set on arrival at each site, spaced at least 20 metres apart. Each net is set from a boat at a 45° angle from the shore and at a depth of no more than three metres. Each gill net should be left out for at least an hour of fishing time (while seine netting is undertaken) and then retrieved.

The catch is then placed into a bucket, with fish over 100 millimetres measured and released alive. Remaining animals are euthanased with Benzocaine (ethyl p-aminobenzoate) then transferred to 10% formalin/seawater for transportation to the laboratory for processing. All fish collected should be identified to the lowest practicable taxonomic level, counted and measured (total length).

For each barrier estuary and ICOLL there will be 30 seine net samples and 18 gill net samples. This data is pooled to calculate the final metrics.

All fish sampling must be undertaken in accordance with the appropriate permit.

9.3 Data analysis and reporting

In applying the EFCI to NSW estuaries, the approach used was to define the reference condition by the best values observed for each metric for a particular estuary type in a particular region. Having established reference conditions for each metric, the extent of deviation from reference can be used to assign thresholds for grading each estuary. The EFCI established thresholds such that a score could be assigned to each metric. This information is detailed in Roper et al. (2011).

10 Other condition indicators

In addition to the core condition indicators discussed previously, councils may wish to monitor additional indicators or more appropriate indicators for their local situation. Guidance on additional condition indicators is available from a number of sources; in particular, for the Southern Rivers CMA region Fraser (2008) provides localised advice on monitoring a range of indicators including sea grass depth limit.

10.1 Macroalgae

While assessment of macroalgae at a statewide scale for use in SoC reports has proved problematic, at a local scale where patterns of macroalgal spatial and temporal distribution are better understood, monitoring of macroalgae may provide useful condition information.

If guidance is required, a simple field methodology has been developed by the Community Environment Network (2005) in conjunction with their methodology for monitoring seagrass distribution. The methodology is based on measuring macroalgae coverage using a system of transects and quadrats.

10.2 Dissolved oxygen

Sampling and assessment of dissolved oxygen presents many challenges. Ideally, dissolved oxygen is best sampled using a deployed meter logging data from near the estuary floor over a 24-hour period. In many cases this will be impractical. OEH is currently measuring dissolved oxygen from surface waters as part of its MER Program sampling using a multiprobe. This method is only useful for determining whether the entire water column is deoxygenated and hence only indicates severe situations. Unless 24-hour logging is feasible, dissolved oxygen sampling is of limited value other than to determine whether severe deoxygenation is occurring.

11 Pressure indicators

Depending on the relevant pressures and stressors acting on an estuary, councils may wish to monitor and report on them. A range of pressure indicators have been assessed to support the condition assessments in the SoC reports; these are described in Table 7 (DECCW 2010c, 2010d, 2010e, 2010f; Roper et al. 2011).

There are a number of additional indicators that would also provide useful information on pressures, although data was not available to report on these in the first round of SoC reports. It is hoped these will be incorporated into future SoC reports as data become available. These are described in Table 8.

At the local scale, if pressure indicators are to be included in a monitoring program, it is essential to consider a variety of indicators that reflect the specific estuary, the main pressures and their likely relationship to condition, and that the spatial and temporal frequency of monitoring is adequate. Table 7 provides guidance on indicators where there is availability of data at a statewide scale and its relevance to specific condition indicators. Table 8 provides advice on additional indicators that may be relevant at a local scale and for which data may become available at the statewide scale.

12 Data storage

Data collected as part of any monitoring program should be stored in appropriate databases accompanied by metadata that complies with the appropriate standard, for example Spatial Information Council of Australia and New Zealand (ANZLIC) standards or AS/NZS ISO 19115:2005 Geographic information—Metadata. ANZMet Lite[4] is the ANZLIC metadata collection tool to facilitate the creation of an ANZLIC- compliant metadata record. Metadata should be stored on the NSW Spatial Data Catalogue to promote access to data.

It is recognised that councils may have different databases and data storage protocols. Currently OEH does not have a water quality database where third parties are able to provide their data remotely. As such, monitoring programs funded through the NSW Estuary Management Program should provide data collected to OEH; a data template and instructions are available for this purpose.

[4] http://spatial.gov.au/resources/metadata#ANZMetLiteTool

Table 7: Estuary pressures indicators used in SoC reports (Roper et al. 2011)

		Strength of link to condition indicator*							
		Chlorophyll *a*	Turbidity	Macroalgae	Seagrass	Mangrove	Saltmarsh	Fish	
Catchment use									
Catchment population	Component of urban stormwater, sewage overflows, contributes to general degradation	✓	✓	✓	✗	✗	✗	✗	Increase from zero baseline
Land use	Increase in sediment, nutrient and organic loads	✓✓	✓✓	✓✓	✓✓	✓	✓	✓	Increase from zero baseline
Catchment runoff	Increase in stream-bank erosion and frequency of erosive events, change in flushing time	✓	✓	✓	✓	✗	✗	✗	Increase from pre-1750
Sediment loads	Reduction in estuary water clarity	✗	✓✓	✗	✓	✓	✗	✗	Increase from pre-1750
Licensed STP discharges	Contributes to nutrient, suspended solid and organic loads	✓	✓	✓	✓	✗	✗	✗	Increase from zero baseline
Nutrient loads	Increase in algal growth, reduction in water clarity	✓✓	✗	✓✓	✓	✗	✗	✓	Increase from pre-1750
Riparian use (freshwater streams and estuary shoreline)									
Water extraction	Reduction in freshwater inputs especially during low flows	✓	✓	✓	✓	✗	✗	✗	Increase from zero baseline
Foreshore use (intertidal and adjacent shallow water)									
Foreshore structures – reclamation, walls, groynes, jetties, oyster depuration sites	Removal of foreshore habitat	✗	✗	✗	✓✓	✓✓	✓✓	✗	Increase from zero baseline
Aquaculture	Shading and/or disturbance of seagrass beds	✗	✗	✗	✓	✗	✗	✗	Increase from zero baseline
Waterway use									
Entrance works	Training walls increase tidal range, flushing,	✓✓	✓✓	✓✓	✗	✗	✗	✓	Increase from zero baseline

		Strength of link to condition indicator*							
		Chlorophyll *a*	Turbidity	Macroalgae	Seagrass	Mangrove	Saltmarsh	Fish	
	marinisation (salinity)								
Artificial entrance opening	Reduces inundation frequency and duration of peripheral aquatic vegetation, increases marinisation (salinity)	✓✓	✓✓	✓✓	✓	✓	✓	✓	Increase from natural frequency
Wild harvest fisheries	Reduces recreationally and commercially important fish and prawn species	×	×	×	×	×	×	✓✓	Increase from zero baseline

* The columns on strength of link indicates the extent to which current literature supports a cause-effect relationship between pressure and condition. The scoring system of ticks and crosses is intended to show:

- ✓✓ Strong link with good potential for development of empirical stressor-response model of pressure and condition
- ✓ Known link but relationship unlikely to be significant or capable of modelling
- × Very indirect link with no modelling potential

Table 8: Potential estuary pressures indicators (Roper et al. 2011)

		Strength of link to condition indicator*							
		Chlorophyll *a*	Turbidity	Macroalgae	Seagrass	Mangrove	Saltmarsh	Fish	
Catchment use									
Soil erosion potential	Potential reduction in estuary water clarity	✗	✓✓	✗	✓	✗	✗	✗	Increase from pre-1750
Reticulation vs unsewered septics	Contributes to nutrient and organic loads	✓	✓	✓	✓	✗	✗	✗	Increase from zero baseline
Riparian use (freshwater streams and estuary shoreline)									
Riparian vegetation extent	Indicative of water quality filtering capacity	✓	✓	✓	✓	✗	✗	✗	Increase from zero baseline
Riverine geomorphic condition	Bed and bank stability and erosion	✗	✓✓	✗	✓	✗	✗	✗	River Styles reference reaches
Riverine macroinvertebrate communities	Indicative of freshwater stream pollution potential and input	✓	✓	✓	✓	✗	✗	✗	Observed / expected SIGNAL2 score
Foreshore use (intertidal and adjacent shallow water)									
Moorings – piles, marinas	Shading and/or disturbance of seagrass beds	✗	✗	✗	✓	✗	✗	✗	Increase from zero baseline
Waterway use									
Dredging	Generates fine sediment plumes, removes aquatic habitat	✗	✓✓	✗	✓	✗	✗	✓	Increase from zero baseline
Invasive species	Competition for native species	✗	✗	✗	✓✓	✗	✗	✗	Increase from zero baseline
Climate change									
Sea level rise	Raises inundation levels of peripheral aquatic vegetation, changes light regimes and submerged aquatic vegetation distribution	✗	✗	✗	✓	✓✓	✓✓	✗	Change from earliest record
Rainfall change	Changes estuary hydrology, pollutant export and flushing rates	✓	✓	✓	✓	✗	✗	✗	Change from earliest record

		Strength of link to condition indicator*							
		Chlorophyll *a*	Turbidity	Macroalgae	Seagrass	Mangrove	Saltmarsh	Fish	
Air temperature change	Changes water temperature, biological productivity, bio-geochemistry, species composition	✓	✗	✓	✗	✗	✗	✗	Change from earliest record

* The columns on strength of link indicates the extent to which current literature supports a cause-effect relationship between pressure and condition. The scoring system of ticks and crosses is intended to show:

- ✓✓ Strong link with good potential for development of empirical stressor-response model of pressure and condition
- ✓ Known link but relationship unlikely to be significant or capable of modelling
- ✗ Very indirect link with no modelling potential

13 Indices

When reporting on condition (and pressure) through a report card, it may be desirable to provide an overall grade that reflects the condition of (and pressure on) the estuary. The integration or aggregation of grades from a number of indictors into a single grade is referred to as an index. The goal of a condition index is to integrate a number of measures to provide a more balanced and complete assessment of ecosystem health. Likewise, the purpose of a pressure index is to provide an overall assessment of the level of pressure on an estuary.

An index of estuary ecosystem health can also play a role in facilitating comparisons between estuaries or regions. The Framework for the Assessment of River and Wetland Health (FARWH) refers to 'integration' as assembling different indicators or indices at a given scale into a combined index at the same scale, while 'aggregation' refers to assembling indicators or indices at a larger spatial scale (NWC 2007). Indices can be valuable for drawing the attention of decision-makers to a problem and are widely used. Any comparisons of relative health based on an index with different subindices or indicators, either spatially (for example between two estuaries) or temporally (for example between years), should only be done with careful attention to the components of each index.

The initial approach adopted for NSW (Roper et al. 2011) has been to integrate the condition indicators based on biological assemblages into a single condition index with certain rules applied and the pressure and stressor indicators into a single pressure index. The rules applied to the condition index for an individual estuary were as follows.

- The indicators were grouped into the three main types: eutrophication (chlorophyll *a*, macroalgae and turbidity), habitat (seagrass, mangrove and saltmarsh) and fish. An integration rule was set that at least one indicator from a minimum of two indicator groups must be populated, for example at least one eutrophication and one habitat or fish indicator.
- Provided more than one indicator type was populated, the scores from all indicators were summed with equal weighting and averaged to give an overall estuary score.

However, it is recognised that further development of indices may be required for subsequent estuary ecosystem health reports.

14 Communication strategy

When reporting on estuary ecosystem health it is important to identify the key messages from the assessment to be communicated, the target audience (for example who they are, their level of technical understanding) and the way in which the information will be communicated (by whom and how) (EcoCheck 2011). It may be useful to prepare a communication strategy to identify these details, and much of the content should be determined in the early stages of the monitoring and assessment.

Reporting on estuary ecosystem health may also present an opportunity to engage the broader community in protection or rehabilitation activities.

Appendix 1 MER Program estuaries

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
1	Tweed River	-28.1693	153.5562	BARRIER RIVER	H							y		
2	Cudgen Creek	-28.2564	153.5847	BARRIER RIVER	VH	y			y					
3	Cudgera Creek	-28.3596	153.5780	BARRIER RIVER	VH	y			y					
4	Mooball Creek	-28.3877	153.5700	BARRIER RIVER	H	y			y					
5	Brunswick River	-28.5379	153.5581	BARRIER RIVER	H	y			y			y		y
6	Belongil Creek	-28.6251	153.5916	CREEK	H	y			y			y		
7	Tallow Creek	-28.6673	153.6216	LAGOON	H	y			y			y		
8	Broken Head Creek	-28.6968	153.6135	LAGOON	M	y			y					
9	Richmond River	-28.8766	153.5910	BARRIER RIVER	H	y			y					
10	Salty Lagoon	-29.0771	153.4376	LAGOON	VL	y			y					
11	Evans River	-29.1128	153.4373	BARRIER RIVER	H							y		y
12	Jerusalem Creek	-29.2145	153.3919	LAGOON	VL	y			y			y		
13	Clarence River	-29.4268	153.3721	BARRIER RIVER	M									
14	Lake Arragan	-29.5651	153.3383	LAKE	VL	y			y			y		
15	Cakora Lagoon	-29.6007	153.3330	LAGOON	VL							y		
16	Sandon River	-29.6728	153.3325	BARRIER RIVER	VL	y			y			y		
17	Wooli Wooli River	-29.8878	153.2683	BARRIER RIVER	VL	y			y			y		
18	Station Creek	-29.9494	153.2587	LAGOON	VL	y			y			y		
19	Corindi River	-29.9805	153.2318	BARRIER RIVER	M	y			y			y		
20	Pipe Clay Creek	-30.0223	153.2069	CREEK	H	y			y			y		y
21	Arrawarra Creek	-30.0582	153.1973	LAGOON	M	y			y			y		
22	Darkum Creek	-30.0959	153.2004	CREEK	VH	y			y					

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
23	Woolgoolga Lake	-30.0987	153.1993	LAGOON	VH	y			y			y		
24	Flat Top Point Creek	-30.1286	153.2047	CREEK	VH	y			y			y		
25	Hearns Lake	-30.1320	153.2025	LAGOON	VH	y			y			y		
26	Moonee Creek	-30.2122	153.1614	BARRIER RIVER	H	y			y			y		
27	Pine Brush Creek	-30.2516	153.1423	CREEK	VH	y			y			y		
28	Coffs Creek	-30.2965	153.1391	BARRIER RIVER	VH	y			y			y		
29	Boambee Creek	-30.3546	153.1062	BARRIER RIVER	VH							y		
30	Bonville Creek	-30.3760	153.1004	BARRIER RIVER	H	y			y					
31	Bundageree Creek	-30.4313	153.0758	CREEK	M							y		
32	Bellinger River	-30.5017	153.0313	BARRIER RIVER	L							y		
33	Dalhousie Creek	-30.5232	153.0281	LAGOON	H	y			y					
34	Oyster Creek	-30.5633	153.0175	LAGOON	M							y		
35	Deep Creek	-30.6010	153.0116	LAGOON	H	y			y					
36	Nambucca River	-30.6483	153.0105	BARRIER RIVER	M	y			y			y		
37	Macleay River	-30.8729	153.0259	BARRIER RIVER	M							y		
38	South West Rocks Creek	-30.8831	153.0379	LAKE	H							y		
39	Saltwater Creek (Frederickton)	-30.8831	153.0428	LAGOON	H	y			y					
40	Korogoro Creek	-31.0536	153.0561	BARRIER RIVER	M	y						y		
41	Killick Creek	-31.1870	152.9784	LAGOON	M	y						y		
42	Goolawah Lagoon	-31.2093	152.9683	BDL	VL							y		
43	Hastings River	-31.4259	152.9168	BARRIER RIVER	M	y			y					y
44	Cathie Creek	-31.5495	152.8598	LAGOON	M	y			y					
45	Duchess Gully	-31.5871	152.8403	CREEK	H	y			y					
46	Camden Haven River	-31.6357	152.8375	LAKE	M							y		

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
47	Manning River	-31.8767	152.6959	BARRIER RIVER	M	y	y	y			y			
48	Khappinghat Creek	-32.0100	152.5656	LAGOON	M	y	y	y	y	y	y	y	y	y
49	Black Head Lagoon	-32.0704	152.5449	CREEK	M			y			y			
50	Wallis Lake	-32.1734	152.5109	LAKE	M	y	y	y	y	y	y	y	y	y
51	Smiths Lake	-32.3954	152.5196	LAKE	M		y				y			
	Myall Lakes	-32.5497	152.2857	LAKE	M	y	y	y	y	y				
52	Myall River	-32.6710	152.1457	BARRIER RIVER	L	y	y	y	y				y	
53	Karuah River	-32.6656	151.9719	BARRIER RIVER	M	y		y			y			y
54	Tilligerry Creek	-32.7280	152.0519	LAKE	H			y			y			
55	Port Stephens	-32.7071	152.1953	DROWNED VALLEY	M			y			y			
56	Hunter River	-32.9143	151.8013	BARRIER RIVER	H			y			y			
57	Glenrock Lagoon	-32.9627	151.7383	CREEK	H			y			y			
58	Lake Macquarie	-33.0855	151.6620	LAKE	M			y			y			
59	Middle Camp Creek	-33.1461	151.6368	BDL	L			y			y			
60	Moonee Beach Creek	-33.1666	151.6328	CREEK	VH									
61	Tuggerah Lake	-33.3447	151.5032	LAKE	M			y			y		y	y
62	Wamberal Lagoon	-33.4299	151.4489	BDL	H			y			y			y
63	Terrigal Lagoon	-33.4427	151.4436	LAGOON	H			y			y			
64	Avoca Lake	-33.4642	151.4365	BDL	H			y			y			y
65	Cockrone Lake	-33.4939	151.4288	BDL	M			y			y			
66	Brisbane Water	-33.5225	151.3341	LAKE	H			y			y			
67	Hawkesbury River	-33.5644	151.3090	DROWNED VALLEY	M			y			y			
68	Pittwater	-33.5799	151.3169	DROWNED VALLEY	M									
69	Broken Bay	-33.5625	151.3410	BARRIER RIVER	M									
70	Narrabeen Lagoon	-33.7037	151.3081	LAKE	M			y			y			
71	Dee Why Lagoon	-33.7469	151.3037	BDL	VH			y			y			

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
72	Curl Curl Lagoon	-33.7673	151.2992	LAGOON	VH			y			y			
73	Manly Lagoon	-33.7864	151.2891	CREEK	VH			y			y			y
74	Middle Harbour Creek	-33.8188	151.2572	DROWNED VALLEY	H			y			y			
75	Lane Cove River	-33.8427	151.1778	DROWNED VALLEY	H			y			y			
76	Parramatta River	-33.8449	151.1873	DROWNED VALLEY	H			y			y			y
77	Port Jackson	-33.8283	151.2901	DROWNED VALLEY	H			y						
78	Cooks River	-33.9494	151.1688	BARRIER RIVER	VH			y			y			
79	Georges River	-33.9975	151.1554	DROWNED VALLEY	VH			y			y			y
80	Botany Bay	-34.0013	151.2337	BAY	VH									
81	Port Hacking	-34.0725	151.1628	DROWNED VALLEY	L			y			y			
82	Wattamolla Creek	-34.1379	151.1182	CREEK	VL			y						y
83	Hargraves Creek	-34.2297	150.9914	CREEK	H									
84	Stanwell Creek	-34.2328	150.9878	CREEK	M									
85	Flanagans Creek	-34.3156	150.9290	CREEK	H									
86	Woodlands Creek	-34.3251	150.9244	CREEK	M									
87	Slacky Creek	-34.3355	150.9251	CREEK	H									
88	Bellambi Gully	-34.3652	150.9228	CREEK	H		y							
89	Bellambi Lake	-34.3768	150.9223	CREEK	H								y	
90	Towradgi Creek	-34.3833	150.9165	CREEK	H					y				y
91	Fairy Creek	-34.4099	150.9022	CREEK	H	y	y	y	y	y	y	y	y	y
92	Allans Creek	-34.4638	150.9003	BARRIER RIVER	H									
93	Port Kembla	-34.4648	150.9116	BAY	H									
94	Lake Illawarra	-34.5436	150.8750	LAKE	H	y	y	y	y	y	y	y	y	y
95	Elliott Lake	-34.5606	150.8699	CREEK	H					y				
96	Minnamurra River	-34.6280	150.8611	BARRIER RIVER	H		y			y				y
97	Spring Creek	-34.6642	150.8545	CREEK	H									

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
98	Munna Munnora Creek	-34.6924	150.8538	CREEK	H		y							
99	Werri Lagoon	-34.7287	150.8394	CREEK	H					y				
100	Crooked River	-34.7728	150.8157	BARRIER RIVER	H		y						y	
101	Shoalhaven River	-34.8979	150.7662	BARRIER RIVER	M	y	y	y	y	y	y	y	y	y
102	Wollumboola Lake	-34.9425	150.7772	BDL	L					y				
103	Currarong Creek	-35.0147	150.8215	CREEK	L					y				
104	Cararma Creek	-35.0020	150.7776	LAKE	VL					y				
105	Wowly Gully	-34.9953	150.7287	LAGOON	M					y				
106	Callala Creek	-35.0067	150.7182	CREEK	M					y				
107	Currambene Creek	-35.0375	150.6714	BARRIER RIVER	M					y				
108	Moona Moona Creek	-35.0499	150.6780	CREEK	M					y				
109	Flat Rock Creek	-35.1241	150.7041	CREEK	VL					y				
110	Captains Beach Lagoon	-35.1264	150.7115	CREEK	VL					y				
111	Telegraph Creek	-35.1363	150.7254	CREEK	VL									
112	Jervis Bay	-35.1039	150.7872	BAY	M									
113	St Georges Basin	-35.1852	150.5938	LAKE	L								y	
114	Swan Lake	-35.2023	150.5598	BDL	M		y						y	
115	Berrara Creek	-35.2108	150.5484	LAGOON	VL		y							
116	Nerrindillah Creek	-35.2276	150.5326	CREEK	L		y							
117	Conjola Lake	-35.2687	150.5078	LAKE	L								y	
118	Narrawallee Inlet	-35.3027	150.4740	BARRIER RIVER	M									
119	Mollymook Creek	-35.3356	150.4743	CREEK	H								y	
120	Millards Creek	-35.3546	150.4757	CREEK	H		y							
121	Ulladulla	-35.3556	150.4784	BAY	H									

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
122	Burrill Lake	-35.3950	150.4474	LAKE	M								y	y
123	Tabourie Lake	-35.4427	150.4106	BDL	L		y						y	
124	Termeil Lake	-35.4623	150.3944	BDL	M	y	y	y	y	y	y	y	y	y
125	Meroo Lake	-35.4829	150.3915	BDL	M	y	y	y	y	y	y	y	y	
126	Willinga Lake	-35.5006	150.3914	BDL	M		y			y				
127	Butlers Creek	-35.5522	150.3827	CREEK	H									
128	Durras Lake	-35.6418	150.3054	LAKE	L	y	y	y	y	y	y	y	y	y
129	Durras Creek	-35.6576	150.2971	CREEK	L		y							
130	Maloneys Creek	-35.7094	150.2437	CREEK	L									
131	Cullendulla Creek	-35.7022	150.2095	BARRIER RIVER	H									
132	Clyde River	-35.7069	150.1818	BARRIER RIVER	L	y	y	y	y	y	y	y	y	y
133	Batemans Bay	-35.7572	150.2500	BAY	L									
134	Saltwater Creek (Rosedale)	-35.8122	150.2259	CREEK	H		y							
135	Tomaga River	-35.8374	150.1852	BARRIER RIVER	M								y	
136	Candlagan Creek	-35.8424	150.1802	BARRIER RIVER	M					y			y	
137	Bengello Creek	-35.8679	150.1632	CREEK	M					y				
138	Moruya River	-35.9058	150.1518	BARRIER RIVER	L								y	
139	Congo Creek	-35.9536	150.1601	CREEK	M									y
140	Meringo Creek	-35.9785	150.1511	BDL	M		y							
141	Kellys Lake	-36.0065	150.1574	BDL	M		y							
142	Coila Lake	-36.0486	150.1416	LAKE	L								y	y
143	Tuross River	-36.0667	150.1344	BARRIER RIVER	L					y			y	
144	Lake Brunderee	-36.0935	150.1372	LAGOON	L		y							
145	Lake Tarourga	-36.1052	150.1356	BDL	VL		y							
146	Lake Brou	-36.1280	150.1264	BDL	L	y	y	y	y	y	y	y	y	

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
147	Lake Mummuga	-36.1621	150.1266	LAGOON	L		y							
148	Kianga Lake	-36.1921	150.1330	BDL	M		y			y				
149	Wagonga Inlet	-36.2095	150.1348	LAKE	L					y				
150	Little Lake (Narooma)	-36.2243	150.1411	BDL	H		y							
151	Bullengella Lake	-36.2421	150.1447	LAKE	M		y							
152	Nangudga Lake	-36.2519	150.1444	LAGOON	H					y				
153	Corunna Lake	-36.2897	150.1312	LAGOON	M									y
154	Tilba Tilba Lake	-36.3281	150.1156	BDL	H		y						y	
155	Little Lake (Wallaga)	-36.3396	150.1025	LAGOON	H					y				
156	Wallaga Lake	-36.3697	150.0799	LAKE	M								y	
157	Bermagui River	-36.4224	150.0731	BARRIER RIVER	M					y				
158	Baragoot Lake	-36.4641	150.0668	BDL	L		y						y	
159	Cuttagee Lake	-36.4880	150.0551	LAGOON	L									y
160	Murrah River	-36.5254	150.0581	BARRIER RIVER	M					y				
161	Bunga Lagoon	-36.5402	150.0555	LAGOON	L					y				
162	Wapengo Lagoon	-36.6285	150.0209	LAKE	L		y							
163	Middle Lagoon	-36.6505	150.0092	BDL	M		y							
164	Nelson Lagoon	-36.6857	149.9940	BARRIER RIVER	VL					y				
165	Bega River	-36.7018	149.9830	BARRIER RIVER	M								y	
166	Wallagoot Lake	-36.7900	149.9600	BDL	L			y	y	y	y	y	y	
167	Bournda Lagoon	-36.8202	149.9389	CREEK	L									
168	Back Lagoon	-36.8833	149.9307	LAGOON	L									
169	Merimbula Lake	-36.8957	149.9228	LAKE	M		y							
170	Pambula River	-36.9469	149.9170	BARRIER RIVER	L								y	
171	Curalo Lagoon	-37.0469	149.9223	LAGOON	L									
172	Shadrachs Creek	-37.0768	149.8787	CREEK	VL									

	Estuary	Latitude (ºS)	Longitude (ºE)	Estuary Type [1]	Disturbance Class [2]	2015-2016	2014-2015	2013-2014	2012-2013	2011-2012	2010-2011	2009-2010	2008-2009	2006-2007
173	Nullica River	-37.0911	149.8729	LAGOON	VL					y				
174	Boydtown Creek	-37.1029	149.8819	CREEK	M									
175	Towamba River	-37.1118	149.9132	BARRIER RIVER	L								y	
176	Fisheries Creek	-37.1107	149.9289	LAGOON	VL									
177	Twofold Bay	-37.0775	149.9481	BAY	L									
178	Saltwater Creek (Eden)	-37.1685	150.0030	CREEK	VL		y							
179	Woodburn Creek	-37.1706	150.0052	CREEK	VL		y							
180	Wonboyn River	-37.2497	149.9662	BARRIER RIVER	VL					y				
181	Merrica River	-37.2966	149.9519	CREEK	VL								y	
182	Table Creek	-37.4063	149.9541	CREEK	VL									
183	Nadgee River	-37.4381	149.9661	CREEK	VL		y	y	y	y	y	y	y	
184	Nadgee Lake	-37.4688	149.9729	BDL	VL		y	y	y	y	y	y	y	

[1] Classification scheme based on estuarine response to pollutant input (see Roper et al. 2011) and extended to provide greater differentiation

[2] Disturbance class (see Section 7.4)

Appendix 2 Field data sheet

MER Data Sheet **Samplers Names:** ______________

Estuary ______________ Entrance: open/partial open/closed/unknown

Date/Time: ______________ Weather: ______________

Observations: Observer Initials: ______________

Fill all details, don't leave blank if nothing seen enter 'none observed'

Macroalgae (cover, spp) ______________

Ruppia (relative abundance) ______________

Zostera (relative abundance) ______________

Saltmarsh (type, abundance) ______________

Birds (type, abundance) ______________

Other (type, abundance) ______________

Shoreline: (describe physical form)

Riparian Veg dominant species ______________ Trees > 10m | Y/N |

%, type native trees/shrubs on shoreline ______________

%, type native grasses on shoreline ______________

%, type introduced trees on shoreline ______________

%, type introduced grasses on shoreline ______________

Take 5 Safety Check	
Initials:	
Weather	Waterway Conditions
Site Access	Specific Hazards
Communication	Dangerous Fauna
PPE	Fire Danger

Water tannin coloured odours? ______________

State of Tide Jelly Fish ______________

Other? ______________

YSI Number		File Name				
Transect	**Start Lat**		**Long**		**Indicative**	
	Finish Lat		**Long**		Temp ©	
	Start time	**Stop Time**			Sal	
Transect			Nutrient Sample? Y / N		Turb (ntu)	
			Bottom depth:		Chl a (ug/L)	
					ColourCDOM	
NOTES:					DO (%)	
					Secchi (m)	
Zone 1	**Lat**		**Long**		**Indicative**	
					Temp ©	
	Start time	**Stop Time**			Sal	
Transect			Nutrient Sample? Y / N		Turb (ntu)	
			Bottom depth:		Chl a (ug/L)	
					ColourCDOM	
NOTES:					DO (%)	
					Secchi (m)	
Zone 2	**Lat**		**Long**		**Indicative**	
					Temp ©	
	Start time	**Stop Time**			Sal	
Transect			Nutrient Sample? Y / N		Turb (ntu)	
			Bottom depth:		Chl a (ug/L)	
					ColourCDOM	
NOTES:					DO (%)	
					Secchi (m)	

Appendix 3 Calculating a water quality condition score

As described in Section 7.9, the process for calculating a condition score for chlorophyll *a* or turbidity for an estuary or zone within an estuary involves six steps. The Excel formulae that can be used for these calculations are provided in the following table.

Step	**Formulae**
1. Calculating the non-compliance (NC_i) score	=IF(Sample>Trigger Value,1,0)
2. Use relevant WEV	WEV values for NSW are provided in Table 2.
3. Calculating the distance from the trigger value (DS_i)	=IF(NC_i=1,((Sample-Trigger Value)/(WEV- Trigger Value)),0) =IF(DS_i>1,1, DS_i)
4. Calculating an indicator score (IS_i) for each zone	=SQRT(NC_i x DS_i)
5. Calculating the zone score (ZS)	=AVERAGE(IS_c : IS_t) where IS_c is indicator score for chlorophyll *a* and IS_t is indicator score for turbidity
6. Grading the zone	=IF(ZS<0.07,"A",IF(ZS<0.23,"B",IF(ZS<0.44,"C", IF(ZS<0.6,"D",IF(ZS<1,"E","E")))))

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