# COMBINING AUTONOMOUS MONITORING WITH CONDITION INDICATORS TO ASSESS ESTUARINE HEALTH

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## Abstract

The task of defining, monitoring and reporting estuarine condition is complex. This task requires choosing one or many condition indicators which may indicate physical, chemical, ecotoxicological and ecological conditions of an estuary. There is no single indicator that defines the condition of an estuary. The choice of an indicator depends on the estuarine values or uses of the estuary that are to be protected (environmental values) and numeric or descriptive statements that must be met within a specified timeframe to protect and maintain the estuarine values and uses (environmental targets). To assist local government with estuarine condition assessment, guidance is provided from the NSW State Government, Office of Environment and Heritage (OEH) which sets protocols for monitoring water quality, estuarine macrophytes, fish assemblage and other indicators (NSW Government 2013).

In this paper, OEH condition indicators for water quality (chlorophyll-a and turbidity) are used to assign regional and state wide consistent condition scores to the Hawkesbury River estuary, NSW. Near real time data obtained from autonomous monitoring buoys is used to inform these indicators. The availability of near real time data enables daily condition reports to be publically presented and provides capacity for managers to make decisions in response to current estuarine conditions (e.g. responding to algal blooms, advising on swimming conditions, oyster harvest area closure/opening). The utility of near real time data and indicators to inform (i) ecosystem health, (ii) baseline condition, (iii) trends through time and, (iv) environmental management is presented using data from Berowra Waters as a case study.

## Introduction

The deterioration of estuarine condition threatens recreational and commercial pursuits, human health and the sustainability of aquatic ecosystems. Further, increased human exploitation of estuarine resources and habitats has potentially altered the trophic structure of estuaries which can provide favourable conditions for algal blooms (Lui et al. 2007).

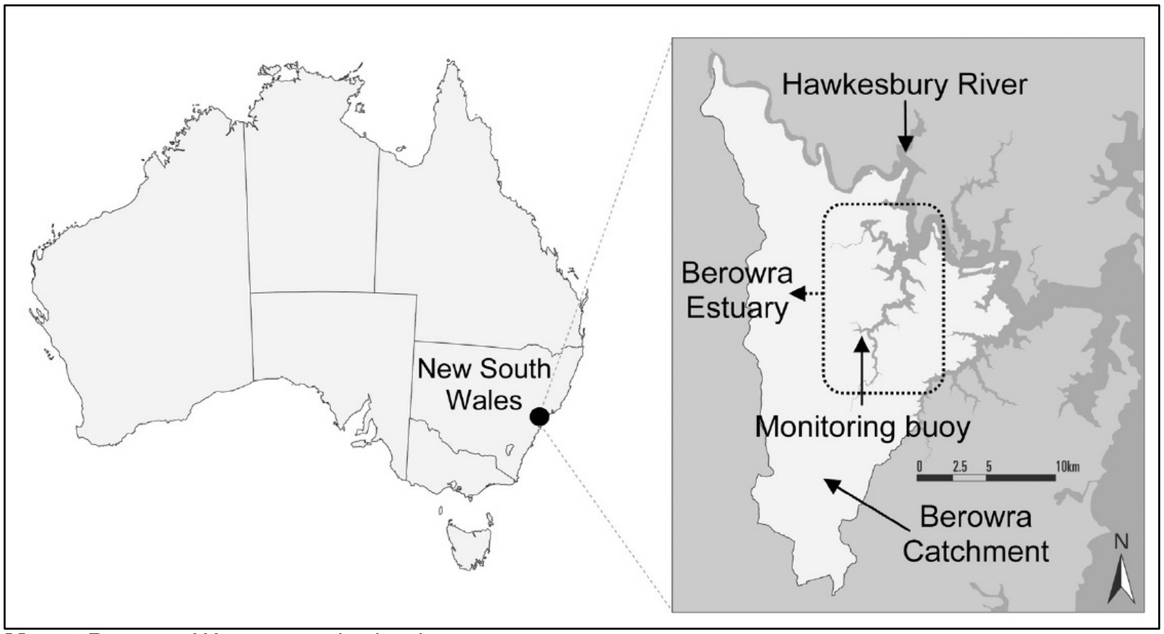
Managing threats to estuarine ecosystems requires a monitoring program to inform and direct an effective management program to reduce these threats. The performance of the management program in being ‘effective’ can be assessed with the use of estuarine condition scores, developed with rigorous, consistent and repeatable methods. Such grades provide a reference or baseline condition from which the current estuarine condition can be assessed and changes to condition can be noted.

To determine the condition of the Hawkesbury estuary within Hornsby Shire Council’s local government area Council has deployed, staggered over time (2002-2014), five autonomous monitoring buoys to gain a better understanding of estuarine processes and to assist with the management of the estuary. To determine condition grades at each probe location, the NSW government guidelines for assessing estuarine health (NSW Government 2013) are used. This paper presents the utility of these protocols to inform estuary management using data from the monitoring buoy at Berowra Waters as a case study.

## Methods

### ***Available data***

Data used in this study is acquired from a telemetered water quality probe housed within a buoy, located at Berowra Waters (Map 1). Berowra Waters is located in an area where salinities typically range between 20-25ppt. The probe sensor (YSI sonde$^{TM}$) is deployed (at 0.5m depth) above a deep hole (approximately 14m in depth) since 2002.




**Map 1** Berowra Waters monitoring buoy

A two year development period followed deployment where operational issues (such as probe reliability, deployment periods to avoid marine fouling, etc) were addressed. Hence, data from 2004 to present is considered to be the most reliable and is used for this analysis. This site was selected as previous estuary process studies indicate CHLa concentrations peak at this site as it has characteristics favourable for algal biomass production. Parameters monitored at this site include: CHLa, temperature, salinity and photosynthetically available radiation. A thermistor cable has been operating since December, 2007 which records temperature data at approximately 30cm intervals through the water column (Figure 1). Turbidity data has only been recorded since 2013. All data is currently collected at 15 minute time steps and is available online to the public via a web link (http://mhl.nsw.gov.au/projects/berowra/latest.php).

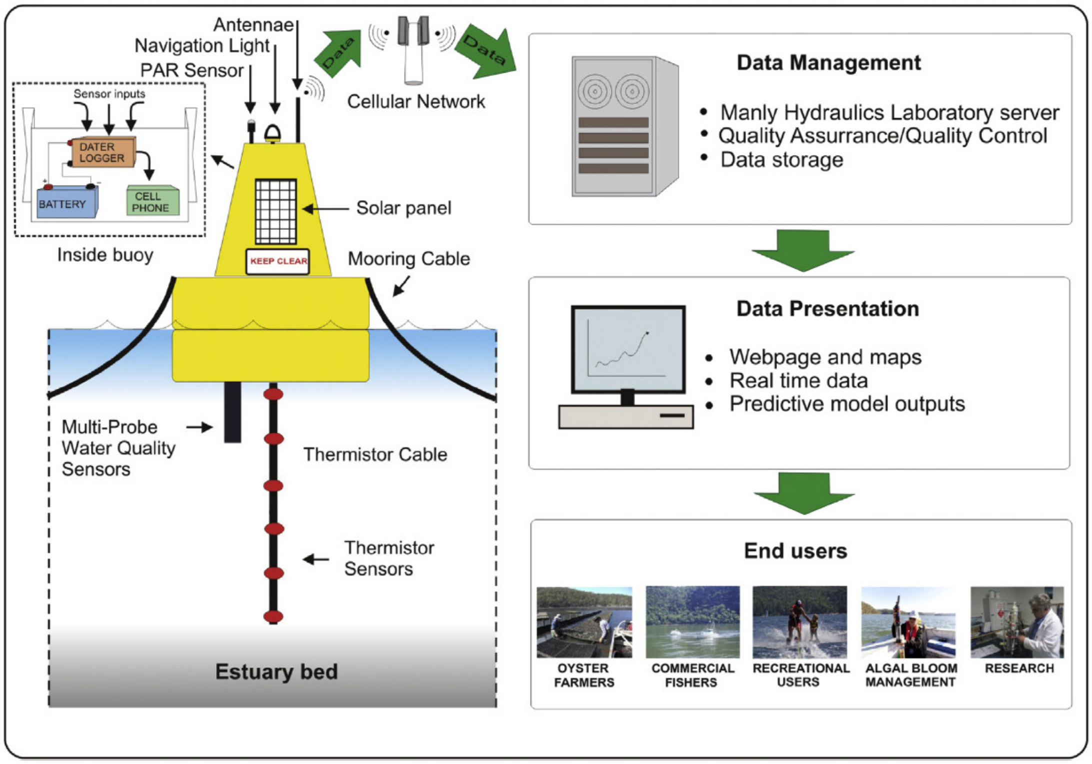



**Figure 1** Schematic diagram of autonomous monitoring stations from the lower Hawkesbury River (diagram taken from Coad et al 2014)

### *Assigning condition scores*

To prepare the raw data for analysis lower boundary outliers (negative values for all parameters) were reassigned to "0". Upper boundary salinity outliers (values greater than 35ppt) and CHLa values greater than the mean + two standard deviations (i.e. 9.12ug/L + 2x35.95= 81.02ug/L) were replaced with the missing data code. This resulted in 0.62% and 0.05% of CHLa and salinity data being omitted respectively.

Condition scores are assigned as outlined by the NSW government procedures (NSW Government 2013) for water quality (chlorophyll-a and turbidity) using the Berowra Waters data.

1. Calculating the non-compliance (NC) score: NC number of samples non-compliant with the trigger value divided by the total number of samples. For CHLa between 2004 to present there were 3624 cases, 3204 non-compliant and 420 compliant. Hence, NCi: 3204/3624 = 0.88. For turbidity between 2013 to present there were 375 cases, 10 non-compliant and 365 compliant. Hence, NCi: 10/375 = 0.03.

2. Calculating the Worst Expected Value (WEV): WEV's used are the suggested OEH values for mid range river salinities (10 to <25ppt). Hence, for chlorophyll a- 30ug/L, for turbidity- 30 NTU.

3. Calculating the distance from trigger value (DSi): Note the 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. It is calculated as DSi=(value-trigger

value)/(WEV-trigger value). Note for CHLa_DSi; WEV=30 and trigger value=2.9 whilst for turbidity_DSi; WEV=30 and trigger value=3.5.

4. Calculating an indicator score: Using the geometric mean the Indicator score combines both non-compliance score (NC) and distance from trigger value (DSi) to provide a single score.

5. Calculating the zone score: The overall zone score is the average of indicator scores for turbidity and CHLa.

6. Grading the zone: Zone grades are assigned individually for turbidity and CHLa with the final grade being the combined average of both of these scores (**Error! Reference source not found.**).

**Table 1** NSW State Government condition 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 |

(source: p13, NSW Government 2013).

## Discussion

The collection of a high frequency data set from autonomous monitoring buoys provides an opportunity to determine and communicate estuary condition on a daily timescale. Whilst high frequency reporting is possible, such as hourly, it is not warranted for end user needs. Anecdotally, a daily timescale is adequate to address community interest regarding estuary condition. These end user's interests broadly include changes to the estuarine condition due to significant rainfall, influence of season and climatic events (e.g. dry periods), seasonal changes and understanding the local estuarine environment. The utility of indicators and near real time data to inform; (i) ecosystem health, (ii) baseline condition, (iii) trends through time and, (iv) environmental management is briefly discussed.

***Ecosystem health***

Using the combined scores, in comparison with the individual scores for CHLa and turbidity significantly influences the final condition score that is determined. Physical characteristics of an estuary such as benthic substrate and bathymetry determine the baseline 'natural' condition of estuarine zone to which a condition score is assigned. For instance, the Lower Hawkesbury is 'naturally' characterised by high concentration of mud in the sediments and strong tidal movements. In shallow areas this results in high levels of turbidity due to the re-suspension of particulate matter. In deeper areas, such as at Berowra Waters, the influence of resuspended particles in surface waters due to tidal processes is minimal. Hence, the sole use of turbidity to assign condition scores at this location would represent a healthy estuarine environment (Figure 2) due to the consistently low levels of turbidity recorded at this site. However, problematic algal concentrations are recorded at this site (note the prevalence of poor grades "D-E" in Figure-2 "Zone Score_CHLa"). Combining the two indicators, as recommended by the NSW government, using an average for all zone scores provides the most appropriate overall condition assessment.

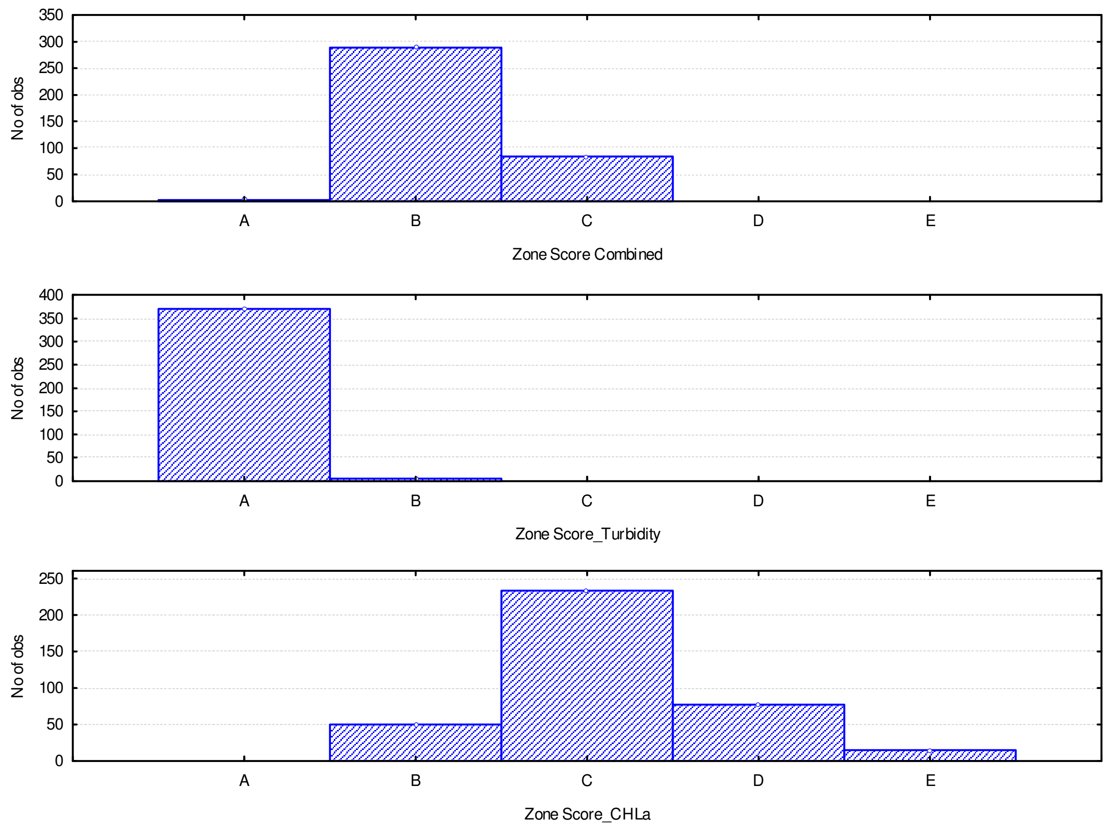



**Figure 2** Estuarine condition scores. Top - Combined scores, Middle- turbidity only, Bottom - cholophylla data only.

The combined zone scores are then used to represent the condition of the estuarine zone of interest in comparison to the overall condition across all NSW estuaries. Notably, these condition scores do not indicate a binary 'pass' or 'fail' measure of compliance rather they indicate a scale of compliance. This approach acknowledges the distance from the trigger value as being the critical determinant of the score and associated condition grade. Hence, estuarine zones are "ranked" along a gradient (from very good to very poor) based on their score (Table 1) as opposed to being "lumped" which would create two estuary zone categories of 'pass' or 'fail'. Relative ranking of estuarine condition can create focused management actions by drawing attention to sites which require, for example, remediation (degraded sites) and those which require protection (pristine sites) and an appropriate mix of remediation and protection actions for intermediate scores.

The use of turbidity and chlorophyll-a data to assign condition scores (using statewide consistent protocols) enables comparison of estuarine condition relative to other estuaries within NSW. These relative comparisons can be made annually for reporting purposes such as State of the Environment reporting or seasonally for quarterly reporting. Seasonal trends in condition scores provide insight to problematic periods for estuaries (Figure 3). Notably at Berowra the condition scores are reasonably consistent throughout the year except in autumn when the scores get slightly worse with a higher proportion of 'C' grades. These autumn scores are influenced by higher rainfall periods which in turn increased turbidity levels and contributed to processes (such as catchment nutrient export) which promoted increased algal activity. Seasonal understanding of ecosystem health can assist in seasonally adjusted management responses and management actions being implemented, such as issuing alerts of periods of poor estuarine condition prior to there occurrence.

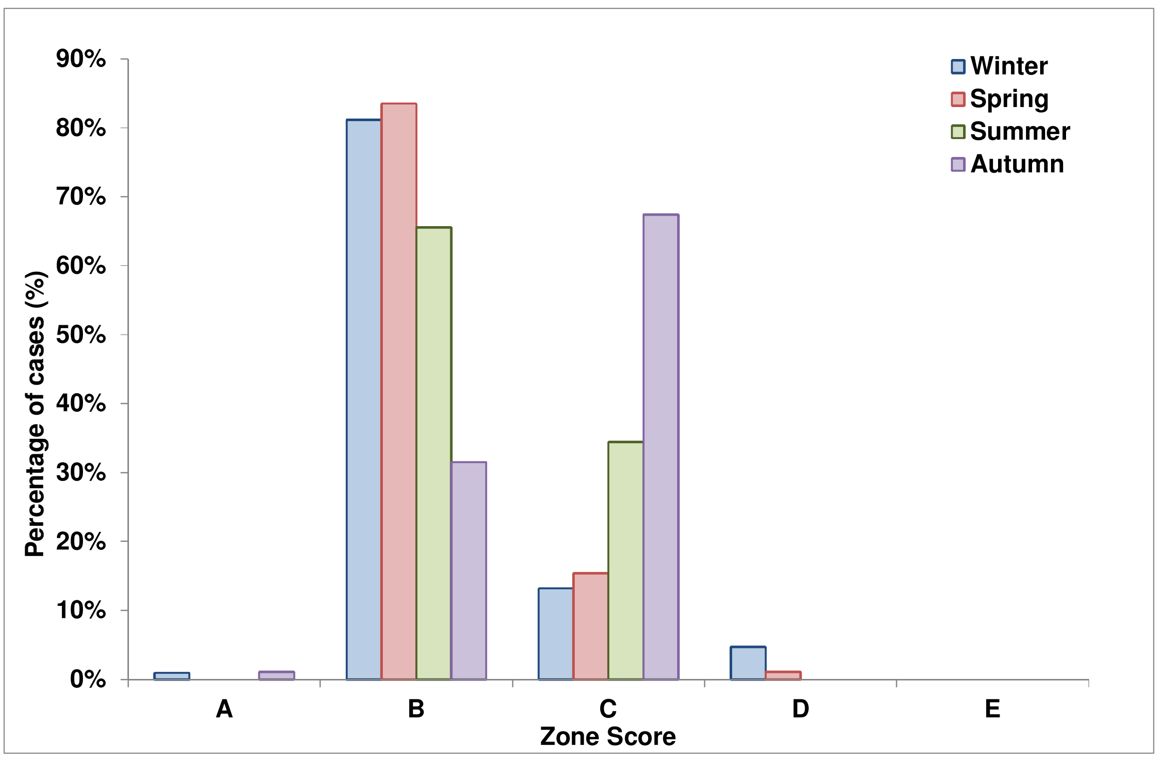



**Figure 3** Seasonal condition scores for Berowra Waters

### ***Baseline condition***

Monitoring the condition of an estuary through long periods of time enables changes, often the result of human activity, to be detected. Continuous data collection via autonomous monitoring buoys provides the opportunity to quantify seasonal and inter annual comparisons of key water quality parameters (Figure 4). Further key process which influence estuarine condition are apparent, such as (i) water temperature is relatively consistent between years with slight variations in extreme values, (ii) salinity values vary based on rainfall, reflecting wet and dry periods, and (iii) CHLa values are influenced by rainfall, with wetter years resulting in more variable concentrations of CHLa.

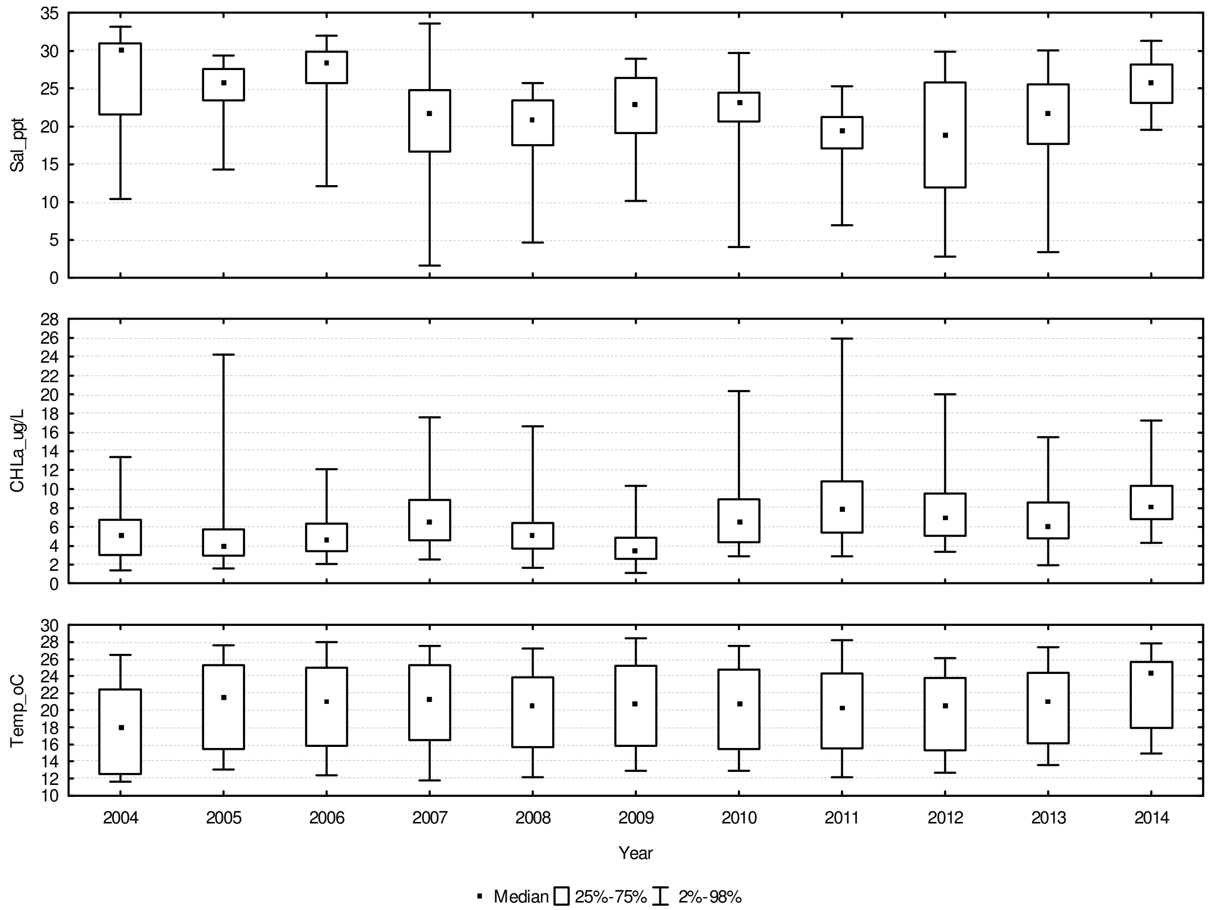



**Figure 4** Baseline data for the Berowra Waters probe

### *Trend analysis*

Long-term data sets are extremely valuable in providing baseline conditions to help identify inter-annual variations and long-term trends. They are also very helpful in understanding the link between climate indices and estuarine conditions with a view of ultimately developing seasonal forecasts. In particular, plots of mean monthly anomalies are beneficial in expressing unusual occurrences within the estuary (Figure 5). Average data close to zero means that it is not different to the long-term average value for that variable. Positive data points mean that they are significantly higher than the long-term average value and negative points that the variable is lower than the usual value. Similarly, condition scores can be used to identify anomalies against a mean condition score through time. For this paper this analysis has not been undertaken as turbidity data has only been collected for one year (starting 2013). Hence a meaningful long term average condition score could not be determined for comparison.

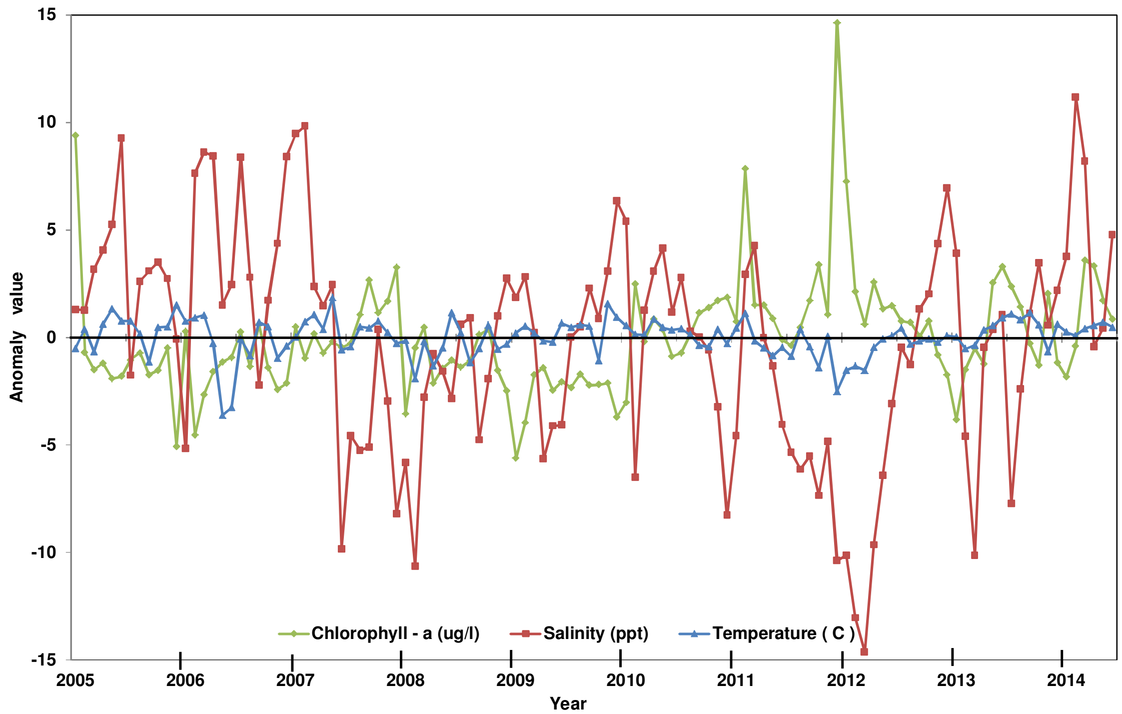



**Figure 5** Occurrence of anomalies between 2005 and 2014 at Berowra Waters

***Environmental management***

Assigning condition scores, in accordance with OEH protocols (NSW Government 2013), provides a standardised method to enable relative condition assessments between and within estuaries of NSW. Once assigned, these grades are reported to the public annually via reporting and daily via a website (Figure 6).

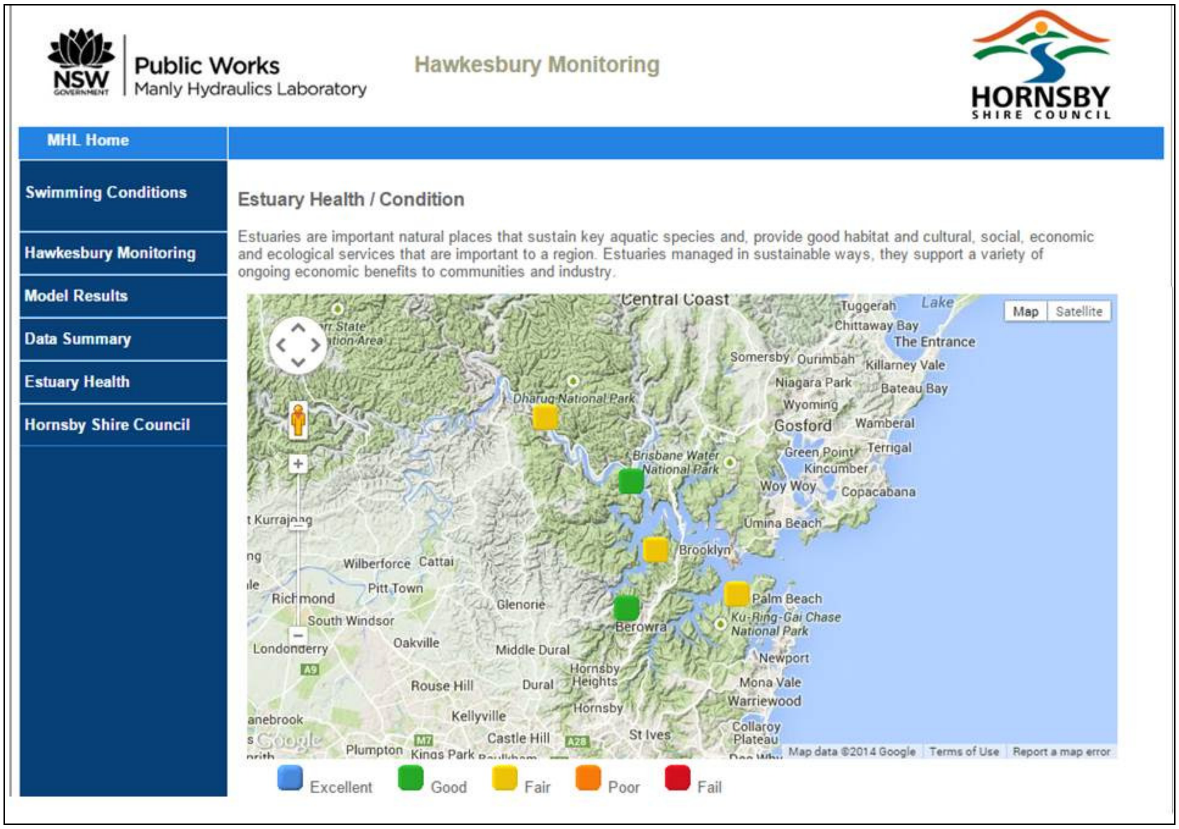



**Figure 6** Web screen capture of estuarine condition scores as per OEH protocols at 5 probe locations in the Hawkesbury estuary
http://new.mhl.nsw.gov.au/users/HSC-EstuaryHealth

Users who benefit from both near real time data and awareness of estuarine condition include swimmers, boaters, recreational fishers, commercial fishers, oyster growers, government agencies managing waterways and industries based on estuaries, and researchers (Table 2).

**Table 2** Example of benefits to end users

| User | Data | Benefit |
|---|---|---|
| Swimmer | Condition score<br>CHLa<br>Salinity<br>Temperature | General estuarine condition<br>Presence of algal blooms<br>Avoidance storm water pollution<br>Water temperature comfort |
| Boater | CHLa<br>Salinity | Presence of algal blooms<br>Presence of floodwater and possible debris |
| Fishers | CHLa<br>Salinity and Temperature | Presence of algal blooms<br>Possible preferential conditions for fishing |
| Oyster Farmers | CHLa<br>Salinity | Presence of algal blooms<br>Harvest area opening and closures |
| Community | Condition score | Estuarine condition awareness |
| Manager | Condition score<br>CHLa<br>Salinity | Estuarine condition performance indicator<br>Algal bloom management<br>Flooding and storm water extent |

The usefulness of the probe data and estuarine condition scores to meet end user needs changes depending on the frequency that it is collected and reported. For example CHLa conditions, which are indicative of algal activity, have more users when reported on a daily compared with an annual timescale (Table 3). Further recreational swimmers are more interested in current rather than historic estuarine conditions and hence preferentially access near real time data.

**Table 3** Data frequency needs by end user

| User | Data frequency | | | | |
|---|---|---|---|---|---|
| | Daily CHLa | Daily Temperature | Daily Salinity | Daily Health grade | Annual Health grade |
| Recreational swimmer | ✓ | ✓ | ✓ | ✓ | |
| Commercial fishing | ✓ | ✓ | ✓ | ✓ | |
| Oyster farming | ✓ | | ✓ | ✓ | |
| Research | ✓ | ✓ | ✓ | ✓ | ✓ |
| Education | ✓ | | | ✓ | ✓ |
| Environmental manager | ✓ | ✓ | ✓ | ✓ | ✓ |
| Emergency manager | ✓ | | ✓ | ✓ | |

## Conclusions

Long-term data sets assist with decision making and estuarine management at a range of timescales: short-term (including daily farming/fishing management decisions, selection of fishing and safe swimming areas, etc.); medium-term (providing information on the relationships between local environmental variability and fish stocks / oyster performance / algal blooms / swimming conditions); and long-term: to link climate variations and estuarine conditions with a view of ultimately developing seasonal forecasts or to provide baseline conditions to help identify inter-annual variations and long-term trends.

Benefits of autonomous monitoring combined with condition scores include:

- Standardised monitoring, analysis and reporting based on best practise provides consistency of results at range of scales (local, regional and state). Further, this enables comparison of assessments and scientific rigor to be incorporated into reporting and information that is provided to the community.

- Condition grades provide a bench mark or reference point from which the effectiveness of management actions can be assessed. Further consideration could be given to the benefits of using a 'localised' Worst Expected Value (WEV) to inform the condition scores rather than using values recommended by the NSW State government. This option would improve localised condition scoring based on unique WEV's but would fore go comparison with state wide estuary condition grades as standardise WEV's aren't being used.

- High frequency data collection enables monitoring of events such as flood and algal blooms in near real time.

- Continuous monitoring enables temporal trends and anomalies to be investigated.

Future development of autonomous monitoring technology combined with telemetry will enable additional parameters to be monitored within the estuary. Specifically, monitoring technology which enables in situ enumeration and identification of problematic and harmful algal species is highly sought. Further research coupling real time data with numeric or statistic models (Coad et al. 2014) will enable the forward prediction of parameters of interest, such as CHLa which is indicative of algal blooms.

## References

**Coad, P., B. Cathers, et al. (2014)**. "Proactive management of estuarine algal blooms using an automated monitoring buoy coupled with an artificial neural network." Environmental Modelling & Software 61: 393-409.

**Lui, G. C. S., W. K. Li, et al. (2007)**. "Modelling algal blooms using vector autoregressive model with exogenous variables and long memory filter." Ecological Modelling 200(1-2): 130-138.

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