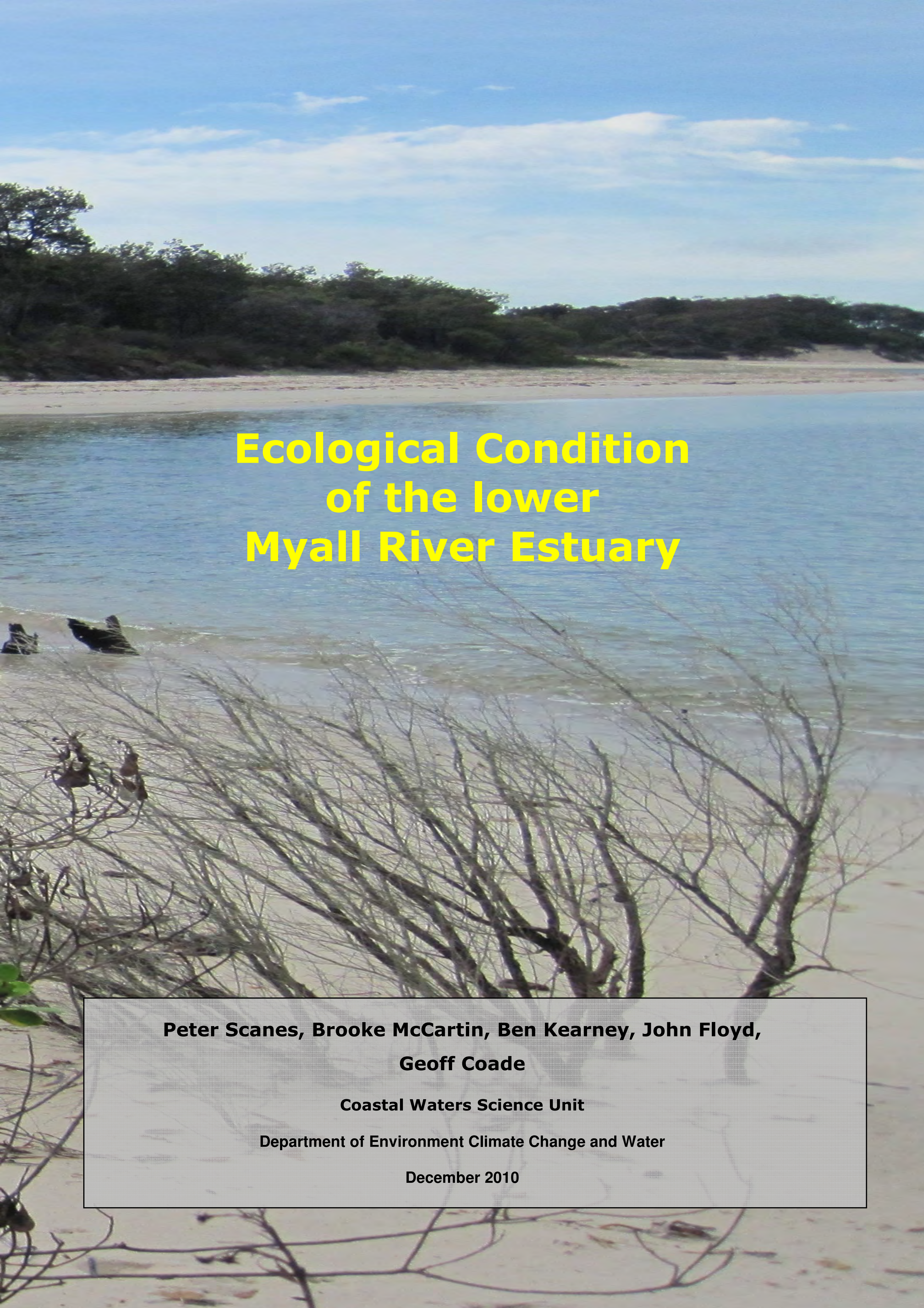

Ecological Condition of the lower Myall River Estuary

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December 2010

Executive Summary

DECCW was contracted by Great Lakes Council to undertake a project involving the "the preparation of an estuary health assessment … of the lower Myall Estuary at Corrie Island/Tea Gardens". The objective of the assessment was to provide baseline information that will assist in making well informed decisions for the future management of the lower Myall River Estuary. The ecological health investigation is part of a broader project to provide an improved understanding of the hydrodynamics and estuarine health, condition and functioning which is imperative in determining the need and practicality of any future interventions in the management of navigation, coastal erosion and/or water quality concerns within the study area.

The local community have expressed concerns about the ecological heath of the estuary following changes to the Myall River entrance channels. DECCW involved the Myall River Action Group when identifying issues of concern and members of this Group contributed to the sampling program. DECCW designed a program for assessing estuary health that met the needs of the local community and attempted to provide answers in a way which is meaningful to them, but is also scientifically rigorous and consistent with contemporary scientific approaches.

This report deals with two main issues:

- Physical consequences of changes to entrance channel conditions. This involved analysis of data from DECCW water level and salinity loggers, as well as summarising the findings of a previous DECCW investigation into tidal flow patterns through the entrance channels
- The ecological health of the estuary. This was assessed by sampling a broad range of ecological health indicators and comparing the results with other similar estuarine locations that have not experienced blocking of entrance conditions, or with existing standards

The proportion of tidal exchange in the two channels has changed from a strong dominance (by volume) in Paddy Marrs Channel to a slight dominance of ebb tide flows through the Corrie Creek Channel and in flood flows through Paddy Marrs Channel. Water clarity is reduced at times, although this is common in NSW estuaries and within State benchmarks for riverine estuaries. The reduced clarity occurred most often at lower tidal levels and is most likely a consequence of the increased proportion of flow in the Corrie Island channel, with a resultant increased exchange with Pindimar Bay rather than the outer basin of Port Stephens. This issue

will be addressed in the concurrent sediment hydrodynamic assessment being prepared by BMT WBM.

Extended periods of low salinity water in the estuary were shown to be entirely a consequence of extended periods of outflow of “stored” fresh water from the Myall Broadwater, and that the rate of this outflow has not altered as the entrance has changed.

Despite these changes to flow, ecological health in the river is excellent and equivalent to other comparable estuarine locations that have not experienced changed entrance conditions. Fish and invertebrate biodiversity and plant communities were consistent with other sites. The rates of important ecological processes such as algal growth, bacterial breakdown of seagrass leaves, energy consumption by fish and invertebrates and herbivory on mangrove leaves were all consistent with other healthy estuaries (see Table below).

These results clearly do not support the community perception that periods of slightly reduced water clarity – whether a result of changed entrance conditions or not – are having a detrimental effect on the river’s ecology.

It could be argued that the periods of poorer clarity constitute an aesthetic concern and impact on economic values through changes in the perceptions of tourists. This may be a valid argument, but is a separate issue and has not been addressed here.

In summary, based on the results of a wide range of ecological studies conducted mostly over the 2009-10 summer period there is no evidence that changes to the river mouth channels are negatively impacting on the estuarine ecology.

Summary of Results from Bioassays for Estuary Health

Measures	Status that would suggest Myall was Impacted	Current Status of Myall River estuary
SYSTEM STRUCTURE		
Presence of healthy mangroves and seagrass	Absence of seagrass, mangrove or saltmarsh	All habitats present
Water Clarity	Water clarity reduced by obvious turbidity (suspended matter in water)	River experiences periods of tannin staining which is normal, but also experiences periods when it is affected by reductions in clarity due to suspended matter. Turbidity is within trigger values for NSW riverine estuaries.
Conductivity Myall lake water height	Low salinity after Bombah Broadwater returns to sea level.	Salinity drops when Bombah Broadwater fills and slowly drains. This is normal. Salinity returns to oceanic levels when Bombah reaches 0.1 m above mean sea level.
BIOLOGICAL STRUCTURE		
Stable extent of main macrophytes	Declines in abundance of seagrass, mangrove or saltmarsh	Mangroves and salt marsh increased in extent. There are apparent losses of seagrass in the upper River, but it is uncertain whether this is an artefact of differences in mapping technique. In the lower River there may be some loss due to changing sand banks but seagrass still occupies most suitable habitat.
Algae (chlorophyll) in water	Chlorophyll concentrations greater than Trigger Levels – 2.3 – 3.2 ug/L	Median chlorophyll concentrations were below trigger values.
Surveys of crabs/crustaceans on intertidal flats	Abundances of ghost shrimp lower than control sites.	Abundances of ghost shrimp were similar to Wallis lake and greater than other control locations. Invertebrate biodiversity was similar to Wallis Lake . The assemblage was similar,

	Invertebrate biodiversity low.	but not identical to Wallis, but differed from Pindimar and Salamander Bays.
Fish sampling	Fish biodiversity low. Fish abundances lower than controls.	Fish biodiversity and abundance were equivalent to control locations. Fish assemblages were similar to controls.
Community fish observations	Continued absence of large rays.	Rays were observed across a wide range of salinities and water clarity, though they were absent at low salinities and could not be seen in poor water clarity.
Bird surveys	Absence of common birds, abnormal numbers of swans.	The bird fauna of Myall/Corrie Winda Woppa is consistent with other parts of the Port and black swan numbers are consistent with previous counts.
ENERGY FLOW		
Leaf growth rates in seagrass	Productivity of Zostera leaves reduced in comparison to controls.	Productivity experiment did not work as expected. The amount of *Zostera* growing did not differ among estuaries.
Benthic Algae Sediment oxygen production	Sediments that consume more oxygen than they produce.	Winter rates were slightly negative and summer rates positive. This pattern is within the normal range.
Algae on seagrass and mangroves	Excessive amounts of algae growing on mangrove roots.	Algal growth on artificial mangrove roots was similar to controls and lower than Pindimar Bay.
	Excessive amounts of algae growing on seagrass fronds.	Algal growth on seagrass fronds was similar to controls and lower than Wallis Lake.
Microbial Decomposition	Decomposition of seagrass leaves lower than controls..	Tissue loss at Myall River did not differ from Wallis Lake and Salamander Bay, but was less than Pindimar Bay.

Micro-carnivore Scavengers	Consumption of baits by micro-carnivores different from controls.	Consumption of baits was high at Myall River, indicating a healthy and active invertebrate assemblage. This is a new area of research and we assume that high rates are good.
Macro-carnivore Scavengers	Consumption of baits by micro-carnivores different from controls.	Consumption of baits was high at Myall River, indicating a healthy and active fish assemblage. This is a new area of research and we assume that high rates are good.
BIOLOGICAL STRESS		
Frequency of ulcers in fish	Proportion of fish with ulcers greater in Myall River.	No ulcers were found during summer 2010.
Leaf damage in mangroves	Higher rates of leaf damage in Myall River.	Proportions of whole leaves did not differ among estuaries.
Parasites in mangroves	Higher rates of parasitism in Myall river	No parasitism

Ecological Condition of the lower Myall River Estuary

Acknowledgements

The authors wish to thank the Myall River Action Group and other members of the Tea Gardens and Hawkes Nest community for raising the profile of the changes to the river entrance and thus providing the opportunity for this study.

We are particularly grateful to Gordon Grainger for many interesting and fruitful discussions on the topic of the lower Myall River; and for his tireless efforts in collecting an outstanding set of data on the clarity of the Myall River and on the relative abundances of rays under the bridge.

The fish sampling would not have been possible without the assistance of volunteers Elliot Scanes, Bruce Nichol and Callan Wilcox.

Martin Fitzhenry and his team organised the collection and analysis of data for the tidal flow gauging and Steve Holtznagel undertook the essential bathymetric surveys that supported the gauging.

Bruce Coates and Phil Watson provided valuable opinion on the changes to Winda Woppa Beach.

Dr Bob Creese (I&I Fisheries Research, Taylors Beach) provided valuable feedback and comment on the study plan and report, as well as generously allowing us to use his laboratories for sample analysis.

Staff from the Port Stephens Great Lakes Marine Park and the DECCW Parks and Wildlife Hunter Region assisted with data and advice when needed.

The study was funded by Great Lakes Council with support from DECCW's Estuary Management Program and managed by Gerard Tuckerman and Prue Tucker from GLC.

Background

Great Lakes Council (GLC) has requested DECCW Coastal Waters Science Unit (CWSU) to undertake a project involving “the preparation of an estuary health assessment … of the lower Myall estuary at Corrie Island/Tea Gardens”. The objective of the assessment was to provide baseline information that will assist in making informed decisions for the future management of the lower Myall River estuary. The ecological health investigation is part of a broader project to provide an improved understanding of the hydrodynamics and estuarine health condition and functioning which is imperative in determining the need and practicality of any future interventions in the management of navigation and/or water quality concerns within the study area. There will be an independent study of the patterns of water and sand movement in the lower estuary commissioned by GLC. Council anticipates that the combined results of the two studies will enable council and government agencies to identify constraints and opportunities for long term management of the estuary including sand shoaling and any associated water quality issues.

It is clear that the wider community has a range of ideas about what they feel constitutes good ecological health. CSWU has canvassed the views of the local community at Tea Gardens on their ideas about estuary health. The main issues that they emphasise are:

- Waters that rapidly clear after rainfall
- Evidence of juvenile fish, toads and rays in shallows
- Recreational fish captures
- Evidence of crabs/crustaceans on intertidal flats
- Lack of stress related disease (red spot) in fish
- Appropriate birds in the estuary
- Minimal amounts of seagrass wrack moving on the tides

Other issues of concern to the community were erosion of Corrie island, impacts of predators on birds using Corrie Island and consequences for an estuarine backwater on Winda Woppa if wave erosion allows a breach from the southern side into the backwater.

DECCWW designed a program for assessing estuary health that met the needs of the local community and provided answers in a way which was meaningful to them, but was also scientifically rigorous and consistent with current scientific thinking on the issue.

Introduction

This report describes a range of short-term studies of the ecological health of the lower reaches of the Myall River estuary. It is prepared in response to community concerns that changes to relative volumes of tidal flow in the two channels that form the river entrance have affected the ecological health of the estuary.

The Myall River discharges into the moderately sheltered waters of Port Stephens, but the river entrance is exposed to swell from the south-east which comes through the entrance to the Port. The river entrance consists of a range of mobile sand features, primarily a large sand island (Corrie Island) with a channel to the east (Paddy Marr's Channel) and another to the north (Corrie Creek Channel) (Figure 1). Other large features of interest are an unconsolidated sand spit to the east of Paddy Mar's Channel (Winda Woppa) and large mobile sand banks offshore and to the east of Paddy Marr's Channel. The evolution of the river mouth is described in Thom et al. 1992 and many of the hydrological characteristics are detailed in MHL (1999) and Vila-Concejo et al. (2007). In summary, early charts show that the Corrie Creek Channel was a small creek, the main channel was what is now known as Paddy Marr's channel and it was partially protected by an extensive vegetated sand spit (Paddy Marr's Spit) which was approx. 1300 metres longer than the current Winda Woppa spit. The charts also show that island, offshore sand banks and Paddy Marr's channel were a dynamic system which did not provide consistent safe passage to the river. In about 1909 the northern channel was dredged to provide safe navigation to the Myall River for transport boats, this created the all weather navigation channel now known as the Corrie Creek Channel. In 1927 a large storm destroyed Paddy Marr's Spit and some of the sand was deposited to form a beach on Corrie Island (Thom et al. 1992).

Studies in 1977 (Public Works Department NSW 1978) showed that the majority (ca. 74%) of the tidal flow into Myall River moved through Paddy Marr's channel, with the remainder through the Corrie Creek Channel (ca. 26%). Up until about 2008, Paddy Marr's Channel was deep enough for small craft to use for navigation. Community members report that in the last few years extensive amounts of sand have moved into Paddy Marr's Channel, reducing the opportunity for navigation and resulting in a reduction in tidal flow through the channel.

The final hydrologic characteristic that has significant impact on the lower Myall River estuary is the storage, after significant rainfall, and subsequent slow release, of freshwater by the Myall Lakes system, which is about 25 km upstream (MHL 1999, Sanderson 2008). These lakes are very large (total surface area 105 million m^2, total volume 278 million m^3 -

Sanderson 2008) and, due to the small and lengthy outlet via Myall River, act as a reservoir for catchment run-off after rainfall. Water levels in Bombah Broadwater (the most downstream lake) can reach levels up to 1.5 m above sea level after significant rain in the catchment. This equates to an increased volume in the lakes of approx. 150 million m^3 . After rain in the catchment ceases, freshwaters continue to flow from the Bombah Broadwater down the lower Myall River at a rate of between 11 and 22 m^3/s (Appendix 2). At an average of 16 m^3/s this equates to a volume of 1,400 m^3 per day. At this rate, it takes about 3 months for the lakes to fall to a height of about 0.1 m above sea level, which is when outflow ceases. Waters in Myall Lakes, and hence the outflow, are typically strongly coloured with natural tannins. One consequence of the storage and release of fresh waters by the Lakes is a sustained period where highly coloured freshwaters displace salt in the lower estuary, even though there may have been no rain for weeks or months. In low rainfall periods and/or during summer, the flow can be reversed, with extensive flow of saltwater up the Myall River (Appendix 2) resulting in sustained periods of moderate salinity (>5) in the Bombah Broadwater.

Myall River, estuary and Lakes and Corrie Island are all contained within the Port-Stephens-Great Lakes Marine Park. The lower estuary around Tea Gardens is primarily zoned for general use, though the western and southern shores of Corrie Island are within a Sanctuary Zone. Corrie Island above mean high water forms the Corrie Island Nature Reserve and is included within the Myall Lakes Ramsar-listed site. The primary objects of a Marine Park are to conserve marine biological diversity and maintain [natural] ecological processes. Ramsar listing requires management of the site to maintain ecological character.

The need for the study described below arises from community concern that changes to the two channels at the mouth of the Myall River (Figure 1) are having detrimental impacts on water quality and, as a consequence, ecological health of the lower Myall River estuary.

The rising concern of increasing environmental degradation around the world has amplified the demand for the development of monitoring programs which measure changes related to the health of affected ecosystems (Scanes *et al.* 1998; Vora 1997). The concept of “estuary health” is often used, but is inconsistently defined. Fairweather (1999) examines the underlying concepts (both explicit and implicit) in the use of “health” in the context of ecosystems and some of the implications for further promotion of the concept. He concludes that, because ecological health focuses on “effects” rather than stresses (for example, levels of a pollutant) it has merit for further investigation. In this study, we have taken the view that a healthy estuary is one in which biological assemblages and processes are within normal ranges of diversity and function. This definition explicitly includes concepts of ecosystem structure (i.e. abundance and diversity of organisms) and ecosystem function (how the components/processes within the system are interacting).

For decades, monitoring programs in estuaries have focused on an analysis of water quality parameters which have been widely promoted as a reliable means of assessing estuary health (Couillard and Lefebvre 1985; Stevenson et al. 1993; Boynton et al. 1996; Cloern 2001; Walker and Veitch 2001). On a global scale, water quality parameters such as temperature, salinity, conductivity, pH, dissolved oxygen (DO), turbidity, total suspended solids (TSS), chlorophyll (chl) *a*, total nitrogen (TN), total phosphorous (TP), oxides of nitrogen (NO_X), ammonia (NH_3) and total organic carbon (TOC) are measured in lakes, estuaries and rivers as part of elaborate monitoring programs. Other commonly studied indicators of estuary health include seagrass and sediment parameters.

The efficacy of many of these water quality indicators as a measure of system status in south-eastern Australia was demonstrated to be poor by Scanes et al. (2007). They tested the indicators over an independently defined gradient of catchment disturbance and demonstrated that almost none of the indicators (with the exception of chlorophyll and turbidity) showed any predictable relationship with the disturbance gradient. The importance and ecological significance of measuring water quality was also questioned by Cooper et al. 1994; Koponen et al. 2002.

Fairweather (1999) reviewed techniques in use for assessing estuary health and concluded that, even though most authors acknowledged a strong element of ecological process understanding, there had been few advances in techniques for assessing ecological processes. In that paper he presented some possible options for process measures, or “ecoassays”, for mangrove forests. Literature searches using the keywords “ecoassay” and “estuary”, and for “ecological process” and “estuary” revealed only 1 paper and 1 unpublished report since 1999 that described measures of ecological processes to determine estuary condition. Dye (2006) used rate of decomposition of seagrass (*Zostera capricorni*) leaf as an ecoassay of the activity of meiofauna. Barton (2003) discusses the potential use of ecoassys in monitoring of estuaries in Victoria (Australia).

A common theme in the scientific literature is a desire to assess the function of all levels of ecosystems, from the microbial through to macro organisms. In this study we combine information on ecosystem structure (or stocks) with a range of ecoassays for rates of ecological processes. We examine ecosystems at a number of levels (see Table 1) to capture a wide range of aspects of system structure and function.

Table 1 Ecological Health Measures

System Component	Measure	Compared to
System Structure	habitat availability	Temporal
	physical influences (water chemistry)	Standards
Biological Structure	abundance of primary producers	Standards
	composition of sand invertebrate assemblages	Controls
	composition of fish assemblages	Controls
	bird assemblages	Temporal
Energy Flow	primary production (seagrass, benthic and pelagic)	Controls
	microbial decomposition	Controls
	micro-carnivore	Controls
	macro-carnivore	Controls
Biological stress	fish ulcers	Standards
	mangrove herbivory	Controls
	Mangrove parasitism	Controls

This study is a "mensurative experiment" (*sensu* Hurlbert 1984) in that it uses a planned design to test the hypothesis that the value of a range of indicators at the test site (in this case Myall River), differs significantly from an expected condition. The expected condition can either be a pre-defined regulatory or management standard (e.g. ANZECC Trigger Value), temporal trends or the mean of the condition of control locations (Table 1). This design is necessary due to the lack of any data from "before" the current period (i.e. prior to restricted flow through the Paddy Marr's Channel). As a consequence, for those indicators where there is no defined goal, the design tests whether the indicators in Myall River lies outside the expected range in comparison to other estuarine locations. The studies are specifically designed to assess whether ecosystem function in the lower Myall River is impaired in comparison to other estuarine environments that do not have the stresses that are perceived to impact on the lower Myall River. It tests the null hypothesis that the status of each of the indicators in lower Myall River is not poorer than the expected condition.

This null hypothesis carries an obvious value judgement, we are stating clearly that a particular status (or direction of change) for an indicator is indicative of a degraded condition. This is contrasted with the value-neutral alternative of "different from". The inclusion of value judgement is consistent with the use of the analogy of health for the system (Fairweather 1999). It does, however, follow that we always have the ability to define a direction of change that indicates degradation. For some of the ecoassays used, it became apparent that insufficient theory currently exists to distinguish between good and poor health. In those cases, we have tested the alternative hypothesis of "difference".

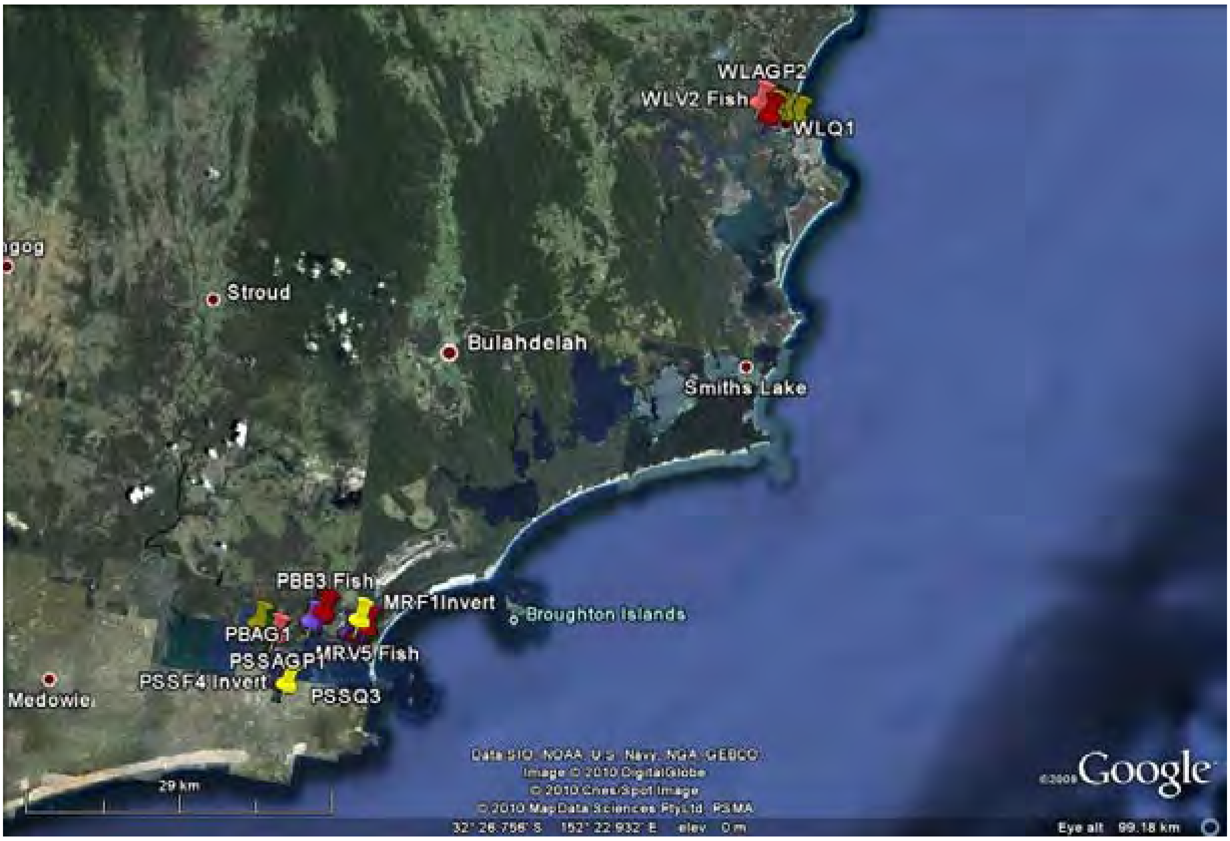


Figure 1 a, b Geographic Location and names of main features in Myall River estuary

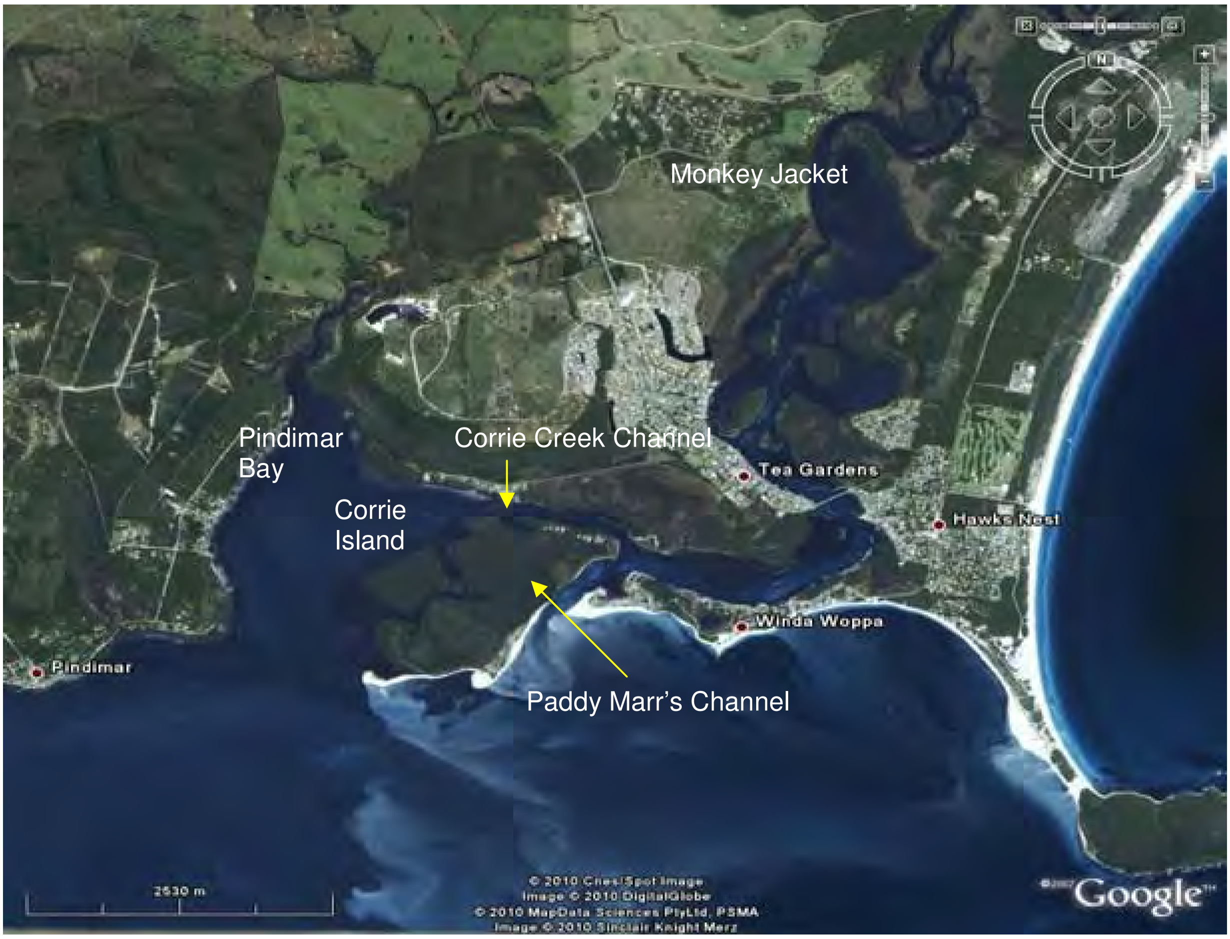


Figure 1 c Myall River Sites: V - vegetated (fish); B - bare (fish); F – flat (invertebrates); AG - algal growth seagrass; AGP – algal growth pneumatophores; Q – seagrass growth

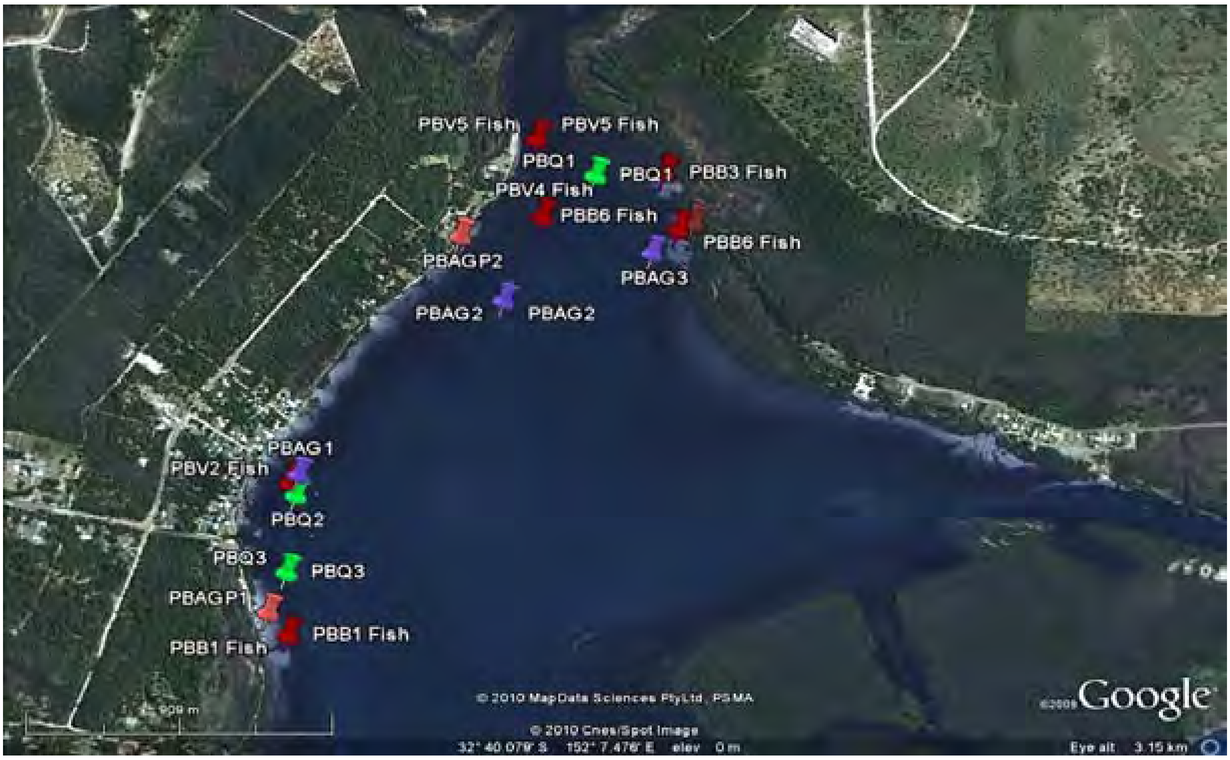


Figure 1 d Pindimar Bay Sites: V - vegetated (fish); B - bare (fish); F – flat (invertebrates); AG - algal growth seagrass; AGP – algal growth pneumatophores; Q – seagrass growth

Figure 1 e Salamander Bay Sites (including Piggys Beach): : V - vegetated (fish); B - bare (fish); F – flat (invertebrates); AG - algal growth seagrass; AGP – algal growth pneumatophores; Q – seagrass growth

Figure 1 f Wallis lake Sites: V - vegetated (fish); B - bare (fish); F – flat (invertebrates); AG - algal growth seagrass; AGP – algal growth pneumatophores; Q – seagrass growth

Figure 1(a –f) Location of sampling sites.

Methods

The study was carried out between November 2009 and May 2010 in the lower Myall River, Pindimar Bay, Salamander Bay, Piggys Beach (all in Port Stephens) and lower Wallamba River in Wallis Lake (Fig 1). Sampling sites for each of the indicators and the names of the locations are summarised in Table 2 and shown Figure 1. GPS locations of sampling sites are in Appendix 1.

As stated above, the study design compared the data from Myall River with the data from the other estuary locations (or standards) to test whether the condition of the Myall River is different (poorer) than expected. Sampling methods and design for Estuary Health bioassays and samples are summarised below in Table 3. Table 3 expands on the Ecological Health Measures introduced in Table 1 and provides the specific indicators and methods that were used to determine the status of these Ecological Health Measures. Additional details on methods can be obtained from DECCW Coastal Waters Science (coastal.waters@environment.nsw.gov.au) if required.

Table 2 Location Names and Description

Estuary Name	Description	Abbreviation
Myall River	Main river channel between Tea Gardens bridge and Corrie Island	MR
Pindimar Bay	Western and northern shores of Pindimar Bay	PB
Salamander Bay	Shores of Salamander Bay off Mambo Wetlands and Piggys Beach on the northern Shore of Port Stephens	SB
Wallis Lake	Lower reaches of Wallamba River and Wallis entrance channels	WL

Statistical analyses were used to determine the significance of any differences between the variables measured at each location. The statistics are used as an independent way to assess whether differences between estuaries were greater than the variability within any estuary, or were no larger than could be expected by chance. Two main types of analysis were used – an analysis of variance (ANOVA) which compares mean values for single variables. It assess whether differences among mean values are greater than would be expected by chance considering the variability of the data that were used to calculate the mean. The result is a probability that a difference occurred by chance, the convention is that if that probability is less than 5% (i.e. $p < 0.05$) then it is deemed to be a significant difference (i.e. unlikely to have occurred by chance). ANOVA was used when assessing single variable questions like, “was the number of bream (or any other fish species) caught the same for all estuaries “ or, “was the number of species found the same for all estuaries”. It can be used to examine the effects of a number of factors simultaneously (e.g. sampling time, estuary, site).

The second type of statistical analysis is known non-metric multi dimensional scaling techniques (Warwick and Clarke 1991) and was done using the Primer software package, Version 5. This technique compares the similarity of whole assemblages (i.e. the types of animals and their abundances) between locations. It is a mainly visual tool that does not assess significance of differences. It produces plots where the similarity of assemblages is indicated by the position and closeness of the labels in the plot. The closer the labels, the more similar the assemblages are. The distances among the centres of the cluster for each estuary can be used to measure the relative scales of difference. The statistical significance of separation in the similarity scores can be assessed by another type of test called Permanova, which was used in some cases.

In addition to the sampling to assess estuary condition, three other issues are reported on in this document as Ancillary Studies

1. access by predators to Corrie Island and potential impacts on birds
2. relative flows of tidal waters in the river and its two main entrance channels
3. description of current status of the small tidal inlet near Winda Woppa

Ancillary Study 1 is based on on-going routine inspections of the Winda Woppa and Corrie Island area by National Parks staff and a specific inspection of Corrie Island in September 2009.

Ancillary Study 2 is addressed in two separate documents, “DECCW Myall River Data Collection September 2008 – September 2009, Report MHL 1943, June 2010”, prepared by Manly Hydraulics Laboratory (cited as MHL 2010); and “Tidal and Catchment Influences on the Myall River”, prepared by John Floyd and included in this report as Appendix 2.

Ancillary Study 3 is based on an inspection of the tidal inlet and Winda Woppa Beach by DECCW staff in July 2010.

Summaries of the results of the outcomes of these Ancilliary Studies are provided at the end of the Results section of this report.

Table 3 Summary of Sampling Methods – Estuary Bioassay and Sampling

Indicators	Objective	Method of Data Collection	Protocol
SYSTEM STRUCTURE			
Presence of healthy mangroves and seagrass	What habitats are available in the river and what is their relative abundance?	Photogrammic analysis of aerial imagery	Existing I & I NSW maps. Temporal trends determined by comparison to earlier dates.
Water Clarity	How does water clarity vary with tide and catchment input.	Secchi Disk	Local community volunteers measured secchi depth from wharf near Tea Gardens. Record time and state of tide when measuring. Secchi data assessed with other other data to find possible reasons for changes in secchi.
Conductivity Myall lake water height	How does conductivity and water height vary with tide and catchment input.	Fixed logger	DECCW/MHL Automated water height and conductivity station at Tea Gardens, Buladelah and Bombah Pt recording every 10 minutes. Historic data from Monkey Jacket. Correlations among data sought to show reasons for changes.
BIOLOGICAL STRUCTURE			
Algae (chlorophyll) in water	What is the abundance of pelagic microalgae?	Fluorometry	Fluorometric data in Corrie Creek Channel, Pindimar Bay and Paddy Marr's Channel collected regularly by DECCW. Data compared to NSW Standards (Trigger values).
Surveys of crabs/crustaceans on intertidal flats	Do the intertidal invertebrate assemblages in Myall River differ from control locations?	Scientific sampling of sand flats using yabby pumps.	4 sites in each of 4 estuary locations (Myall River, Pindimar Bay, Salamander Bay and Wallis Lake). At each site, 20 random pump points were chosen. At each pump site 8 "sucks" with a commercial yabby pump were ejected into a large diameter 1mm sieve. The sample was then washed to remove sediment and the remaining organisms were retained to be counted and identified (to

			family level) in the lab. Sampled in Nov 09 and Jan 10.
Fish sampling	Do the near-shore fish assemblages in Myall River differ from control locations?	Scientific fish sampling.	Samples were collected using a 20m headline x 2m drop x 12mm stretched mesh seine net with cod-end. This was undertaken at 3 bare sites and 3 *Zostera* sites in each of 3 estuary locations (Myall River, Pindimar Bay, Wallis Lake). 5 seine net shots and 3 x 25m multi panelled gill nets were deployed per site, with gill nets left out for a minimum of 1 hour. Samples were undertaken in Nov/Dec 09 and Feb 10. All fish in each sample were then counted, measured and identified and released alive where possible.
Community fish observations	What is the abundance of large rays and how is it influenced by river condition.	Standardised visual count from Tea Gardens Bridge.	Local community volunteers made counts of rays and other fish for 5 min. from bridge each morning. Data correlated with water data to find possible patterns.
Bird surveys	Have there been changes in bird utilisation of the river over the last 6 years?	Existing visual bird survey	NPWS bird survey data, 2004 – 2010, plus additional surveys River to Tea gardens Bridge in 2010. Temporal trends examined.
ENERGY FLOW	*Tea Gardens, Port Stephens, Wallis Lake*		
Leaf growth rates in seagrass	Does the amount and rate of growth of *Zostera* in Myall River differ from control locations?.	Field measurements of the amount of new leaf growth by *Zostera* at each location.	Done at 3 sites in each of 4 estuary locations (Myall River, Pindimar Bay, Salamander Bay, Wallis Lake). Place 4 20 x 20 cm fixed quadrats in seagrass bed at each site. Using a thick hypodermic needle, punch a hole through every leaf base in quadrat. After 6-8 weeks, collect all seagrass plants in each quadrat and measure the distance that the hole has moved using the hole in the leaf sheath as a reference point. Also count the number of unmarked new leaves that have been

			produced since marking. Dry and weigh all the above-ground biomass of the seagrass harvested.
Benthic Algae Sediment oxygen production	What is the abundance of benthic microalgae? What is the nett respiration of benthic sediments?	Experimental incubation of sediment samples and measurement of changes in oxygen.	4 cores from 2 sites in Myall River. Cores are incubated in day and night for 4 hours and changes in oxygen measured. At the end, samples of surface sediment are then collected from each core and analysed for photosynthetic pigments. Data compared to results from other studies.
Algae on seagrass and mangroves	Does the amount of algae colonising seagrass in Myall River differ from control locations?	Amount of algae settling on “artificial seagrass”.	Done at 3 sites in each of 4 estuary locations (Myall River, Pindimar Bay, Salamander Bay and Wallis Lake). Bunches of artificial seagrass were made by fixing 4 oven dried, individually identified, pre-weighed 30 cm strips of packing tape to a short wooden stake. 5 stakes were deployed at each site in each bed so that straps were among seagrass fronds. After 6 weeks, stakes and straps were retrieved. Straps were removed, oven dried and re-weighed.
	Does the biomass of algae colonising mangroves in Myall River differ from control locations?	Amount of algae settling on artificial mangrove pneumatophores.	Done at 3 sites in each of 4 estuary locations (Myall River, Pindimar Bay, Salamander Bay and Wallis Lake). Artificial mangrove pneumatophores were made from 12mm dowel cut to lengths of 30cm. The rods were oven dried and individually weighed and identified prior to deployment. At each site, 5 rods were placed in the sediment at the height of the existing mangrove pneumatophores (approx. 100mm). The rods were placed 5 metres apart and 1 metre from the estuary edge of the “pneumatophore zone.” After 6 weeks, they were retrieved, oven dried and re-weighed. The exact length of each rod that was exposed above the sediment was recorded.

Microbial Decomposition	Does the rate of decomposition of *Zostera* wrack in Myall River differ from control locations?	Placement of seagrass leaves in special containers at sites in each estuary location.	Done at 3 sites in each of 4 estuary locations (Myall River, Pindimar Bay, Salamander Bay and Wallis Lake). 8 replicates were done per site. These consisted of cylindrical containers 75 mm diameter x 50mm high, with 1mm mesh ends. Approximately 6g of 24 hour air dried *Zostera* leaves were placed in each container. At this time 20 samples of *Zostera* leaves were oven dried for 24 hours to generate a reference weight dataset. The containers were secured to a stake and placed in the seagrass bed where they were left for 6 weeks. On retrieval, each container was opened and the contents washed using the 1mm mesh as a sieve. The contents were then oven dried for 24 hours and weighed. These weights were then compared to the oven dry reference weights.
Micro-carnivore Scavengers	Does the rate of consumption of fish flesh by small (<10 mm) organisms in Myall River differ from control locations?.	Fish baits (pilchard) were placed on the sediment surface in a 10 mm mesh container.	Done at 3 sites in each of 4 estuary locations (Myall River, Pindimar Bay, Salamander Bay and Wallis Lake). A single deployment of 8 separate pre-weighed baits per site was made. Baits were left for 4 hours and retrieved. After retrieval, baits were reweighed and tissue loss per hour calculated.
Macro-carnivore Scavengers	Does the rate of consumption of fish flesh by all scavengers in Myall River differ from control locations?.	Unprotected fish baits (pilchard) were placed on the sediment surface. Video cameras were used to record the species of fish attracted by the baits.	Done at 3 sites in each of 4 estuary locations (Myall River, Pindimar Bay, Salamander Bay, and Wallis Lake). Two deployments of 8 separate pre-weighed baits per site were done in the same day. Baits were left for 1 hour and retrieved. After retrieval, baits were reweighed and tissue loss per hour calculated. A single baited remote underwater video (BRUV) was used to record the species and abundance of fish

			attracted to pilchard baits at the Myall River, Pindimar Bay and Salamandar Bay locations. The videos were analysed to determine the number of fish of each species attacking the bait.
BIOLOGICAL STRESS			
Frequency of ulcers in fish	Is the rate of fish ulceration greater in Myall River compared to control locations?	Record number of ulcerated fish in fish sampling.	The presence of ulcers or any external damage to fish was recorded for all net samples from fish sampling.
Leaf damage and parasites in mangroves	Is the rate of mangrove leaf herbivory greater in Myall River compared to control locations? Is the rate of mangrove infestation my mistletoe greater in Myall River compared to control locations?	Visual assessment of the extent of parasitism (mistletoe) and leaf damage to mangrove trees.	4 estuaries, 2 sites per estuary, 4 trees per site with 5 small branches removed from the tree. Leaves were examined for presence of various conditions including galls, pitts and whether they were chewed or whole. Presence of seeds was also recorded but not used in analyses.

Results

System Structure

Habitat availability

Question: Are there fewer types of habitat available in Myall River?

Answer: All expected habitat types are present.

The most recent assessment of the extent of marine vegetation in Myall River was made in 2004 (Creese et al. 2009). All the expected macrophyte habitats (seagrass, mangrove and saltmarsh) are available in the lower Myall Estuary (Appendix 3) along with sandy and muddy un-vegetated areas, intertidal sand flats and natural and man-made hard substrata (Creese et al. 2009).

Water Clarity (summarised from Appendix 4)

Questions: What processes affect water clarity in Myall River? Is the water clarity (turbidity) in Myall River poorer than would be expected?

Answers: Water clarity is poorest when the river conductivity is low (and lake levels high). When conductivity is high, tide has a strong influence, with greatest clarity at high tide and less clarity at low tide. Within this, there is still a large amount of variability caused by turbidity from an unknown source. Turbidity is within guideline values.

Water clarity has been assessed measuring the depth at which a secchi disk (a circular disk about 40 cm in diameter, with alternate black and white quadrants) was visible from above the water. Secchi disk readings provide a simple and generally repeatable method of determining light penetration through the water column.

Secchi disk readings were taken by community volunteers (mainly Gordon Grainger) generally twice daily, at the approximate high and low tides that occurred during daylight hours. This was undertaken when ever possible, and generally taken every day over nearly the whole year. Some days were missed, some tides were missed, but overall the coverage was very good. In the following analyses, readings that were not near to the recorded high and low tides were ignored.

High and low tide readings related closely to end of flood and end of ebb flows respectively.

All data are presented in Appendix 4, and have been plotted with respect to Australian Eastern Standard Time (AEST).

General

Over the whole record, secchi mean depth values varied between 0.8 to 2.88 metres, with a mean value of 1.68m. Secchi values would generally exceed 2.5m on high tide, with low tide values around the 1.0 to 1.5m.

In all cases there is generally a significant difference between high and low tide readings on the same and consecutive days of around 1.0 to 1.5m. Low tide readings (corresponding approximately to end of ebb flow) are generally the lower values (more turbid). This appears to indicate that the flood tide is bringing in cleaner water. This observation is partly why taking readings at the end of flood and ebb flows is preferred, as at other times in the tidal cycle it is possible that you are sampling water that is the result of the previous tide.

Rainfall

The effect of rainfall in the Myall Lakes catchment on Tea Gardens secchi is shown in the November 2009 plot (Appendix 4). Around the 6^{th} November, Bombah water level increased to around 0.3m. At this time low tide secchi readings at Tea Gardens were around 1.5m (a relatively high value). Over the course of the next 5 days the values dropped to around 1.0m but after that they slightly improved to 1.3m even though Bombah water level remained elevated. Through December 2009, low tide secchi readings remained above 1.2m. During December, Bombah lake heights remained low, and even went negative, due to evaporation dominating over rainfall. A lake level below zero results in a net flow from Port Stephens up the Myall River to balance the loss due to the evaporation. Bombah water levels only represent significant catchment rainfall.

Cloud/Overcast Effects

Looking at the secchi values collected on cloudy days shows no apparent effects on the readings. The cloud indicator has been based on comments in the original data sheets indicating cloudy, showers or rain conditions at the time of the readings.

Observed High Turbidity

Comments in the data sheets also indicated apparent obvious turbidity (cloudiness in the water) at the time of readings. Half of the noted turbidity observations at Tea Gardens occur on or near low tide. About a quarter each are attributable to each of high and mid tide observations. Few of these appear to correspond to associated wind events. Large numbers of these observations do appear to correspond to periods of higher daily conductivity variations (due to catchment flow), but high turbidity was also observed where conductivity was near ocean values.

Tide Effects

Tides dominate the local currents at Tea Gardens, except under large catchment events. The influence is readily seen in the comparison of conductivity with water level, where the conductivity extremes (highs and lows) correspond with the highs and lows of the water level. This linkage is due to the end of the flood tide flow corresponding with high tide and the end of the ebb tide flow corresponding with low tide. Another possible effect is due to the fortnightly spring-neap tidal cycle. This cycle results in both higher high tides and lower low tides and associated increased flood and ebb flow and velocities. This spring-neap characteristic is represented in the plot of the measured tidal range (Appendix 4). However from this data set there does not appear to be any dominant link between spring-neap tidal differences and water column clarity.

January, February and March 2010 (Appendix 4 Figures 7 to 9), show short periods of increased conductivity variations, starting near the 'peak' of the neap tide and continuing through approximately the 10 days. During January and February, the conductivity at low tide drops to nearly half the high tide value which is near oceanic water values. By March the effects are substantially smaller, with the conductivity varying by around 10%. This would appear to be a result of the location of the salinity gradient in the river, with the March result due to that gradient moving upstream, and having lesser effect on the Tea Gardens site, as the system as a whole becomes more marine in nature. Observations from other NSW estuaries indicate that the conductivity/salinity gradient can move around 5km longitudinally over a tide. Over a month they can move substantially upstream or downstream depending on the driving mechanisms at the time. The upstream movement of the salinity gradient is generally slow (being driven by tides over months) whilst the downstream movement is generally much quicker (driven by catchment events over just weeks or days).

It is difficult to separate the effects of the tidal currents on turbidity. In one case higher velocities will help lift sediment particles from the bed increasing turbidity, whilst at the same time, transporting it faster and further from the pickup site. However, depending on the sediment particle size, this pickup function is most likely to be more evident at mid tide, when velocities are greatest.

The influence of tides can also have an impact of other forcing functions. For example, the state of the tide and hence local depths at the time of peak wind gusts (which may only last for an hour) may be critical in the impact on turbidity.

Conductivity

Over the period of the secchi records, conductivity recorded at Tea Gardens shows significant variation from fresh water to oceanic values, conductivity values of 2.1 to above 50 respectively. During periods of high fresh water flow down the river, the conductivity varies the most, as the downstream fresh flow is replaced during the flood tide, with ocean water mixed with fresh. When the river is dominated by tidal processes, the conductivity value is up around 50 mS/cm, with small variation. The daily variation is the result of a number of factors, including tidal range on the day, and the preceding events which determine the longitudinal distribution of salinity gradient. The salinity can move approximately 5km along a river just due to the tidal velocities, in both upstream and downstream directions. Conductivity was below 30 mS/cm on approximately 100 days out of 330 days of this analysis period. This occurred predominantly through July, August and November 2009. All other months had on average 3 days under 30 mS/cm.

Wind Effects

Wind effects have been hard to isolate as a cause of increased turbidity with the data available. Although there were a significant number of wind events with average wind speed above 35km/hr, there does not appear to be any major changes in secchi readings during or immediately after such events. For example, an event around the 25/26th August 2009, where maximum wind speed exceeded 60km/hr, shows an immediate dip in the secchi reading but quickly returns to previous values in the days following. A similar event around the 23rd September shows no appreciable effect, with most secchi depths remaining in the higher range. It was followed on 26th by a 60km/hr event with a single reading at 1.4m then returning to around 2.0m. The influence of wind on water column turbidity may be tightly linked to the tidal depths (that is the state of the tide) at the time and duration of the event. It is also possible that wind effects are not long lasting, and the turbidity created quickly settles out. On this basis, major effects, if they occur, may happen more around mid and higher tides and not at all at low tide, when tidal flats are exposed.

Water Chemistry

The freshwater flow from the Myall Lakes is highly coloured from what are usually referred to as tannins. These tannins are a complex mixture of dissolved natural organic chemical compounds. When the tannin-rich freshwaters begin to mix with saltwater, a variety of chemical and biological reactions occur. These reactions cause the organic molecules to clump forming very fine particles (and hence turbidity) in the water. These fine particles can settle to the bottom as an organic layer, but are easily resuspended by water movement.

A longitudinal transect from Corrie Island to Myall Broadwater on 22 September 2009 clearly showed the relationship between salinity and some aspects of water chemistry. Colour increases steadily as the water becomes less saline. Turbidity has two peaks, one in the lower estuary and another near the Broadwater.

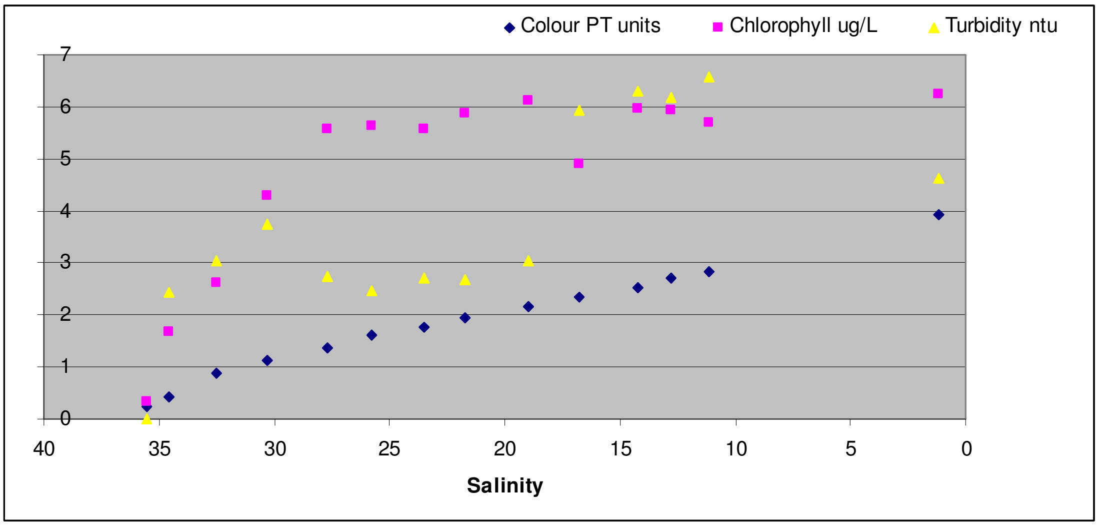


Figure 2 Colour, chlorophyll and turbidity along a transect up the Myall River to the Bombah Broadwater

Factors Affecting Secchi Depth

Secchi Depths were plotted against conductivity at Tea Gardens to investigate whether the state of the tide (high or low) affected secchi depth (Figure 3). Secchi data that was mid tide were ignored for this comparison. This figure shows that for low conductivities, below 30 mS/cm, low secchi values (below 1.5m) can be expected. These values also occur predominantly at low tides. High secchi values will occur predominantly at high tides, with very few high tides producing low secchi values. High tide approximately corresponds to the end of the flood tide. This shows that the flood tide flushing of the Tea Gardens area is generally very good, with clear

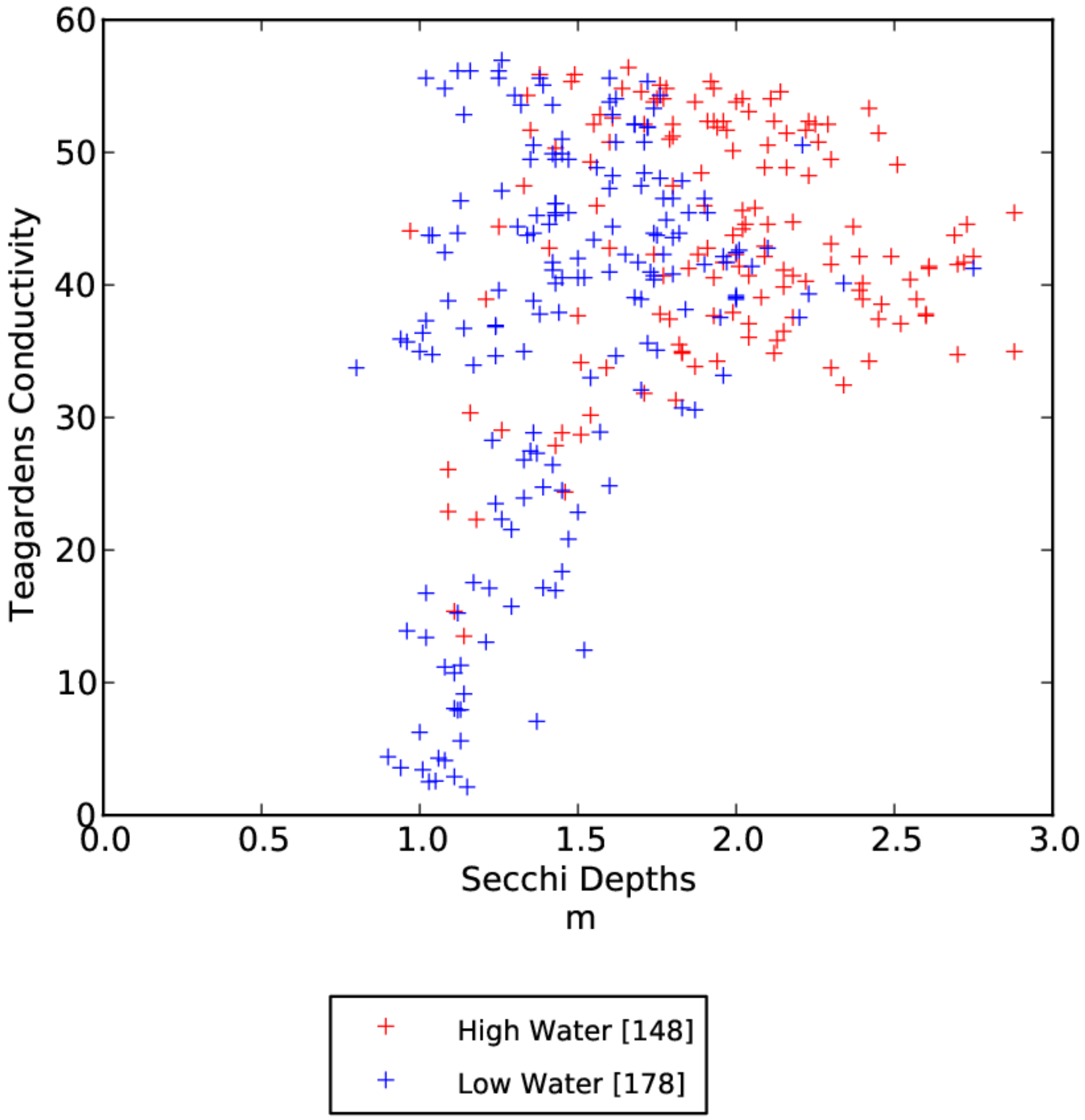


Figure 3 Effects of tidal state and conductivity on water clarity

water brought in on the high tide. Low tide (at the end of the ebb tide flow) very rarely results in high secchi values, though results are frequently up to 2m secchi depths. This is indicative of the riverine nature of the system, with catchment effects being evident. This also suggests that the Tea Gardens area can be a major mixing zone and interface between the fresh river flow and the marine waters of Port Stephens.

A plot of secchi values against conductivity, with plot points highlighted with the Lakes water level (as represented by Bombah Point water level data) was also made (Figure 4). This figure clearly shows that low conductivity is driven by higher water levels in the lakes, which results in increased fresh water downstream. The higher lake water levels can generate increased downstream flows, which limit the penetration upstream of the saline marine waters. This water has increased turbidity, most probably due to the catchment runoff which results in the low secchi depth values. However, high lake water levels do not guarantee low secchi values. Due to size of the lower Myall River, the lakes drain at a relatively fixed rate, with the river regulating that flow. Because of this the lake system has the characteristic behaviour

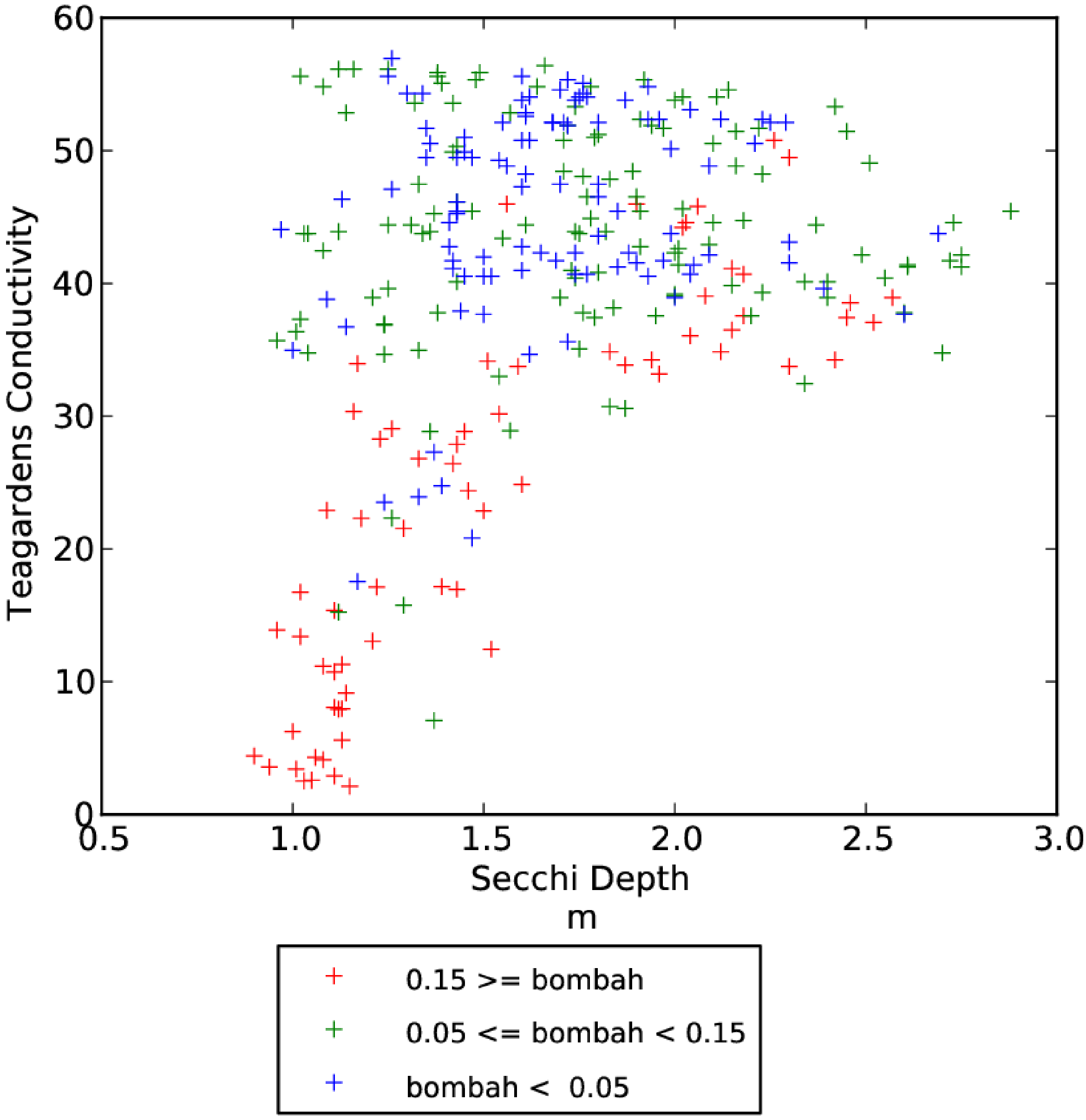


Figure 4 Effect of Conductivity and Bombah water level on water clarity

of 'filling' quickly in significant events and draining slowly over the following number of weeks or months. Therefore, given sufficient time, catchment sediments generating turbidity may settle out in the Lakes and high water levels may also result in clearer waters at Tea Gardens. There is most probably an influence from wind, where a large wind event may stir up bed material in the lakes, and if they are in a 'draining' mode, may influence downstream water quality.

Turbidity

Turbidity data were generally very low (Figure 5) and were not correlated with salinity, though there are few data at low salinities. This is consistent with the findings from the secchi disk measurements, where at moderate to high salinities, factors other than salinity were the strongest influence on water clarity.

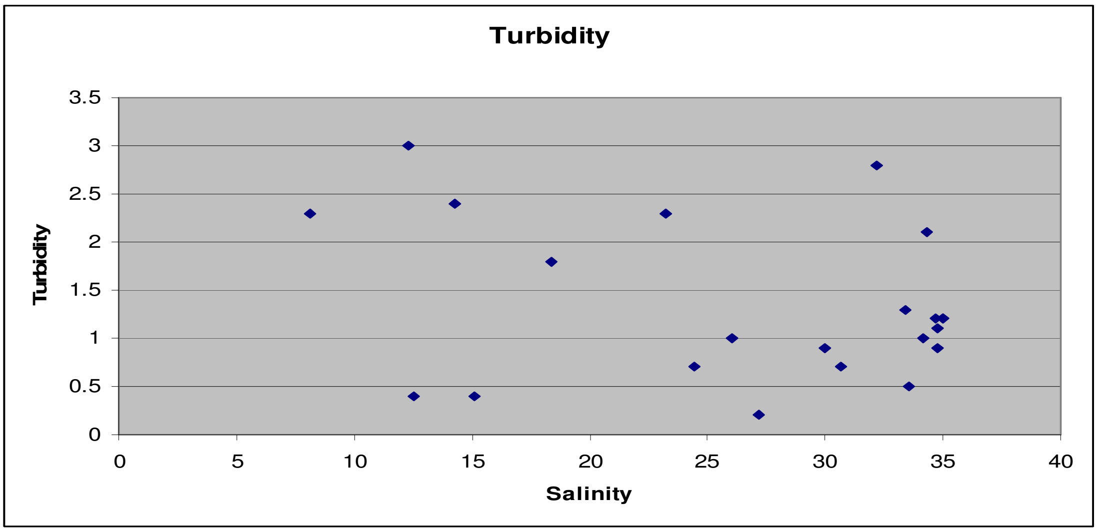


Figure 5 Relationship between measured turbidity and salinity

Roper et al. (2010) provided locally relevant trigger values for turbidity in NSW estuaries and these were used to interpret whether the turbidity data were within accepted limits. These values are derived for upper, mid and lower zones within rivers, with zones defined by salinity.

To compare measured data with trigger values, median values for turbidity measured at salinities greater than 31 ppt, and between 30 and 15 ppt were calculated from the measured data (Table 4). These represent the lower and middle parts of the estuary (respectively). Medians were used in preference to means to reduce the bias from occasional high values (which are expected in environmental data). It can be seen that the median turbidity is well within trigger values.

Table 4 Comparison of measured turbidities with trigger values

	Median Measured Turbidity	Trigger
Lower	1.2	4.4
Mid	0.8	4.2

Conductivity and water height (summarised from Appendix 2)

Question: What factors affect salinity (conductivity) in the Myall River?

Answer: The main factor influencing salinity is outflow of stored water from Bombah Broadwater.

Over the period July 09 to June 10, conductivity (salinity) of the Myall River at Tea Gardens varied between 1 and 58 mS cm^{-1}, noting that conductivity of 53 mS cm^{-1} is approximately equivalent to ocean salinity. It is apparent that freshwater flows from the Myall Lakes can, at times, strongly reduce salinity at Tea Gardens. The Lake's water level directly influences flow in the lower Myall River. When elevated above the 'normal' tidal level, there is a flow of freshwater produced down the Myall as the system tries to reach its stable level. When the Lake's water level is elevated (it can reach a height of 1.5 m above sea level), water level records show that the water level drops at rates around 1 to 2cm/day and this has not changed as entrance conditions have altered (Figure 6). This is equates to 11 and $22m^3/s$ respectively. At an average of 16 m^3/s about 1,400 ML of freshwater per day flows down the river and, from a starting height of 1.2m, it would take about 70 days for the lakes to reach a height of about 0.1 m above sea level, which is when outflow ceases. This rate of freshwater flow is around 50% of typical tidal flow into and out of the lakes. The freshwater flow will restrict tidal penetration up the river and push the saline water downstream under these conditions. It is not just a mixing process diluting the saline waters, but elevated lake water levels push the saline waters out of the upstream parts of the river system. How far it manages to do this depends on the length of time that the elevated water conditions persist and the volume of the flow. The longer the flow-time, the further downstream the saline waters are moved.

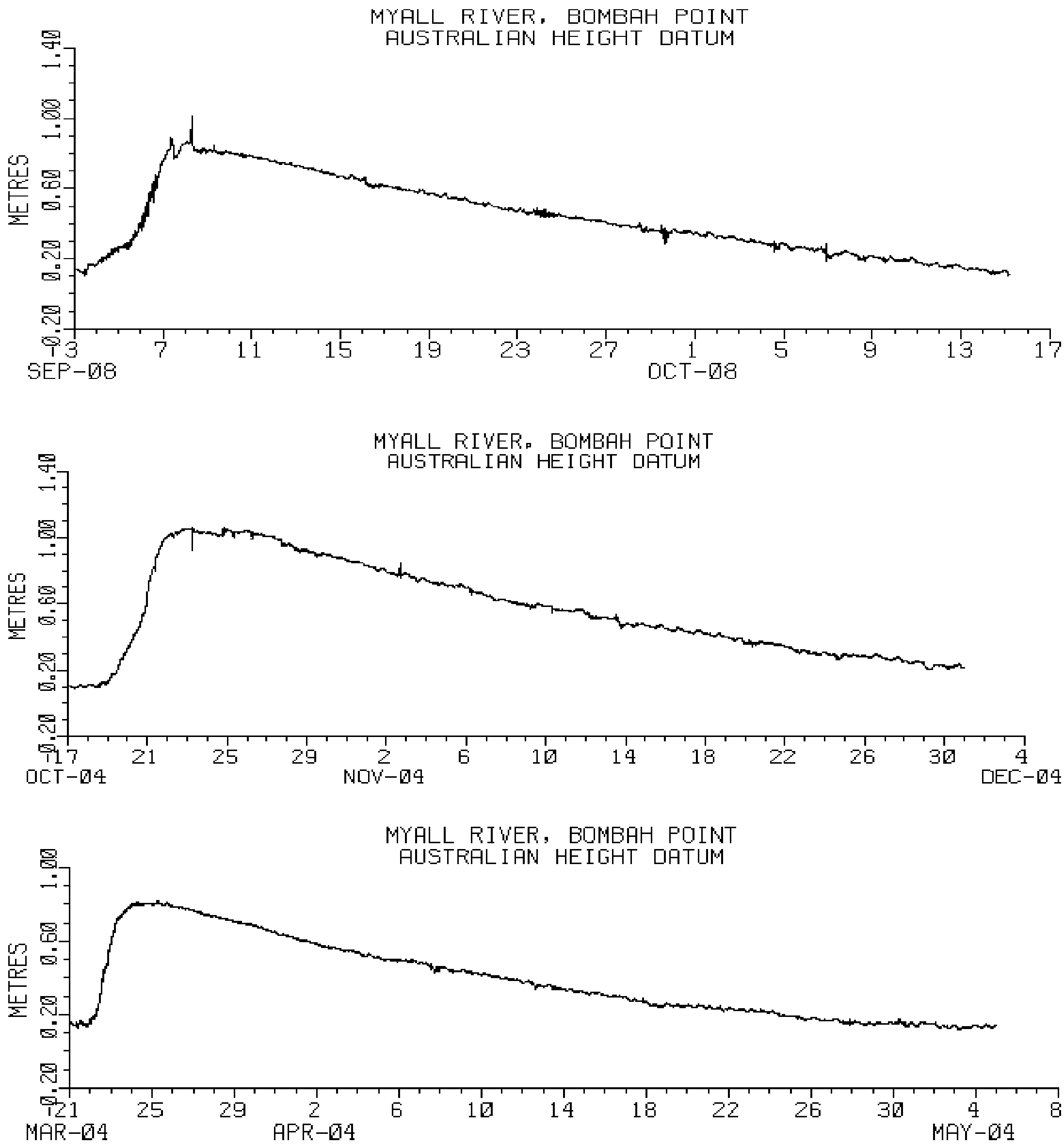


Figure 6 Changes in lake water level at Bombah Point. Levels fell by 1.9 cm/day in October 2008, 1.9 cm/day in November 2004, 1.5 cm/day in April 2004.

When the Lake's water level is below 0.1 m, as occurs under dry, hot conditions due to evaporation, the lakes effectively 'suck' water up the lower Myall River, again trying to reach that stable level. In this later case, with 3mm/day (expected NSW east coast) evaporation, the lakes need a compensatory flow of 3.5m^3/s to balance the evaporation.

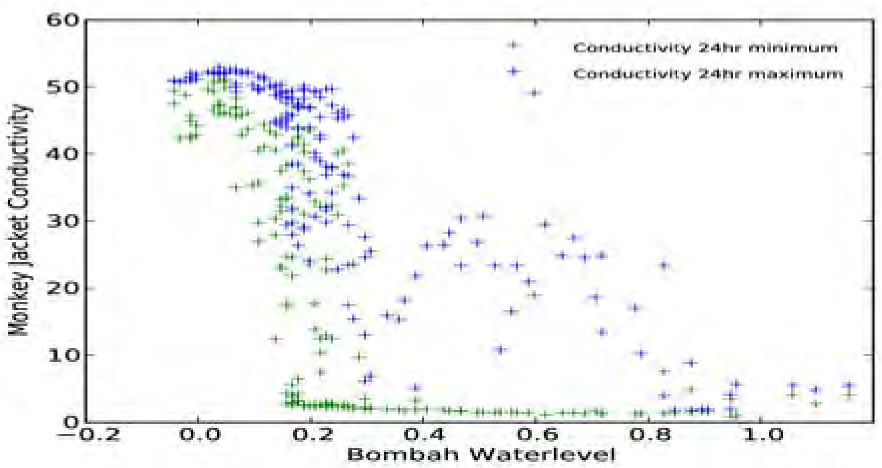


Figure 7 Effects of Bombah water level on conductivity at Monkey Jacket

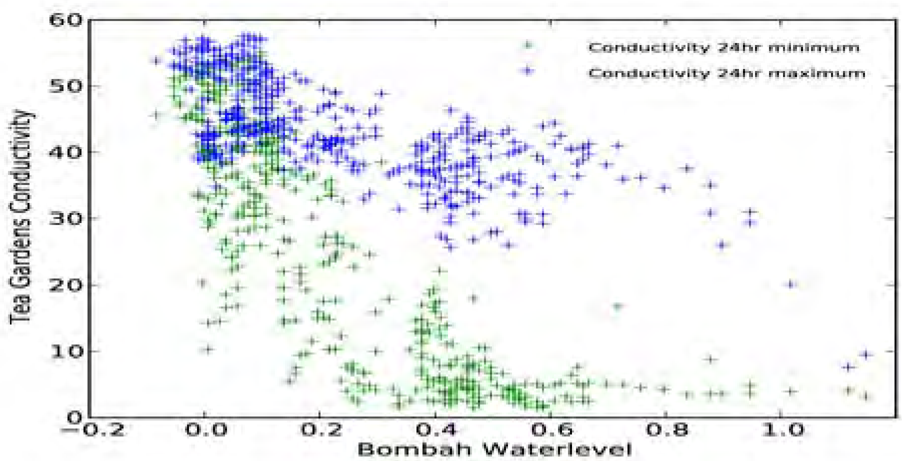


Figure 8 Effects of Bombah water level on conductivity at Tea Gardens

Plots were used to examine the effects of Bombah lake water level on conductivity (as a salinity indicator) at Monkey Jacket and Tea Gardens (Figures 7 and 8). A conductivity value of 53 mS/cm is approximately equivalent to ocean salinity, and zero is fresh water. The Bombah water level, due to its fairly slow rate of change is reduced to the daily water level at midnight each day, and the conductivities plotted are the minimum and maximum over the preceding 24 hours.

Figures 7 and 8 show that higher Bombah water levels results in lower conductivities downstream. At the same time though, reasonably high conductivities can also be recorded. This is the result of the flood and ebb tide. The flood tide can still bring in higher conductive marine water despite low values on the ebb tide.

Thus the height of water in the Myall Lakes has a significant impact on salinity in the lower Myall River. Freshwater catchment flows begin to dominate ebb-tide flows at Tea Gardens when lake levels are greater than 0.55 m, and at Monkey Jacket when lake levels are greater than 0.20 m. Freshwater flows from the lakes effectively displace all saltwater at Tea Gardens, even on flood tides, when lake levels are greater than 1.0 m, at Monkey Jacket this occurs when lake levels are greater than 0.8 m.

Lake height is a measure of the total amount of rainfall that has fallen in the catchment and accumulated in the lakes. The total rainfall volume across the catchment can be quite different from that recorded in rain gauges because of spatial variation in rainfall and the location of rain gauges along the coastal plain rather than in the catchment. Lake heights in 2008 were significantly greater than the long term average (Appendix 2), and since records began in 1986, were only exceeded in 1990, 1999 and 2001. Lake heights in 2009 were slightly below the long term average.

Biological Structure

Abundance of primary producers

Questions: Is the abundance of macrophytes declining in Myall River? Is the abundance of planktonic algae in Myall River greater than guidelines?

Answers: Seagrass has shown some declines but interpretation is difficult due to mapping differences and changes in sandbanks. Coverages of mangroves and saltmarsh have increased slightly. Planktonic algal abundance is within guidelines.

Macrophytes

The extent of mangroves, seagrass and saltmarsh is shown in Table 5. The seagrass is all *Zostera capricorni*. Williams and West (2004) compared the current extent of vegetated habitats with hand-drawn maps from the 1979 (West et al. 1985; Appendix 3). There has been apparent loss of seagrass between 1980's and 2004 and some gains in the extent of mangrove and saltmarsh (Table 5). The main reason for an apparent change in seagrass cover appears to be related to changes in the accuracy of mapping. In West et al. (1985) Zostera is shown to be occupying the entire river channel from about Monkey Jacket to Bombah Broadwater, but in Williams and West (2004) it is more accurately depicted as a very thin fringe along the river. Visual comparison of the beds shown downstream of Monkey Jacket suggests very little change in distribution. We conclude that the main source of difference is the accuracy of mapping in the river.

Un-quantified local observations (G Grainger pers. comm.) suggest that after a period of stability lasting many years, there have been recent significant changes to some of the sand banks near the Tea Gardens Bridge with consequent losses of seagrass. Changes appears to be mainly resulting from covering of existing beds downstream of the bridge with sand. This phenomenon was also noted within our study where quadrats marked for seagrass growth on 4 May 2010 were completely covered by sand by 16 June 2010. These changes are not represented in the data above because it occurred after those data were recorded.

Table 5 Area of vegetated habitat in lower Myall River (from Williams and West 2004)

	Area seagrass (km^2)	Area mangrove (km^2)	Area saltmarsh (km^2)
2004	1.50	1.3	1.89
1985	2.73	1.02	1.78
% change	-45	+27	+6

The most recent observations suggest that the area of seagrass is dynamic, showing periods of stability and other times of rapid change when the sand-banks in the river bed change. Despite this, it appears that most sediments of a suitable depth that are not actively shifting are colonised by seagrass.

Planktonic Algae

Chlorophyll concentrations were used as a measure of the amount of planktonic algae. Excessive amounts of algae can indicate poor health of an estuary (Scanes et al. 2007). In this study, chlorophyll concentrations were determined by fluorometry, and were shown to be strongly linked to salinity in the lower estuary (Figure 9, Figure 2). It is known that tannin colour can interfere with fluorometric determination of chlorophyll, so some of the signal may be also due to colour, potentially over-estimating chlorophyll. DECCW have also determined that, due to differences in calibration, the fluorometric signal on the DECCW meters needs to be adjusted by a factor of 0.67 to reflect true chlorophyll (Roper et al. 2010). The data in Figure 9 have been corrected to remove the calibration offset.

Roper et al. (2010) provides locally relevant trigger values for chlorophyll in NSW estuaries and these were used to interpret whether the concentrations of chlorophyll in Myall River were within accepted limits.

The measured data were compared to trigger values in two ways. Median values for chlorophyll measured at salinities between 35 and 31 ppt, and between 30 and 15 ppt were calculated from the measured data (Table 6). Medians were used in preference to means to reduce the bias from occasional high values (which are expected in environmental data). In addition, using the relationship from Figure 9, the expected chlorophyll concentrations at oceanic salinity (35 ppt) and mid-estuary salinity (25 ppt) were calculated (Table 6). It can be seen that the median and predicted measured chlorophyll is within trigger values. Chlorophyll at lower salinities (10 ppt) is above the trigger values (2.5 ug/L). This chlorophyll is being carried down from the lakes by freshwater and emphasises the previously recognised problems with large algal abundances in Bombah Broadwater. The high fluorometry readings (and apparent chlorophyll) will also be strongly elevated by the presence of tannins as they are most intense when salinities are low.

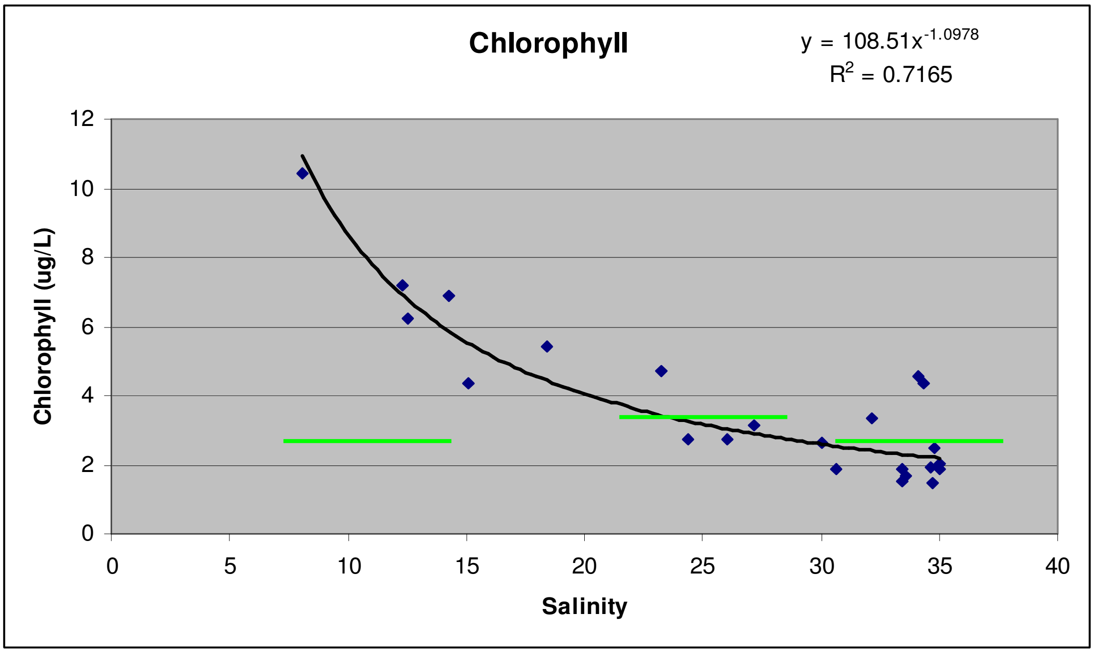


Figure 9 – Relationship between measured chlorophyll and salinity. Trigger values at each salinity are shown in green.

Table 6 Comparison of chlorophyll concentrations from lower Myall River with trigger values from Roper et al. 2010.

River Section	Median Chlorophyll	Predicted (from Figure 9) Chlorophyll	Trigger
Lower (> 31 ppt)	1.9	2.2	2.3
Mid (15-30 ppt)	2.9	3.2	3.2

Sand-flat invertebrate assemblages

Question: Is the diversity and abundance of sand flat animals in summer 2009/10 significantly lower in Myall River?

Answer: No, diversity was greatest at Myall River and ghost shrimp abundances were greatest in Myall River.

Twenty two separate types of organism were identified in the invertebrate samples (they will be referred to as taxa). Most taxa were only identified to Family level (Appendix 5), but ghost shrimps were identified to species (*Trypaea australiensis*) and soldier crabs to genus (*Mictyris* sp.).

The number of taxa per estuary (a measure of biodiversity) did not differ between the two times of sampling nor was there an interaction between estuary and time (ANOVA, $p>0.05$). There was, however, a significant difference among estuaries – Myall River had the greatest biodiversity (10.6 taxa) and Salamander Bay the least (7.2 taxa), with Pindimar Bay and Wallis Lake being intermediate (8.5, 8.9 taxa respectively) and not significantly different from either Myall River or Salamander Bay.

Of the 22 taxa, 6 were abundant enough to analyse for spatial and temporal patterns using ANOVA. For all taxa, sites within the estuary was the dominant source of variation (Table 7), with only Mactrid bivalves exhibiting differences among times and estuaries which were larger than those within estuaries (Table 7). Mictridea (soldier crabs) were more abundant everywhere in December and, overall, least abundant in Wallis Lake. The data were re-analysed without sites as a factor to determine if there were larger scale patterns of difference among estuaries and times. These analyses showed significant interactions between estuary and time for Mactrid bivalves and *Mysella* sp (bivalve), Oweniid polycheates and soldier crabs (*Mictyris* sp.). In the case of soldier crabs, there was an increase in abundance at Myall River and Salamander Bay between Dec 09 and Jan 10 and a decrease in abundance at Pindimar Bay and Wallis Lake for the same dates. Generally, soldier crabs were most abundant at Salamander Bay (0.37 crabs per pump site), moderately abundant at Myall River and Pindimar Bay (0.2 and 0.22 crabs per pump site) and least abundant at Wallis Lake (0.04 crabs per pump site). Unidentified polycheate showed consistent differences among estuaries, most abundant at Myall River and Wallis Lake (0.36 and 0.29 per pump site, respectively) and least abundant at Pindimar Bay and Salamander Bay (0.09 and 0.04 per pump site, respectively). Abundances of the ghost shrimp (also known as yabby or nipper; *Trypaea australiensis*) were significantly greater in December (1.6 cf 1.3 per pump site) and significantly greater at Myall River and Wallis Lake (both 1.8 per pump site) than Pindimar Bay and Salamander Bay (1.3 and 1.1 per pump site, respectively). The lack of an interaction term indicates that the reduction from December to January occurred at all estuary locations, including the protected Salamander Bay location, making human induced change an unlikely explanation.

Data for animal assemblages was analysed with non-metric multi dimensional scaling techniques (Warwick and Clarke 1991), using the Primer software package, Version 5. The plot shown in Figure 10 indicates how similar the invertebrate assemblages are by the position and closeness of the labels in the Figure. The closer the labels, the more similar the invertebrate assemblages are. The distances among the centres of the cluster for each estuary (centroids) can be used to measure the relative scales of difference. Comparisons of the mean abundances of each taxa for each estuary at each time showed that the Pindimar Bay and Salamander Bay locations have very similar assemblages (cluster centres only 11 units apart) with only small change between December 2009 and January 2010. This is demonstrated in Figure 10 by the relatively small size of the orange circle around the

PB and SB labels. The assemblage from Wallis Lake (green circle in Figure 10), is distinctly apart from the PB and SB assemblages (average 29 units away) and somewhat different from the Myall River assemblage (20 units away, red circle in Figure 10) . Myall is also distinctly different from the SB, PB cluster (average 29 units away).

Analysis by PERMANOVA confirms that assemblages differ significantly among estuaries, but do not show a significant difference among times within summer 2009/10, nor an interaction between estuary and time.

Taken together, the two groups of analyses (abundance and MDS) show consistent patterns, with Pindimar Bay and Salamander Bay having similar assemblages and abundances of major taxa. Wallis Lake and Myall River are distinct from each other, but show greater similarity to each other than to the other sites and had similar abundances of common species such as soldier crabs and ghost shrimps. Variation between the two sampling occasions in summer 2009/10 was generally small.

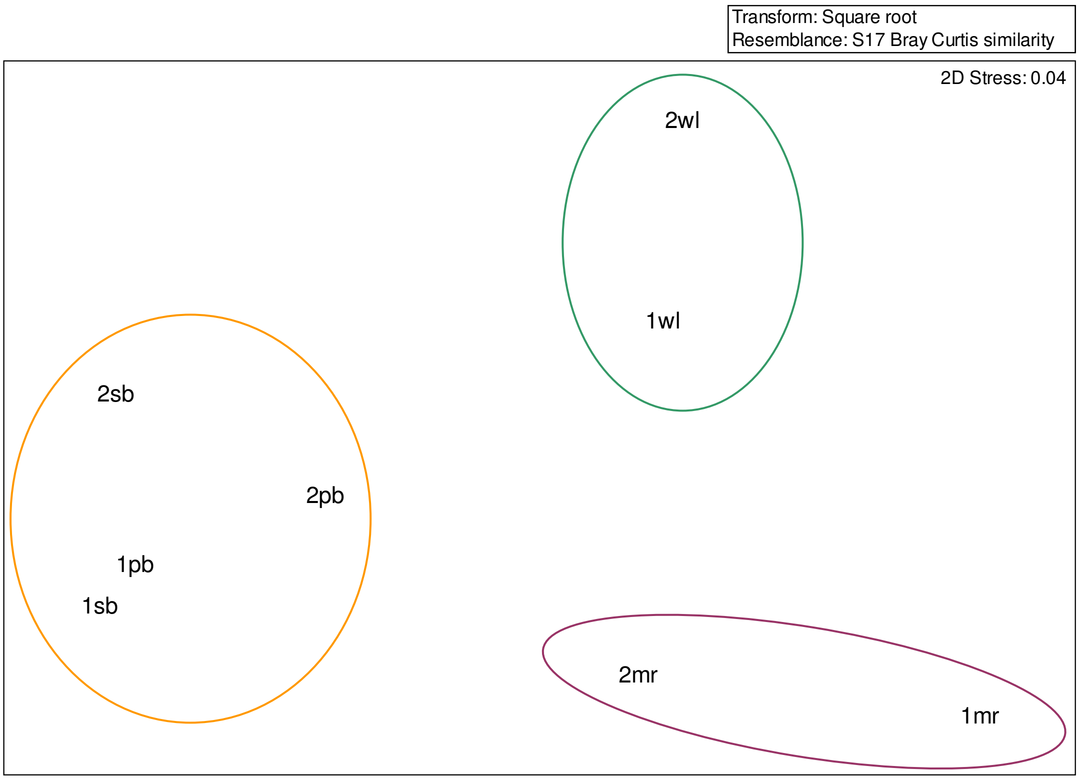


Figure 10 Similarity of invertebrate assemblages at sites and estuaries. The closeness of points on the plots indicates the degree of similarity in the types and abundances of animals found at each site. mr – Myall River, wl – Wallis Lake, pb – Pindimar Bay, sb – Salamander Bay. 1 and 2 are samples from Dec 09 and Jan 10 respectively.

Table 7 Summary of results of analyses of variance on abundances of most common taxa. The first half of the table relates to analyses that include sites with locations as a nested factor; the second half omits sites as a factor. T = Time (Dec 09 vs Jan 10); E = Estuary location (Myall River, Pindimar Bay, Salamander Bay, Wallis Lake); Site = replicate random sand flat sites at each estuary location. n = 20 pump points at each site. X indicates significant differences for the factor in the ANOVA (i.e. p < 0.05).

	Mactridea (bivalves)	Mictryris sp. (soldier crabs)	Mysella sp. (bivalve)	Oweniidae (polycheate)	Unidentified polycheate	*Trypaea australiensis* (ghost shrimp)
Time	X					
Estuary	X					
T x E						
Site (TxE)	X	X	X	X	X	X

	Mactridea (bivalves)	*Mictryris* sp. (soldier crabs)	*Mysella* sp. (bivalve)	Oweniidae (polycheate)	Unidentified polycheate	*Trypaea australiensis* (ghost shrimp)
Time	X			X		X
Estuary	X	X	X	X	X	X
T x E	X	X	X	X		

Fish Assemblages

Question: Is the diversity and abundance of fish in summer 2009/10 significantly lower in Myall River?

Answer: No, diversity was not different among estuaries and abundances of most fish species were not different among estuaries. Luderick were in equal greatest abundance in Myall River.

In the following analyses the number of fish/species reported for each site on each date is the total of all fish from the mesh nets and 5 individual hauls done at that site/time.

There was a total of 60 species caught over all estuaries and the total number of species caught per estuary was very similar (43 for Pindimar Bay, 42 Wallis Lake, Myall River 40 (Table 8; see Appendix 6 for full species list). All species were typical of NSW estuaries. There was no significant difference in the number of species caught per sample among estuaries (Table 9), though there were, on average, more species caught from sites with seagrass than from bare sites (18 vs 7 species per sample) and more species in January 2010 (14 species per sample) than in December 2009 (11 species per sample).

The number of individuals per sample was compared among estuaries for bream, flathead, luderick, sea mullet, tailor, tarwhine, striped trumpeter and sand whiting (Table 10). The majority of these species were caught in equal numbers in each estuary. Only luderick showed a difference among estuaries, with fewer at the Pindimar Bay sites compared to either Myall River or Wallis Lake, which did not differ.

There were, however, significant differences between samples from seagrass and bare areas, irrespective of which estuary was sampled. Bream, luderick, tarwhine and striped trumpeter were all more abundant in samples from seagrass than from bare areas. The pattern for sand whiting was more complex, with significantly more in Pindimar Bay compared to Myall or Wallis in Jan 2010, but no differences in Dec 2009; there was also significantly more whiting in bare sites at Pindimar in Jan 2010, but no difference in Dec 2009.

Table 8 Summary Catch Statistics (see Appendix 5 for details)

Estuary	Number of Species caught	Total Number of fish caught
Myall River	40	2501
Pindimar Bay	43	1391
Wallis Lake	42	3107

Table 9 Number of Species per sample

Estuary	Average number of species per sample	Average number of species per sample - seagrass	Average number of species per sample - bare
Myall River	12.8	19	6.5
Pindimar Bay	11.8	16	8
Wallis Lake	13.8	19.5	8

Table 10 Abundances of fish per sample

	Estuary	Average number of fish per sample	Average number of fish per sample - bare	Average number of fish per sample - seagrass
Bream	Myall River	1.3	0.2	2.5
	Pindimar Bay	1.6	0	3.2
	Wallis Lake	1.7	0.7	2.7
Flathead	Myall River	0.8	0.5	1.2
	Pindimar Bay	0.25	0	0.5
	Wallis Lake	0.25	0.3	0.2
Luderick	Myall River	8.7	1.7	15.7
	Pindimar Bay	0.8	0.3	1.2
	Wallis Lake	3.3	0.3	6.3
Mullet	Myall River	5	5	5
	Pindimar Bay	2	1.2	2.7

	Wallis Lake	5.5	9	2.3
Tailor	Myall River	3.2	2.3	4
	Pindimar Bay	4.8	3	6.7
	Wallis Lake	1.4	0.7	2.2
Tarwhine	Myall River	1.8	0.2	3.3
	Pindimar Bay	2.6	0.7	4.5
	Wallis Lake	1.8	0	3.5
Striped Trumpeter	Myall River	12.3	0	24.5
	Pindimar Bay	10.8	0.3	21.3
	Wallis Lake	16.2	0	32.3
Sand Whiting	Myall River	2.2	3.2	1.2
	Pindimar Bay	7.7	13.2	2.2
	Wallis Lake	2.6	2.5	2.7

The similarity of the fish assemblages (mean abundances per estuary at each date) was also examined using multi-dimensional scaling. Comparisons of the overall composition of the fish assemblage (Figure 11) showed that most of the samples from seagrass were very similar, with the exception of Pindimar Bay, Jan 2010. This is shown by the closeness of all the labels ending in “V” in Figure 11, with a slight separation of PB10V and the relatively small size of the green circle around the “V” labels. Samples from bare areas (labels ending in “B”) were much less similar to each other (note the large orange circle in Figure 11), but are still distinctly different from samples from seagrass (no overlap in circles).

Analysis by PERMANOVA confirms that assemblages from seagrass and bare areas are significantly different, and also that the assemblage from Pindimar Bay differs significantly from Myall River and Wallis Lake.

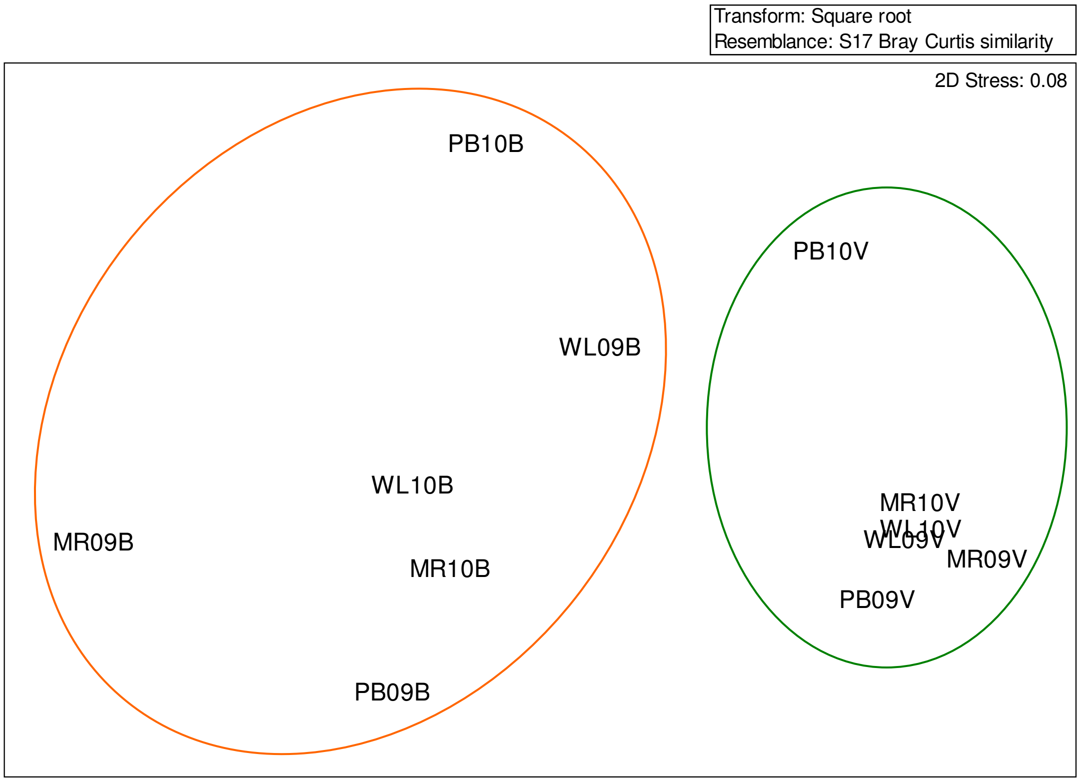


Figure 11 MDS plot showing relative closeness of samples of fish from each estuary (MR – Myall River, PB – Pindimar Bay, WL – Wallis Lake). 9 and 10 indicate samples from December 09 and January 10 respectively. B and V indicate samples from bare (i.e. sand) and vegetated (seagrass) sites. Data are mean abundances of each species at each time.

Bird Assemblages

Question: Is the diversity of birds smaller and abundance swans greater in the Corrie Island area in 2008 – 2010?

Answer: No, diversity has not declined since 2004. Number of swans is variable but has not increased since 2004.

Counts of birds have been made each year since 2004 by members of the Hunter Bird Observers Club on behalf of National Parks and Wildlife Service. These counts were divided into Sectors. Alpha sector covers Winda Woppa, Corrie Island, Pindimar Bay and Piggy's Beach. In 2009 and 2010, an additional sector covering lower Myall River up to Tea Gardens was added.

There has been no consistent decline in the number of species of shore birds or water birds in Alpha Sector since 2004, nor has there been any marked increase in the number of swans. Swans are vegetarian and typically feed on vegetation such as seagrass or macroalgae. Advice from Hunter Bird Observers is that swans have always been a consistent part of the bird community of Myall River and Port

Stephens and frequently move between feeding sites. Presence of swans is considered a sign of good ecological condition.

Table 11 Swan abundances and number of shore and water bird species. Winda Woppa and Corrie Island are in Alpha Sector.

Sector	Alpha	Bravo	Charlie	Delta	Echo	Foxtrot	Myall
	NUMBER OF BLACK SWANS						
Summer 2004	150	360	500	6	40		
Summer 2005	122		0	54	32		
Summer 2006	0	9	33	128	18	12	
Summer 2007	0	19	238	45	102	14	
Winter 2008	0	4	2	15	13	5	
Summer 2009	5	30	90	236	202	0	
Winter 2009	28	0	42	52	23	99	
Summer 2010	150	344	242	129	42	213	92
Winter 2010	0	8	0	0	27	11	0
	NUMBER OF SHORE BIRD SPECIES OBSERVED						
Summer 2004	5	6	5	10	8		
Summer 2005	6		4	7	3		
Summer 2006	13	3	7	8	13	7	
Summer 2007	7	8	10	12	12	11	
Winter 2008	3	6	3	5	4	7	
Summer 2009	4	4	8	11	9	5	
Winter 2009	1	3	3	7	5	3	
Summer 2010	8	6	6	9	8	7	2
Winter 2010	3	5	4	6	6	4	2
	NUMBER OF WATER BIRD SPECIES OBSERVED						
Summer 2004	15	11	12	10	16		
Summer 2005	12		7	10	8		
Summer 2006	11	13	15	12	12	9	
Summer 2007	15	15	15	15	11	14	
Winter 2008	11	15	14	14	17	16	
Summer 2009	12	11	11	11	8	11	
Winter 2009	16	9	14	13	14	14	
Summer 2010	13	18	16	16	14	15	15
Winter 2010	8	14	10	15	12	18	10

Community Fish Observations

Community members (primarily Gordon Grainger) counted the numbers of large rays visible during a 5 minute period in the mornings. The number of rays counted was correlated with environmental variables (water clarity (secchi), water conductivity, water height (tide)) to investigate whether these factors influenced the number of rays. Tide height did not seem to affect the number of rays present (Figure 12). There were few rays observed when clarity was poor (Figure 12; secchi < 1.0m) but it is not possible to know whether this is due to their absence, or an inability to see them. Conductivity had a strong influence on the abundance of rays. No rays were observed at conductivities less than 25 mS/cm (possibly due to poor clarity), and they were not abundant until conductivities of 38 mS/cm (Figure 12).

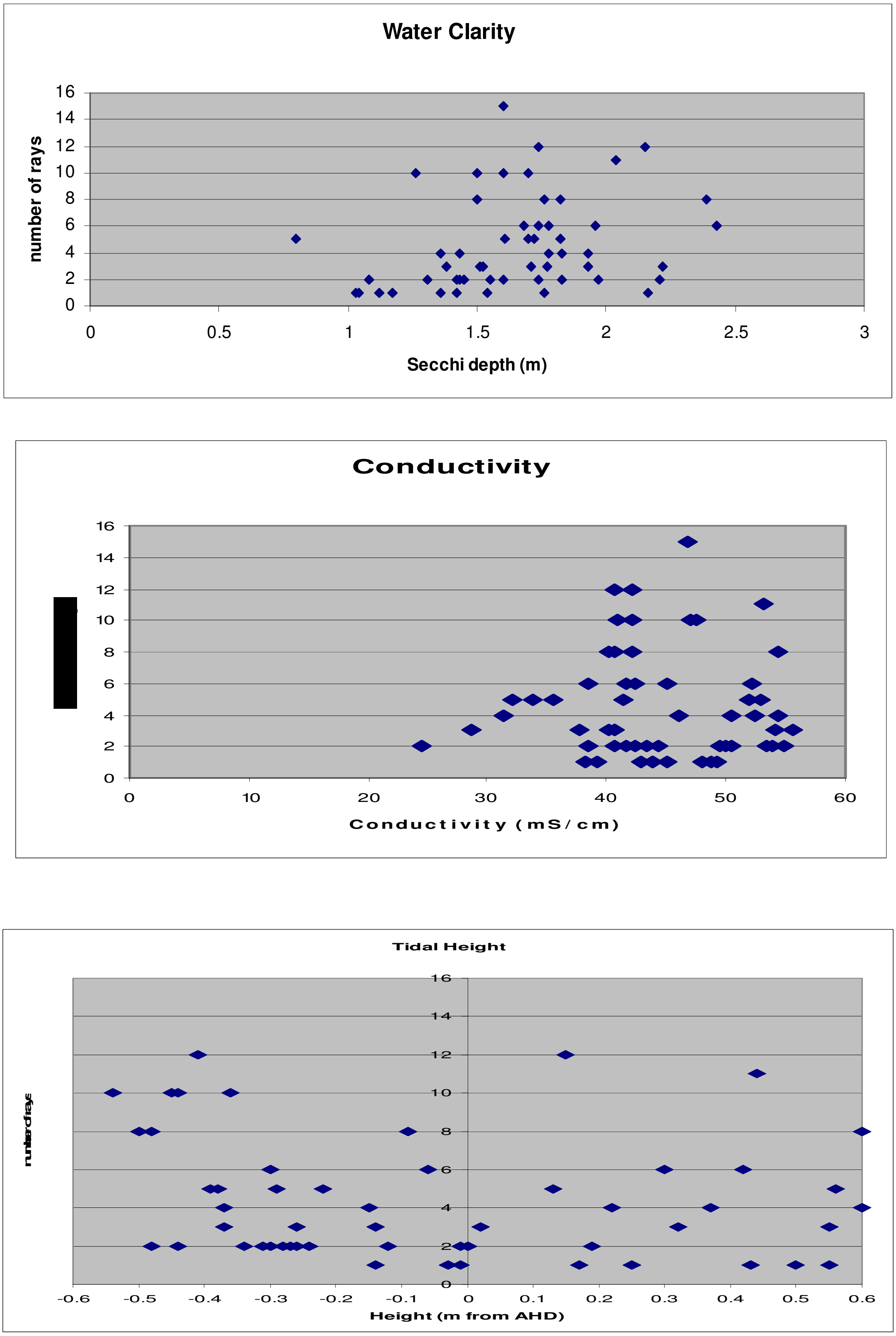


Figure 12 Influence of water clarity (secchi, m), conductivity (mS/cm) and tidal height (m from AHD) on the number of large rays observed in 5 mins from Tea Gardens bridge.

Energy Flow

Water column algal production

Question: Is the Myall River likely to experience periods of low oxygen?

Answer: Nett oxygen production was negative in cold water and positive in warm water, but the deficits were small and within normal limits, and hence unlikely to lead to low oxygen in the river.

Production was measured as change in oxygen concentrations in experimental chambers containing only river water. It is a measure of whether organisms in the water column are net consumers of oxygen (due to respiration and decomposition of organic matter) or net producers of oxygen (due to growth of algae). A negative change indicates consumption of oxygen. The experiments were done in July, when water temperatures were about 14 º C. In the experiment, after the initial measurements were made, the water temperature was artificially raised to 25 º C to simulate summer temperatures and held there for 10 hours prior to a second set of measurements. This procedure can be criticised because the actual microbes and algae that would be present in summer may not be present, so it should be viewed as a test of how winter microbes and algae operate at elevated light and temperatures. The experimental procedure exposed some chambers to light at the same levels that existed when the chambers were collected (220 micro einsteins) and a higher light level for the elevated temperature (325 micro einsteins). This measured the rate of oxygen production by photosynthesis. Light levels were relatively low due to the presence of tannins in the water column when the experiment was conducted. Other chambers were kept in the dark to measure the rate of oxygen consumption by respiration. The rates for dark and light were then combined (in proportion to the number of daylight hours) to estimate the net production/consumption of oxygen over 24 hours. This overall change is referred to as the net daily metabolism (NDM) of the system.

Measured rates were about -1900 umol $O_2.m^{-3}.hr^{-1}$ at 14 º C and +110 umol $O_2.m^{-3}.hr^{-1}$ at 25 º C (Figure 13). This result indicates that at low temperatures, the daylight algal production of oxygen is exceeded by the combined day and night oxygen consumption and that on average, water is consuming oxygen. At higher temperatures (and light) the production of oxygen by algae exceeds consumption and there is net production of oxygen in the water. This pattern is not un-expected. The consumption of oxygen is probably increased by microbial breakdown of the dissolved tannin compounds in the water and breakdown of freshwater algal cells in the estuary. The daily replacement of water by the tides ensures that the river water does not experience depletion of oxygen, particularly at night.

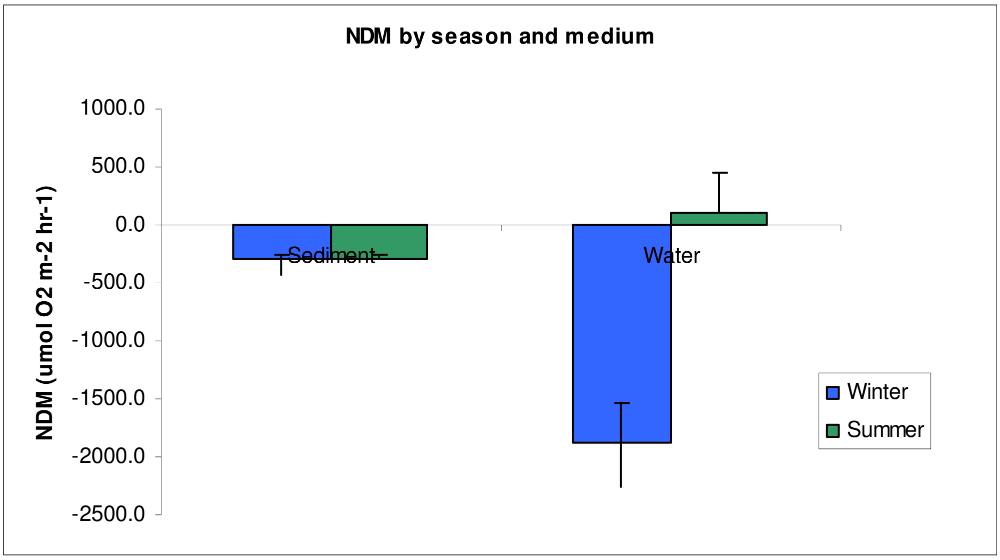


Figure 13 Net daily metabolism (NDM) for waters and sediment at 14 (winter) and 25 º C (summer)

Benthic Production

Question: Is the Myall River likely to experience periods of low oxygen?

Answer: Nett oxygen production was negative in sediments, but the deficits were small and within normal limits, and hence unlikely to lead to low oxygen in the river.

Benthic production was measured as change in oxygen concentrations in experimental cores which contained water and un-disturbed sediment from the river bed, collected in waters of about 1.5 m depth . It provides a measure of whether sediments are net consumers of oxygen (due to respiration and decomposition of organic matter) or net producers of oxygen (due to growth of algae on the sediment surface). A negative change indicates consumption of oxygen by sediments. The experimental procedures were the same as for water production, above. The main difference in data analysis was that the change in oxygen due to water processes (estimated above) was subtracted from the changes in the core to estimate the changes due to the sediments alone.

Measured rates for sediment NDM were about -290 umol $O_2.m^{-2}.hr^{-1}$ at both 14 º C and 25º C (Figure 13). The lack of difference between high and low temperatures probably indicates that the sediment temperatures did not increase by the same amount as the water temperatures. These rates are fairly typical of estuarine sediments in moderate to low light levels. Sediments from 1.5 m depth in Coomba Bay (Wallis Lake) had winter NDM of approx. -150 umol $O_2.m^{-2}.hr^{-1}$ and from 2.8 m depth had NDM of approx. -350 umol $O_2.m^{-2}.hr^{-1}$. This places the Myall River sediment NDM approximately between the two, the slightly higher negative NDM probably reflects the impacts of the tannin waters.

Seagrass Production

Question: Is the seagrass in Myall River growing more slowly than expected?

Answer: Growth rates were not able to be determined. The amount of seagrass per square meter in Myall River is not less than the other control estuaries.

The technique used for estimating growth did not deliver any results. The hole that was meant to be used to measure growth was not visible on leaves or sheaths. It is thought that the needle used to make the hole was too fine and did not leave a sufficient scar. In addition, a number of marked quadrats were covered by shifting sand.

The *Zostera* harvested from the remaining quadrats for analysis of growth has been used to provide an estimate of the biomass of the standing crop (i.e. total amount growing) of seagrass in each estuary. Biomass has been estimated for above ground (leaves and shoots) and below ground (roots and rhizomes). Below ground biomass was 2 to 4 times greater than above ground. In both cases, there were no significant differences among estuaries (Figure 14).

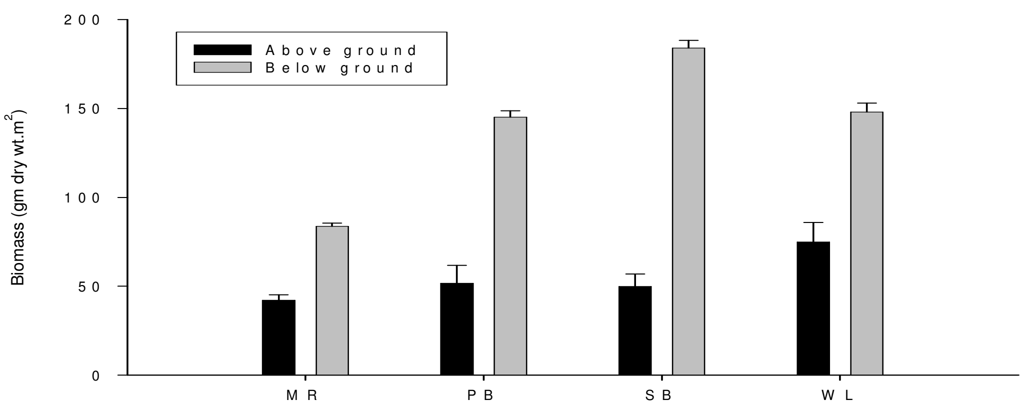
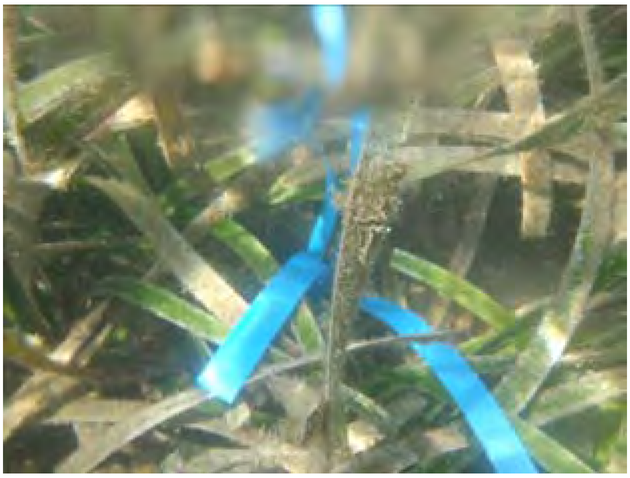


Figure 14 Above and below ground biomass of Zostera per square meter in June 2010.



Algal Settlement on Mangroves and Seagrass

Question: Is the settlement of algae in Myall River greater than other estuaries?

Answer: The rate of settlement of algae on seagrass was small and did not differ among estuaries. Myall River, Salamander Bay and Wallis Lake had lower levels of settlement on mangrove pneumatophores than Pindimar Bay.

Algal settlement on artificial pneumatophores (c.a. 1.2 mg dry weight per sq cm per day) was approximately one order of magnitude greater than settlement on artificial seagrass (ca 0.06 mg dw per sq cm per day). Settlement on pneumatophores at Pindimar (1.32 g mg dw/sq cm/day) was significantly greater than at Myall River, Salamander Bay and Wallis Lake (0.86, 0.86, 0.6 mg dw/sq cm/day, respectively;

Figure 15). Settlement of algae on artificial seagrass did not differ among estuaries, nor among sites with estuaries (Figure 15). In both cases, variability among replicates was small, co-efficients of variation (CV) for mangrove pneumatophores ranged between 0.18 and 0.06; whilst CV for seagrass was between 0.06 and 0.08.

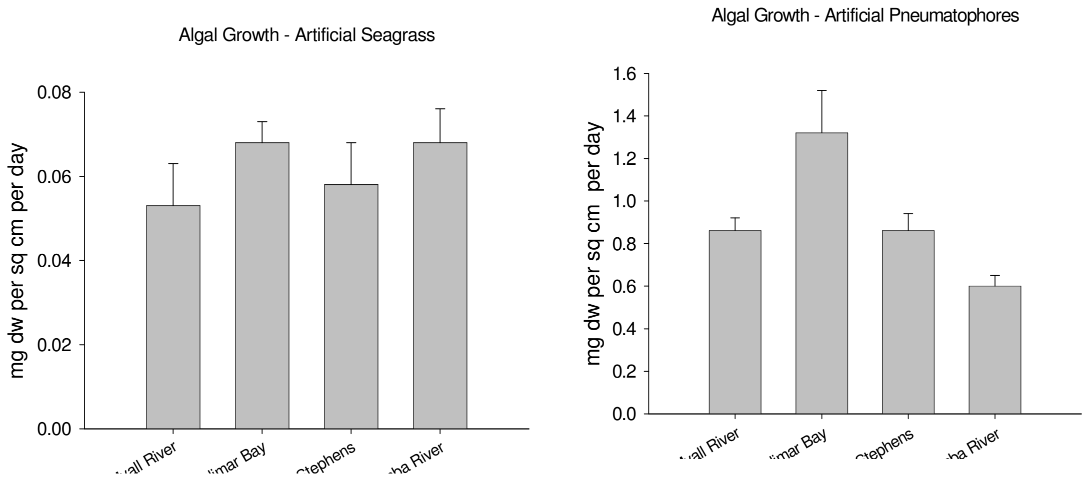


Figure 15 Rates of settlement of algae on artificial seagrass and mangrove pneumatophores

Microbial decomposition

Question: Is the rate of seagrass decomposition less in Myall River than other estuaries?

Answer: The rate was greatest in Pindimar Bay, but Myall River was no less than Wallis Lake or Salamandar Bay.

Rates of decomposition of *Zostera* by meiofauna and bacteria were determined in containers covered with 1mm mesh and left in place for 32 days at each estuary location. Approximately 25% of *Zostera* tissue weight was consumed at Myall River, Salamander Bay and Wallis Lake, with 40% consumed at Pindimar Bay. Analysis of variance showed that the weight loss at Pindimar (78 $\pm$ 3 mg/d) was significantly greater than at Myall River, Salamander Bay and Wallis Lake (47 $\pm$ 6 mg/d, 53 $\pm$ 7 mg/d, 49 $\pm$ 4 mg/d respectively; Figure 16). There were no significant differences among sites at each estuary location.

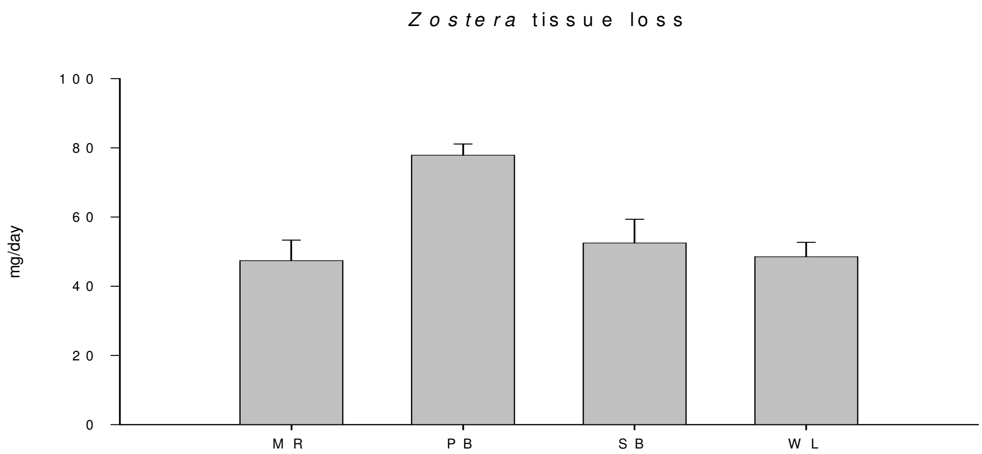


Figure 16 Rates of decomposition of Zostera leaves

Micro-carnivore Scavenging

Question: Is the rate of microcarnivore scavenging different in Myall River than other estuaries?

Answer: The rate was not different in Myall River, Wallis Lake and Pindimar Bay, but was less in Salamandar Bay.

Scavenging by micro-carnivores will include very small fish as well as snails, worms and small crustaceans. It measures the activity of the lower levels in the food chain. Scavenging tests were done twice at Myall River (only), 4 weeks apart, to determine the temporal repeatability of the technique. There was no significant difference between the data for the two times at Myall River. Consumption of pilchard at Myall River, Pindimar Bay and Wallis Lake (4.7, 3.1, 4 gm/hr respectively) were not significantly different from each other, but were significantly greater than consumption at Salamander Bay (2 gm/hr). There is no well developed theory to accurately interpret whether a high rate is “good” or “bad”. We have assumed that a high rate is better than a low rate as it indicates that there is a large and/or active invertebrate community.

Macro-carnivore Scavenging

Question: Is the rate of macro-carnivore scavenging different in Myall River than other estuaries?

Answer: The rate was greatest in Myall River, then Wallis Lake and Pindimar Bay which were not different and least in Salamandar Bay.

Scavenging by macro-carnivores includes fish and crabs, as well as snails, worms and crustaceans. It measures the activity of the upper levels in the food chain. Scavenging tests were done twice at Myall River, 4 weeks apart, to determine the temporal repeatability of the technique. There was no significant difference between the data for the two times at Myall River. Consumption of pilchard at Myall River (25 gm/hr) was significantly greater than Pindimar Bay and Wallis Lake (16.3, 16.9 gm/hr respectively) which were in turn significantly greater than consumption at Salamander Bay (6 gm/hr).

Quantitative data on scavenging was supported by video recordings of fish attracted to baits at one site at each of Myall River, Pindimar Bay and Salamander Bay. The technique is known as Baited Remote Underwater Video (or BRUV). The recordings provide further quantitative data on the species of fish attracted to baits. Data were collected from “views”, which are samples collected every 30 seconds through the 15 – 18 min videos. These data were the maximum number of fish in a single view (max N), the percentage of views with fish, the number of each species per view and the delay until fish arrive at baits.

Only one species of fish was seen to be involved in scavenging at the three locations, *Pelates sexilineatus* , the striped trumpeter. The analysis of the video supported the data from the scavenger baits, greatest activity occurred at Myall River, then Pindimar bay, then Salamander Bay (Table 12). This difference in activity and scavenging occurred despite the fact that striped trumpeter are in the same abundance at Myall River and Pindimar Bay (see fish assemblage analyses) and that schools of striped trumpeter that are not interested in the baits can be seen in the video at Salamander Bay.

Table 12 Data collected from Baited Remote Underwater Video (BRUV)

	Max n	% views with fish near bait	Average number trumpeter per view	Min til fish arrive
MR	16	100	9.9	5.5
PB	5	60	1.6	4.5
SB	3	16	0.16	4

Biological stress

Fish ulcers

Question: Is the rate of fish ulceration in Myall River greater than other estuaries?

Answer: There was no ulceration in fish sampled in this study. NSW Department of Industry & Investment advise that ulceration is a widespread issue.

No ulcers or other signs of external damage or stress were observed on any fish.

Community observers report ulceration as being reasonably common when the river turns fresh after Bombah Broadwater levels rise and flow out over an extended period. Ulcers were noted in September 2008, June 2009 and most recently reported in June and July 2010. Ulcers are most commonly a result of epizootic ulcerative syndrome (EUS) or 'red spot disease', a disease that can affect many species of fish. Whether the ulceration in Myall River in winter 2010 was EUS can not be confirmed without detailed pathological testing on fresh fish. Red spot disease is known to be endemic in a number of coastal waterways in NSW. It is believed that EUS is most commonly a response to stress factors (such as freshwater) so, in the absence of any evidence of un-natural stressors, this is not deemed to be abnormal or unhealthy (Appendix 7).

Mangrove leaf damage

Question: Is the rate of mangrove leaf damage in Myall River greater than other estuaries?

Answer: There was no difference in the proportion of whole leaves among estuaries.

Mangrove leaves were assessed for damage from the presence of galls or lumps, evidence of chewing of leaves or by the presence of small pits and mines in the leaves. Analysis of variance indicated that the proportion of whole leaves in growing branch tips varied among sites within an estuary, but that variation among estuaries was not larger than that within estuaries (mean % whole leaves: MR - 19, PB – 14, SB – 26, WL - 18).

This pattern was confirmed by MDS (Fig 15) where the distance between sites within an estuary was as great as that among estuaries. Principle Component Analysis (Fig 16 confirmed that a large proportion of whole leaves caused SB2 and MR 1 to be very close, a greater number of galls separated WL 2, PB 1 and a greater number of pits separated MR 2; while chewed leaves separated WL1. There was no specific influence causing SB1 and PB2 to separate from the other sites.

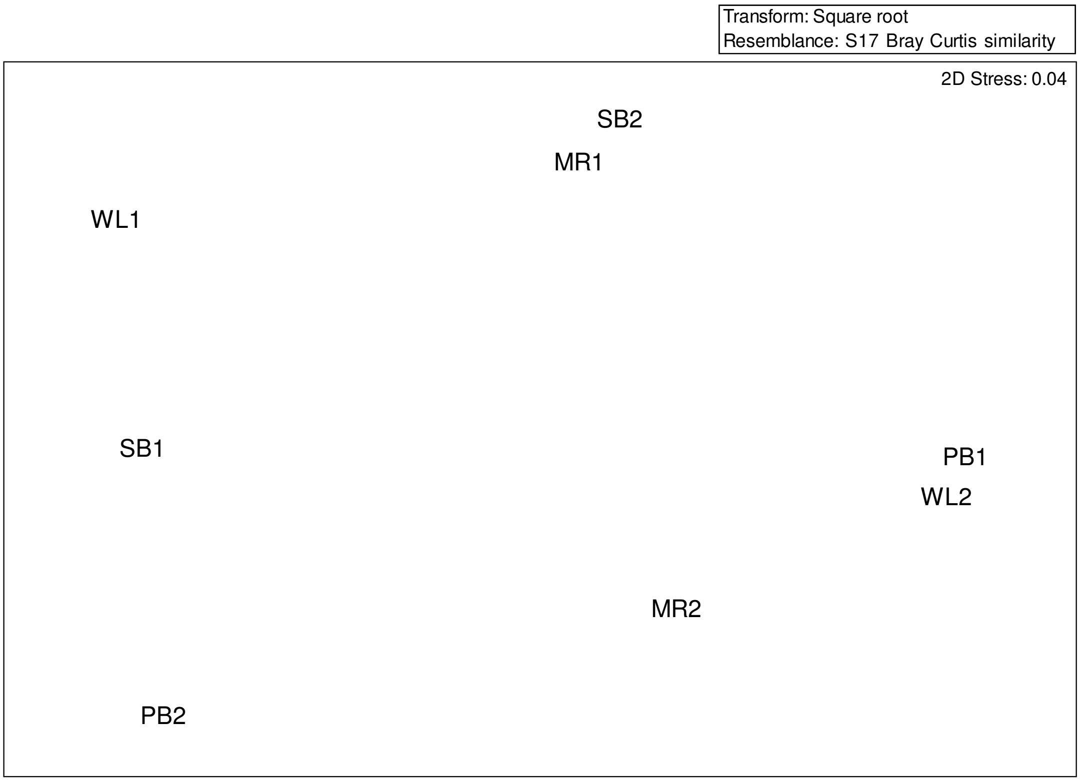


Figure 17 Plot of the similarity of sites according to the extent and type of leaf damage

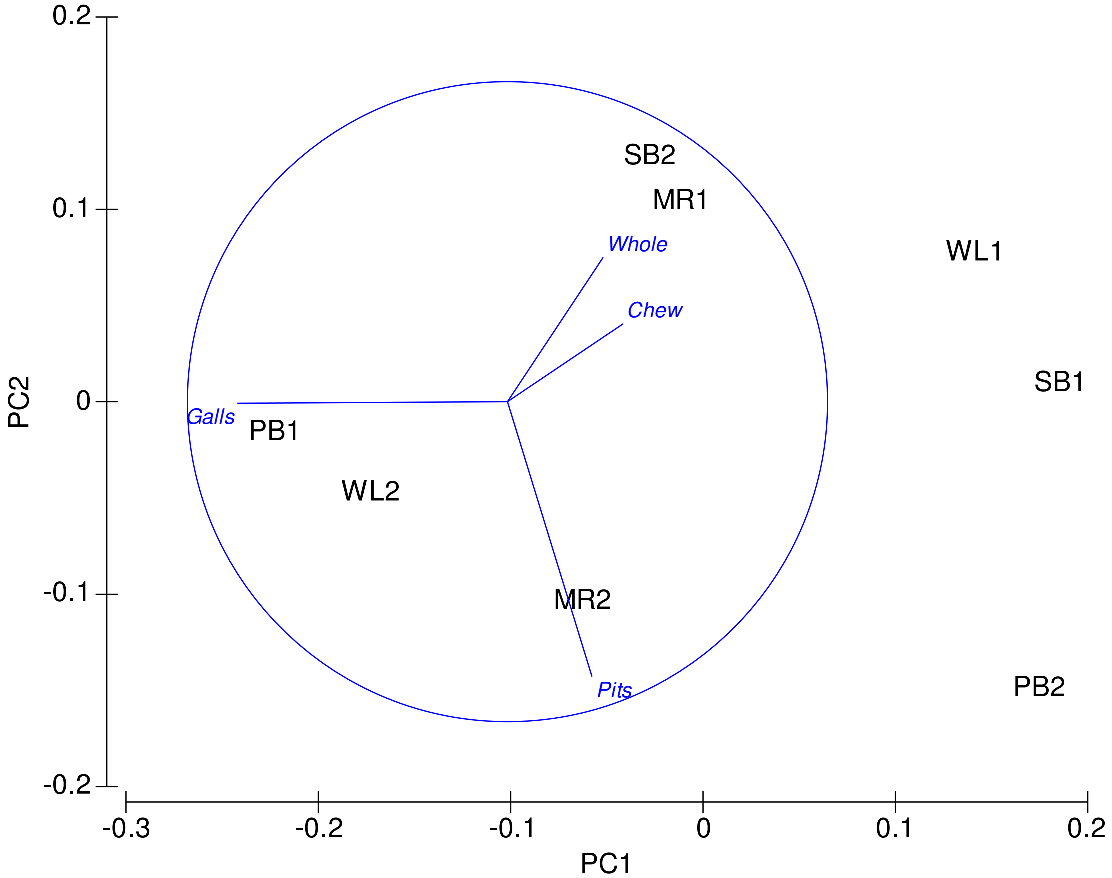


Figure 18 Principal Components Analysis showing which types of leaf damage are most important in separating sites.

Mangrove parasitism

Question: Is the rate of mangrove parasitism in Myall River greater than other estuaries?

Answer: There was no parasitism in trees sampled in this study.

No mistletoe was observed on any mangrove trees in this study. Fairweather (1999) also sampled for mistletoe, but did not report the results. Presumably this indicates that he also did not find any mistletoe.

Ancillary Studies

Predator Access to Corrie Island

An inspection of Corrie Island was made by officers from the Worrimi National Park in September 2009. They found very little evidence of activity by foxes or dogs, though interestingly did find signs of activity by the endangered spotted quoll. There was no evidence of shore birds attempting to nest, but this is not surprising as the island is only used as a feeding and roosting area for shore birds. Feeding and roosting are very low risk activities with respect to large predators such as foxes and dogs. Indeed, it was noted that near-by Winda Woppa, which has full access to a wide range of predators, is a much preferred habitat to Corrie Island. This suggests that predation is a natural facet of wild populations and that roosting and feeding birds have well developed strategies to cope with the presence of predators.

It was concluded that the limited access to Corrie Island by large predators is within natural limits and does not compromise its value as a shore-bird feeding and roosting area.

Tidal Movements

The following summary was provided by DECCW Coastal Branch (Martin Fitzhenry). It compares the results of the September 2009 tidal gauging (MHL 2010) with tidal flow data collected in 1977 (Public Works Department NSW 1978).

Table 13 Flow and Volume of water in Paddy Marr's Channel and Corrie Creek in 1977 and 2009

	Peak Flow (m^3/s)				Tidal Prisms (million m^3)			
	Flood		Ebb		Flood		Ebb	
	1977	2009	1977	2009	1977	2009	1977	2009
Paddy Marrs Channel	290	195	275	173	3.56	2.51	4.24	2.27
Corrie Creek	135	173	80	167	1.67	2.80	1.03	2.55

Tidal Range at 1977 ~1.3m, 2009 1.1m

Table 14 Ratio of Flow Volume in Paddy Marr's Channel to Corrie Creek, 1977 and 2009.

	Flood Tide	Ebb Tide
Ratio Paddy Marr: Corrie 1977	2.1	4.1
Ratio Paddy Marr: Corrie 2009	0.9	0.9

The 1977 gauging data shows that Paddy Marr's Channel provided over 4 times the ebb flow volume and over 2 times for the flood volume compared to the Corrie Creek (Tables 13 and 14). The 2009 results now show that the volume of water flowing in and out of each channel is around the same for a flood and ebb tide. While the flow distribution of the two channels has changed over the last 30 years, the combined ebb and flood volumes for both channels are still roughly the same. It should be noted that the accuracy of the 2009 discharge data is considered to be in the order of +/- 5%, while the accuracy of the 1977 data maybe up to +/- 50% due to the gauging equipment used and location of gauging lines.

It is assumed that the change in flow distribution follows a reduction in the tidal flow of Paddy Marr's Channel in recent times. The reduction in tidal flow in Paddy Marrs Channel is due to the formation and growth of a sand shoal on the eastern side (Winda Woppa) over the last 4 or so years, resulting in a constriction in the channel and a reduction in tidal flow.

Taking into account the conditions experienced during the 1977 and 2009 gaugings (ie tidal range and lake level) it can be concluded, that while the flow distribution of the two channels has changed, the tidal exchange or flushing characteristics for the lower Myall River is still roughly the same.

The conclusion that the change in flow distribution has not appreciably altered the size of tides in the Myall River is supported by the detailed analyses of tidal harmonics in Appendix 1. It was concluded that there has been no change in the amplitude (height) of the tide from 1996/7 to 2008/9, but that there has been a slight increase in the "lag" (i.e. the time taken for high tide to be reached in comparison to open ocean tides) of about 10 min. This was attributed to the increased distance that the majority of the tidal wave has to travel around Corrie Island due to shoaling of Paddy Marr's Channel.

Winda Woppa Beach Erosion

Myall River Action Group members have reported the possibility of a breach in Winda Woppa spit developing into a new channel. DECCW has inspected the site where shoreline erosion has occurred on Winda Woppa Beach a number of times in 2008, 2009 and most recently on 29 July 2010. Photographs illustrating the situation are included in Appendix 8, along with a time series of the shoreline position from 1979 to 2008.

Inspection shows that wave energy has focussed on the shore in one place and the subsequent shoreline recession has exposed the estuarine peat layer which was acting as a basement for the wave action that seemed to be focused in this area. The cause is unknown, but could be due to changes in the offshore shoal configuration or a slight decrease in the net longshore sediment supply from the updrift side (Bruce

Coates, DECCW, pers. com.). The erosion was not evident in the 2004 aerial image, but the shoreline was in approximately the current position by 2006 (plots in Appendix 8). Photos taken in 2008 (Appendix 8; G Grainger) show that an existing road was washed away and a relatively low level channel had developed into the mangrove area behind the berm which drains to river. This mangrove forest is composed primarily of *Avicennia marina*, with a littoral fringe of *Aegiceras corniculatum*. There is also a narrow fringe of saltmarsh, primarily *Sporobolus* sp and *Sarcocornia* sp. In July 2010 there was considerable longshore extension of the erosion to the west, but there was also now a low dune (which had just overtopped on the previous high tide (1.7m), very low swell). Inundation had been frequent enough to kill the vegetation on the berm (bitou and teatree). DECCW also observed that considerable amounts of sand had washed over the berm and had covered parts of the saltmarsh and had entered the mangrove forest.

There have been no data collected or investigations undertaken in this area, so any assessment of this situation is speculative. Phil Watson (DECCW Coastal specialist) offered the following opinion based on the information available:

"The specific area of interest … was never the focus of previous investigations or monitoring exercises. That said, there would appear little immediate likelihood of a breakthrough in the spit at this point due to a large storm. It is highly likely that the berm formation will continue to roll landward as part of the active profile migration whilst there are no unnatural impediments (protection works etc). There is limitless sediment in the active system readily available to feed the maintenance of a low barrier/berm system. Under continued landward migration there maybe a limiting point at which a small beach may occur and this should be monitored. The apparent dominance of coastal (wave) processes and active sediment transport in the vicinity of the area of interest would probably result in limited capacity for a breach to remain open due to the comparatively less dominant fluvial processes down the Myall behind the spit."

Table 14 Summary of Results from Bioassays for Estuary Health

Measures	Status that would suggest Myall was Impacted	Current Status of Myall River estuary
SYSTEM STRUCTURE		
Presence of healthy mangroves and seagrass	Absence of seagrass, mangrove or saltmarsh	All habitats present
Water Clarity	Water clarity reduced by obvious turbidity (suspended matter in water)	River experiences periods of tannin staining which is normal, but also experiences periods when it is affected by reductions in clarity due to suspended matter. Turbidity is within trigger values for NSW riverine estuaries.
Conductivity Myall lake water height	Low salinity after Bombah Broadwater returns to sea level.	Salinity drops when Bombah Broadwater fills and slowly drains. This is normal. Salinity returns to oceanic levels when Bombah reaches 0.1 m.
BIOLOGICAL STRUCTURE		
Stable extent of main macrophytes	Declines in abundance of seagrass, mangrove or saltmarsh	Seagrass shows some loss due to changing sand banks but occupies most suitable habitat. Mangroves and salt marsh increased in extent.
Algae (chlorophyll) in water	Chlorophyll concentrations greater than Trigger Levels – 2.3 – 3.2 ug/L	Median chlorophyll concentrations were below trigger values.
Surveys of crabs/crustaceans on intertidal flats	Abundances of ghost shrimp lower than control sites. Invertebrate biodiversity low.	Abundances of ghost shrimp were similar to Wallis lake and greater than other control locations. Invertebrate biodiversity was similar to Wallis Lake . The assemblage was similar, but not identical to Wallis, but differed from Pindimar and Salamander Bays.

Fish sampling	Fish biodiversity low. Fish abundances lower than controls.	Fish biodiversity and abundance were equivalent to control locations. Fish assemblages were similar to controls.
Community fish observations	Continued absence of large rays.	Rays were observed across a wide range of salinities and water clarity, though they were absent at low salinities and could not be seen in poor water clarity.
Bird surveys	Absence of common birds, abnormal numbers of swans.	The bird fauna of Myall/Corrie Winda Woppa is consistent with other parts of the Port and black swan numbers are normal.
ENERGY FLOW		
Leaf growth rates in seagrass	Productivity of Zostera leaves reduced in comparison to controls.	Productivity experiment did not work as expected. The amount of *Zostera* growing did not differ among estuaries.
Benthic Algae Sediment oxygen production	Sediments that consume more oxygen than they produce.	Winter rates were slightly negative and summer rates positive. This pattern is within the normal range.
Algae on seagrass and mangroves	Excessive amounts of algae growing on mangrove roots.	Algal growth on artificial mangrove roots was similar to controls and lower than Pindimar Bay.
	Excessive amounts of algae growing on seagrass fronds.	Algal growth on seagrass fronds was similar to controls and lower than Wallis Lake.
Microbial Decomposition	Decomposition of seagrass leaves lower than controls..	Tissue loss at Myall River did not differ from Wallis Lake and Salamander Bay, but was less than Pindimar Bay.
Micro-carnivore Scavengers	Consumption of baits by micro-carnivores different	Consumption of baits was high at Myall River, indicating a healthy and active invertebrate assemblage. This is a new area of research and we assume that high

	from controls.	rates are good.
Macro-carnivore Scavengers	Consumption of baits by micro-carnivores different from controls.	Consumption of baits was high at Myall River, indicating a healthy and active fish assemblage. This is a new area of research and we assume that high rates are good.
BIOLOGICAL STRESS		
Frequency of ulcers in fish	Proportion of fish with ulcers greater in Myall River.	No ulcers were found.
Leaf damage in mangroves	Higher rates of leaf damage in Myall River.	Proportions of whole leaves did not differ among estuaries.
Parasites in mangroves	Higher rates of parasitism in Myall river	No parasitism

Conclusions

The main driver for this study was a perception that changes to the patterns of water flow through the two entrance channels had led to a reduction in water quality and hence a reduction in the ecological condition or “health” of the Myall estuary.

The scientific literature has no consensus on what exactly constitutes ecological health, nor on how to measure it. However, many established methods are available to measure various components of ‘ecological health’. As noted in the introduction, the local community have provided some feedback on what they consider is a healthy estuary, they highlighted:

- Waters that rapidly clear after rainfall
- Evidence of juvenile fish, toads and rays in shallows
- Recreational fish captures
- Evidence of crabs/crustaceans on intertidal flats
- Lack of stress related disease (red spot) in fish
- Appropriate birds in the estuary
- Minimal amounts of seagrass wrack moving on the tides

These issues contain one causal factor (waters that clear rapidly) and a range of biological responses.

In order to address these concerns, we need to look at the physical driving mechanisms that structure the river (tides, floods, habitats), the intermediate effects on water characteristics (clarity, salinity) and the ultimate biological responses.

The means to look at the driving mechanisms and water quality are well established and well defined. MHL (2010) examined the volume and velocity of the tidal flow through the two entrance channels and use those data to calculate the relative flows and total river volume exchanged on each tide. These were compared to previous data. In this study, we used the fixed water level and salinity loggers to search for any changes in the behaviour of tides (the tidal height and timing).

Water characteristics were examined by using the fixed loggers to construct time series of salinity and community groups monitored river water clarity to match with these data. We also used the information from the height and salinity loggers to look at the effects of discharge from the Myall Lakes on river water characteristics.

Because approaches for assessment of ecological condition or health are less well established we have addressed this question using a broad a range of methods. These methods examine structure and function of the river ecosystems.

As is common in these types of study, there is no one measure that provides the definitive answer, so we rely on what is known as a “weight of evidence” approach. This is based on the concept that if most or all measures are all saying pretty much the same thing, then it is reasonable to conclude that the direction indicated is the correct answer.

So, what was found?

It is clear that the Paddy Marr’s Channel is providing less water on each tidal exchange than it used to (2009 vs 1977). The Corrie Creek Channel is now carrying relatively more water than in 1977. In Sept 2009, approximately equal volumes came in through the two channels. It is also clear that the total volume exchanged on a tide has NOT changed, nor has the height that is reached by each tide. The tidal lag is slightly longer (10 min) due to a greater proportion of the tidal volume having to travel via Corrie Creek Channel. This all means that the connection with the open waters of Port Stephens is NOT choked or blocked, but that the relative influence of the two channels HAS changed, from a dominance through Paddy Marr’s to equal contribution from the two channels.

Water characteristics in the lower Myall River were influenced by flow from the Myall Lakes when the lake water height was greater than 0.1 m. At other times, water characteristics were dominated by tidal input. When the lakes were high (> 0.5m AHD) salinity was consistently low and water clarity poor. Outflow from the lakes after a large event can last for up to 3 months and the rate of outflow has not changed. When the lakes were only moderately elevated (0.5 – 0.1 m AHD), and when tides dominated, clarity was variable, sometimes good, sometimes poor and salinity was mostly only low on the ebb tide. Clarity (secchi disk depth) was consistently greater on high tides than low tides, indicating the presence of clearer Port waters on the flood tide. Water colour (tannin) was not a good indicator of low clarity as there are plenty of occasions where the water was highly coloured but clear. Turbidity was occasionally obvious. There is no obvious explanation for the cause of the turbidity. NSW has guidelines for turbidity and whenever it was measured directly it complied with these guidelines. Whilst there are no previous studies to compare river salinity or clarity with, there is no evidence to suggest that they have changed as a result of the changed tidal flow. This study can not answer the question of whether the increased exchange through Corrie Creek Channel could result in river water from the previous ebb tide being brought back in on the next flood tide (rather than clearer Port waters) thus increasing the time taken for the river to clear after rain. This question will need to be addressed by a Hydrodynamic Modelling study.

Assessment of the ecological health of the estuary was the primary focus of this study. All the indicators of estuary health were positive in summer 09-10 (Table 14). Habitat was present and diverse, there were possibly some losses of seagrass (but mapping error could account for these), but mangrove and saltmarsh extent had increased slightly. Biodiversity and abundances of fish and invertebrates were similar to comparable estuaries. Energy flow through the systems was high in Myall River and indicators of biological stress were low. All in all, these measures indicate that ecological condition was excellent, and uniformly as good as other similar estuarine locations which do not have the issues that are perceived to impact on Myall River. The weight of evidence is overwhelming that Myall River ecological health is NOT POORER than comparable estuaries.

How can these results be aligned with the community's concerns?

Table 15 Addressing Community Concerns

Community Concern	Findings
Waters that rapidly clear after rainfall	There is no evidence to suggest that there has been any change to the rate at which waters clear, though this needs to be tested further with a hydrologic model. There are times when water clarity is poor, but the cause is not known.
Evidence of juvenile fish, toads and rays in shallows	Fish sampling shows that the fish populations and biodiversity is equivalent to other comparable estuaries. The number of rays is lower when the waters are fresh, but this is a function of lake outflow not entrance condition.
Recreational fish captures	No data were collected.
Evidence of crabs/crustaceans on intertidal flats	Invertebrate sampling shows that the crab and nipper populations and general

	biodiversity is equivalent to other comparable estuaries.
Lack of stress related disease (red spot) in fish	No red spot was seen in fish sampled for this study.
Appropriate birds in the estuary	The bird populations have not changed since the entrance began to shoal. It is clear that swans have always been present and their presence is not an indicator of poor health.
Minimal amounts of seagrass wrack moving on the tides	No data were collected. Seagrass wrack is a natural phenomenon and is greatest in late summer and autumn when *Zostera* plants shed their leaves.

Summary

The proportion of tidal exchange in the two channels has changed from a strong dominance (by volume) in Paddy Marrs Channel to a slight dominance of ebb tide flows through the Corrie Creek Channel and in flood flows through Paddy Marrs Channel. Water clarity is reduced at times, although this is common in NSW estuaries and within State benchmarks for riverine estuaries. The reduced clarity occurred most often at lower tidal levels and is most likely a consequence of the increased proportion of flow in the Corrie Island channel, with a resultant increased exchange with Pindimar Bay rather than the outer basin of Port Stephens. This issue will be addressed in the concurrent sediment hydrodynamic assessment being prepared by BMT WBM.

Extended periods of low salinity water in the estuary were shown to be entirely a consequence of extended periods of outflow of “stored” fresh water from the Myall Broadwater, and that the rate of this outflow has not altered as the entrance has changed.

Despite these changes to flow, ecological health in the river is excellent and equivalent to other comparable estuarine locations that have not experienced changed entrance conditions. Fish and invertebrate biodiversity and plant communities were consistent with other sites. The rates of important ecological processes such as algal growth, bacterial breakdown of seagrass leaves, energy consumption by fish and invertebrates and herbivory on mangrove leaves were all consistent with other healthy estuaries (see Table below).

These results clearly do not support the community perception that periods of slightly reduced water clarity or salinity – whether a result of changed entrance conditions or not – are having a detrimental effect on the river's ecology.

It could be argued that the periods of poorer clarity constitute an aesthetic concern and impact on economic values through changes in the perceptions of tourists. This may be a valid argument, but is a separate issue and has not been addressed here.

What is very clear is that the two arguments should not confused. Whatever the merits of concern about aesthetics or economics, this study provides no basis for claiming that changes to the river mouth channels are impacting on the estuarine ecology.

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Appendix 1 – Sampling Locations

Invertebrate Flats	Lat	Long
MRF1Invert	-32.663502	152.162
MRF2 Invert	-32.6703	152.168
MRF3 invert	-32.672798	152.172
MRF4 Invert	-32.6768	152.166
PSSF1 Invert	-32.687698	152.075
PSSF2 Invert	-32.680801	152.063
PSSF3 Invert	-32.727901	152.097
PSSF4 Invert	-32.727299	152.101
WLF1 Invert	-32.181599	152.492
WLF2	-32.183201	152.506
WLF3	-32.181599	152.480
WLF4	-32.181999	152.484

Seagrass Growth Quadrat Sites	Lat	Long
WLQ1	-32.186401	152.479
WLQ2	-32.1786	152.48
WLQ3	-32.182701	152.506
MRQ1	-32.670502	152.16901
MRQ2	-32.671902	152.172
MRQ3	-32.676601	152.15401
PSSQ1	-32.687698	152.076
PSSQ2	-32.726501	152.09801
PSSQ3	-32.7271	152.10001
PBQ1	-32.662498	152.123
PBQ2	-32.672798	152.11501
PBQ3	-32.675098	152.11501

Algae Growth Sites Seagrass	Lat	Long
WLAG2	-32.176201	152.468
WLAG1	-32.178299	152.48
WLAG3	-32.1856	152.478
MRAG1	-32.676601	152.15401
MRAG2	-32.673	152.17101
MRAG3	-32.669498	152.17
PBAG1	-32.672199	152.11501
PBAG2	-32.6665	152.121
PBAG3	-32.6647	152.125
PSSAG1	-32.689899	152.082
PSSAG2	-32.7271	152.092
PSSAG3	-32.726398	152.09801

Fish survey sites	Lat	Long
MRB2fish	-32.6759	152.167
MRB4 fish	-32.6768	152.154
MRB6 fish	-32.6641	152.162
MRV1 fish	-32.672	152.172
MRV3 Fish	-32.6779	152.162
MRV5 Fish	-32.669	152.169
PBB1 Fish	-32.6769	152.115
PBB3 Fish	-32.6623	152.125
PBB6 Fish	-32.6639	152.126
PBV2 Fish	-32.6724	152.115
PBV5 Fish	-32.6616	152.121
PBV4 Fish	-32.6639	152.122
WLB4 Fish	-32.1811	152.484
WLB5 Fish	-32.1811	152.492
WLB6 Fish	-32.1809	152.48
WLV1 Fish	-32.1761	152.468
WLV2 Fish	-32.1865	152.479
WLV3 Fish	-32.1783	152.481

Algae Growth Sites Pneumatophores	Lat	Long
PSSAGP3	-32.7281	152.098
PSSAGP2	-32.7281	152.093
PSSAGP1	-32.6883	152.081
PBAGP1	-32.6763	152.114
PBAGP2	-32.6647	152.119
PBAGP3	-32.6637	152.126
MRAGP1	-32.6768	152.154
MRAGP2	-32.6732	152.172
MRAGP3	-32.6692	152.17
WLAGP1	-32.1783	152.48
WLAGP2	-32.1763	152.468
WLAGP3	-32.1856	152.478

MR - Myall River
PB - Pindimar Bay
PSS - Salamander bay
WL - Wallis Lake
V - vegetated (fish)
B - bare (fish)
F – flat (invertebrates);
AG - algal growth - seagrass
AGP – algal growth - pneumatophores
Q – seagrass growth

Appendix 2 – Tidal and Catchment Influences on the Myall River

The characteristics of the Myall River depend on both tidal and catchment events and processes. In conjunction with these, the changing entrance conditions of the Myall River is expected to influence both of these drivers on the river. Using the extensive data sets collected at different sites including Bulahdelah, Bombah Point and specific limited period data collection exercises done since the 1980s, the relative characteristics can be described.

Tidal Analysis

Tidal Harmonic Analysis is a very useful tool to look at the tidal characteristics of an estuary system. Tidal Harmonic Analysis breaks down the signal into base components that are the direct result of the major astronomical drivers of tides. In any tidal record on the NSW coast, the major tidal constituents due to the moon and sun are known as the M2, S2, K1 and O1 constituents. The method calculates the amplitudes and the relative phasing of these constituents that are present in the recorded water level. In a full tidal analysis, up to around 60 constituents can be calculated. However there are constraints limiting which constituents can be calculated due to the record length analysed.

The results presented are based on the analysis of 4 weeks of continuous water level record, but repeated on a weekly basis through the whole record. In the case of the Myall River, the M2 constituent is the dominant constituent being at least two times larger then all the others. The M2 constituent represents the tidal component that is directly generated by the moon. The phasing of the M2 constituent indicates the tidal lag of the tidal wave as it propagates up the river. By also running a simultaneous tidal analysis for the Middle Head water level data from Sydney Harbour , comparisons of the Myall River analyses results can be referenced to typical ocean response. The simultaneous results allows the variations that occur in the natural system (represented by an ocean gauge) to be removed from the comparison.

Harmonics analysis was undertaken on the water level records available for Monkey Jacket (1996/8, 2001 and 2008) and for Tea Gardens (2009/10). Figure 1 shows the analyses results for Monkey Jacket. The figure shows the analysis results for data consisting of approximately 3 years of data spread over nearly 15 years. The 2001 data was recorded as part of the bathymetry survey and only covers a relatively short period of less then 2 months. The figure shows the individual results for the main constituents for both Monkey Jacket and Sydney, the fraction of the Monkey jacket M2 result compared to Sydney, and the tidal lag in minutes calculated from the phase difference between Sydney and Monkey Jacket. As well, the water level for Bombah Point is plotted.

This figure shows there is significant variation in the M2 tidal response at Monkey Jacket over the full record. There is no discernible trend over the analysis period with the M2 amplitude approximately 75% of the Sydney value. However for the calculated lag, there is a marked variation of around 20% total through the 1996/7 records and an increase of around 10% from the 2008 records. The end of the 2008 records sees an appreciable increase. This 2008 response is most probably due to the changes occurring at the entrance. Even though there is an increase in the lag, at the same time there is minimal change in the M2 Amplitude relative to Sydney.

An interesting feature of the plots is the significant dip in the M2 ratio in 1997, which also corresponds to a decrease in the tidal lag. This is due to the increased water levels in Myall Lakes represented by at Bombah Point gauge. The elevated water level (peaking at 0.8m AHD) produces a fresh flow down the Myall River which directly impacts on the tidal penetration at Monkey Jacket, resulting in a decrease of around 15% in the tidal amplitude. The reduction in the lag over this period suggest that the entrance went through a period of scour due to the flood, which reduced the time for the tidal wave to propagate into the river. However it quickly returned to the conditions that existed before the event.

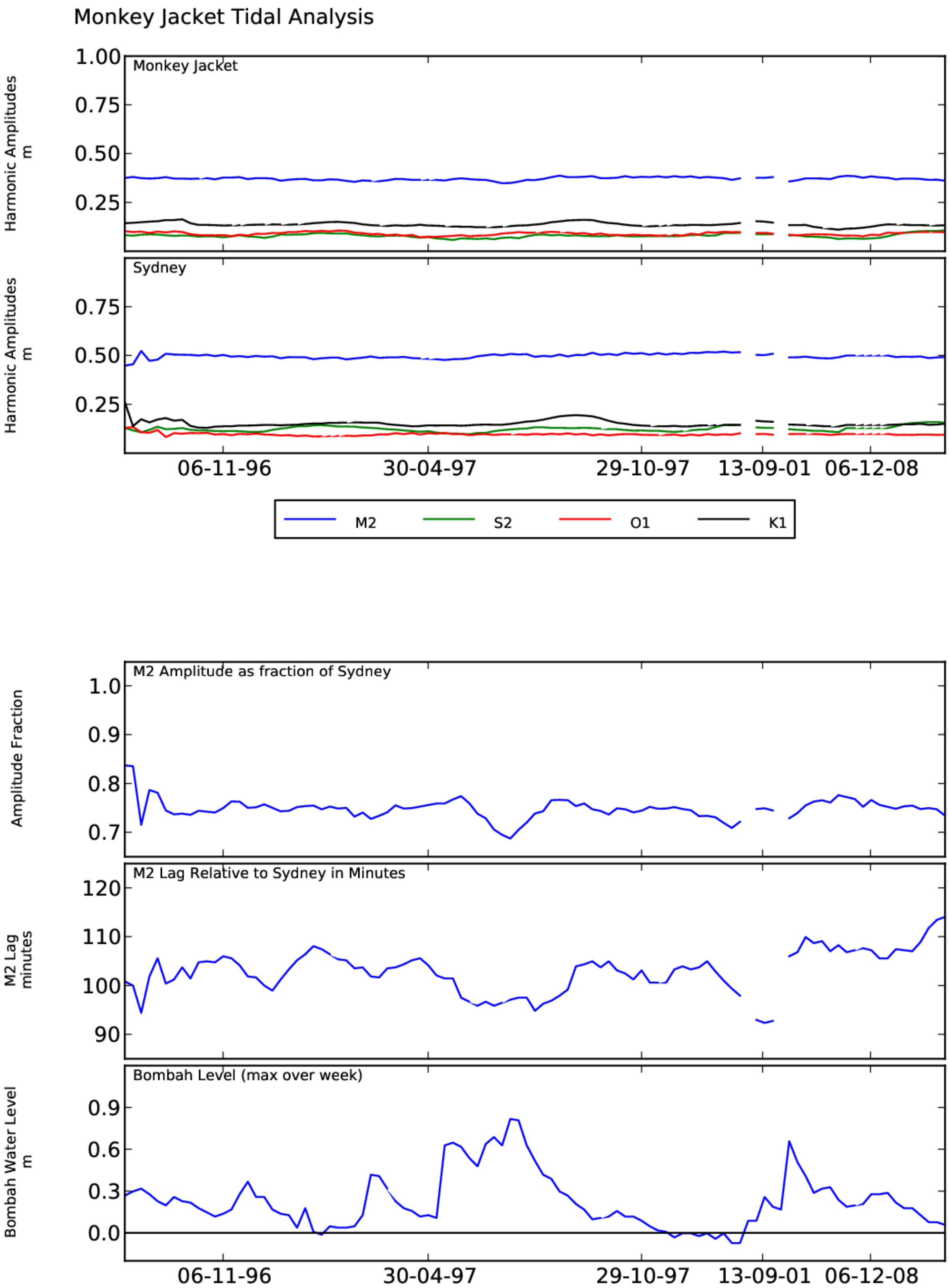


Figure 1: Harmonic Analysis Results for Monkey Jacket

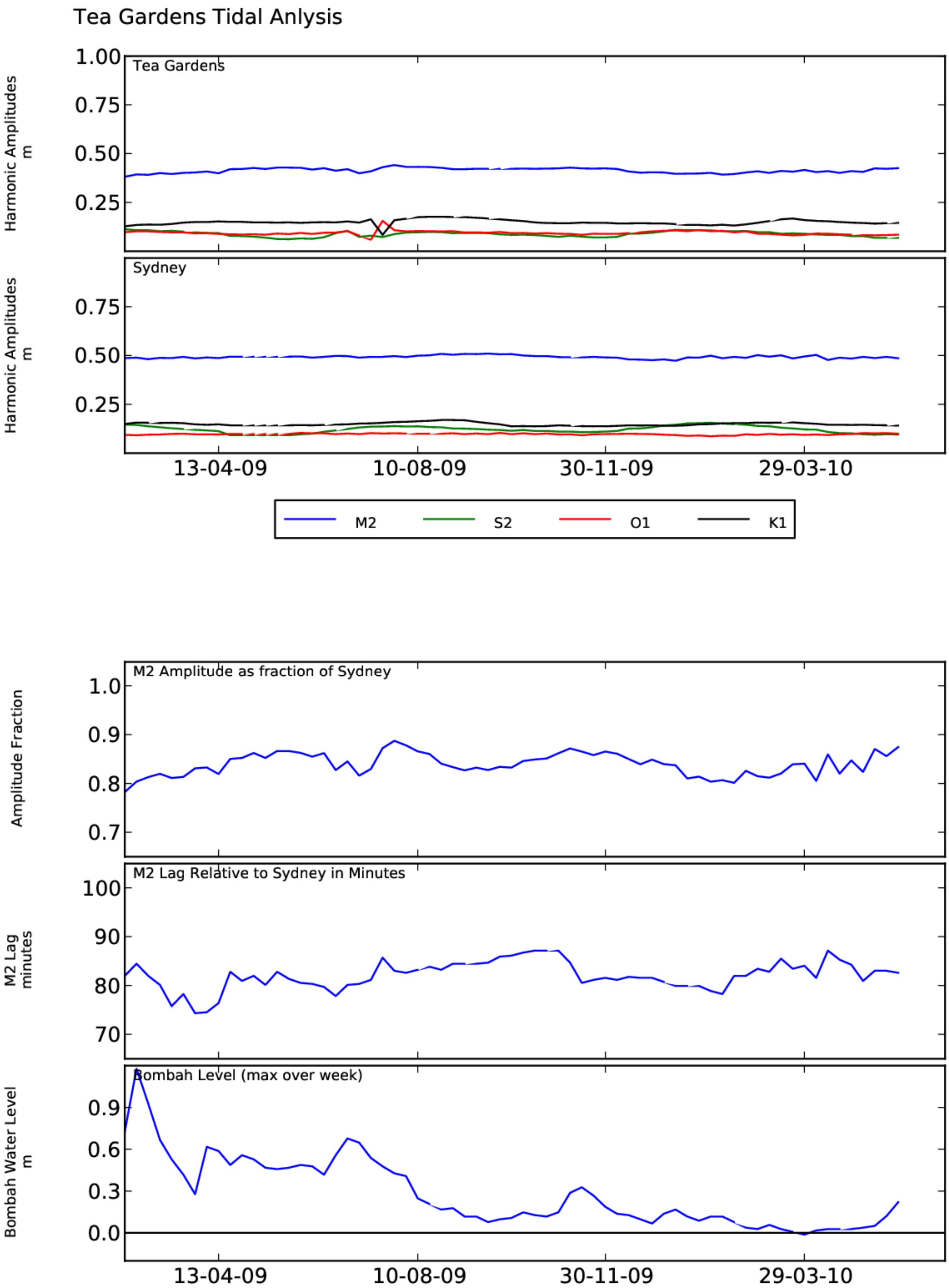


Figure 2: Harmonic Analysis for Tea Gardens

The same technique is used to look at the Tea Gardens water level data recorded since January 2009. The results are shown in Figure 3, with the first analysis centred on mid February. Again there is significant variation in both the M2 value and the tidal lag relative to Sydney over the whole record of approximately 18 months. The M2 and the tidal lag results show relatively constant behaviour over the time period. Possibly the M2 ratio has a small increasing trend over the time. At the beginning of this analysis period, an event caused significant lake water levels, peaking at nearly 1m AHD. Over the rest of the analysis period, the lakes water level is predominantly dropping with the occasional 'topup' due to catchment run off. The lakes have stayed above the long term tidal level for the duration of these records. The slow drop off in the lake water level corresponds with the very slight increase in relative M2 response. There also appears to be a slight increase in the lag over the period. This increase appears to be linked to the shoaling entrance conditions.

Comparing the Monkey jacket and Tea Gardens results is difficult due the different locations of the sites. Monkey Jacket and Tea Gardens are respectively approximately 7.6km and 4.2km upstream from what is considered the tidal origin on the front of the middle ground shoal. This is the location where it would be expected to still experience a full ocean tide. On this basis the M2 tidal results fit a linear relation between the 2 sites. However such a simple relation is not applicable for tidal lag as the relationship is a function of the tidal wave speed which is a non-linear function of depth, in combination with side effects due to the inter-tidal flats. Also the influence of the shallow entrance shoals has a marked impact on the initial tidal lags.

An explanation of the tidal responses seen over the 15 years period of data would be in the long term the Corrie Island east channel has been slowly shoaling, possibly due to a more hydraulically efficient development of the Corrie Island west channel. This would explain the increased M2 response over time, with a corresponding increase in tidal lag. Tidal lag will increase due the increased distance that the tidal wave has to travel around Corrie Island. Those increases are small though, in the order of only approximately 10 minutes

This type of analysis cannot be done for the lake water level records, as the tidal range is only of the order of 1cm. Such a small tidal signal is easily swamped by any wind or catchment event.

Lower Myall River Salinity and the Lakes

Tea Gardens salinity is influenced marked by the lakes water level. The lakes water level directly influences flow in the lower Myall River. When elevated above the ‘normal’ tidal level, there is a flow produced down the Myall as the system tries to reach its stable level.

When the water level is elevated, water level records show that the water level drops at rates around 1 to 2cm/day. This is equates to 11 and 22m^3/s respectively, or around 50% of typical tidal flow into and out of the lakes. This flow will restrict tidal penetration up the river and push the saline water downstream under these conditions. It is not just a mixing process diluting the saline waters but elevated lake water levels pushes the saline waters out of the upstream parts of the river system. How far it manages to do this depends on the length of time that the elevated water conditions exist. The longer the time the further downstream the saline waters are moved.

When the water level is below this stable level, as occurs under dry, hot conditions due to evaporation, the lakes effectively 'suck' water up the lower Myall River, again trying to reach that stable level. In this later case, with 3mm/day (expected NSW east coast) evaporation, the lakes need a compensatory flow of 3.5m^3/s balance the evaporation. Tidal gauging at Tamboy shows that a peak tidal flow of around 50m^3/s occurs which also equates to a 1cm tidal range in the lakes. Therefore evaporation can generate a upstream flow that is about 7% of the tidal current at the upper end of the lower Myall River. This increased flow upstream will help ocean saline water to move further up the river under these conditions.

An explanation of a site's salinity/conductivity variability due to catchment flow can be made referring to Figure 4. The blue line represents the salinity at the end of flood tide flow, whilst the green line represents the salinity at the end of the ebb flow. Generally there is about a 5km difference in their positions in an estuary system when the system is tidally dominant. Considering Site A in the figure which is closer to the entrance, under normal flow its recorded salinity is high, and its variation between flood and ebb is low. Under high catchment flows, its highest salinity is still near the ocean value but its variation over the tide is much bigger. This occurs because the fresh flow in the system effectively pushes the saline water downstream (if not completely out of the estuary for a limited time). Considering Site B, a different situation occurs. At normal flows, its has a large variation in the flood and ebb values with neither showing dominant marine or fresh characteristics. However under high catchment flows, the variation drops and all values are closer to fresh.

Using conductivity as a salinity indicator, Figures 4 to 6 show the relationships at Monkey Jacket and Tea Gardens based on recorded water levels at Bombah Point. A conductivity value of 53mS/cm is approximately equivalent to ocean salinity, and zero is fresh water. These plots are based on a reduction of the full data set. The Bombah water level, due to its fairly slow rate of change is reduced to the daily water level at midnight each day, and the conductivities plotted are the minimum and maximum over the preceding 24 hours.

All these figures show that higher Bombah water levels results in lower conductivities. At the same time though, reasonably high conductivities can also be recorded. This is the result of the flood and ebb tide. The flood tide can still bring in higher conductive marine water despite low values on the ebb tide. Low Bombah water levels (values less then 0.1m AHD) will generally result in high conductivities above 40mS/cm and during these periods, the differences between minimum and maximum values are low around 10mS/cm. It is also noticeable that the variation between maximums and minimums at a particular water level varies considerably between the years. This can be attributed to the varying lake water level conditions during each of the instrument deployments.

The following table presents the Mean and RMS (root-mean-square) values for the Bombah water levels over the deployment periods. The RMS value is relative to zero water level (the assumed 'n tidal level).

	Mean Level	**RMS Level**
Monkey Jacket 1996/8	0.143	0.249
Monkey Jacket 2008	0.276	0.378
Tea Gardens 2009/10	0.222	0.316

These values show that the lake conditions were significantly more elevated during the Monkey Jacket 2008 deployment. This is also reflected in the figures – where the maximum overall conductivities are lower, especially for the higher water levels. The large spread of conductivity values for a specific water level shows that the salinity front is oscillating through that deployment site, depending on the tidal conditions. Here neither tide nor catchment flows dominates the salinity.

The water level where the minimum conductivity variation drops with increasing water level is around 0.20m for both Monkey Jacket deployments, and around 0.55m for Tea Gardens. This lake level is indicative of where catchment flows begins to dominate the ebb flow processes. There is still a significant tidal flood flow impact on all of the sites, as represented by the maximum conductivities recorded, but significant mixing is taking place. During the 2008 and 2009 deployments both sites did experience the situation where the maximum conductivity does not rise above 10mS/cm. The lakes had to be above the 1m level for this to occur. Even under these conditions, Tea Gardens sees a maximum conductivity around 2 times that of Monkey Jacket, which is a location based characteristic.

During 2008, the Monkey Jacket site shows a marked decrease in maximum conductivity recorded for lake levels below 1.0m. This is most probably due the near continuously elevated lake levels, represented by the RMS lake level value, significantly reducing the flood tide upstream penetration against the downstream catchment flow. The difference between the Monkey Jacket 1996 and 2008 deployments shows that this is not just site related but also catchment run off related.

A major difficulty with salinity monitoring at a fixed site is that the recorded values are a function of where the salinity limit is located longitudinally in the system, which itself is dependant on the flow rate out of the lakes as well as the duration of that flow. The previous section indicates that the flow rate due to lake elevation appears to relatively constant for this system, hence the duration of that flow is major influence on location of the salinity limit. However higher lake levels will produce longer flow durations.

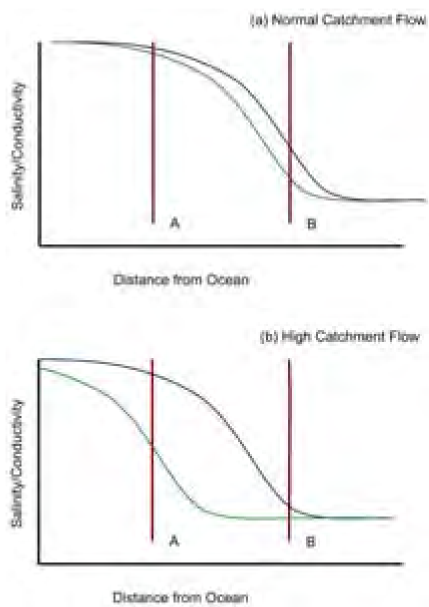


Figure 3: Effect of Catchment Flow on Longitudinal Salinity

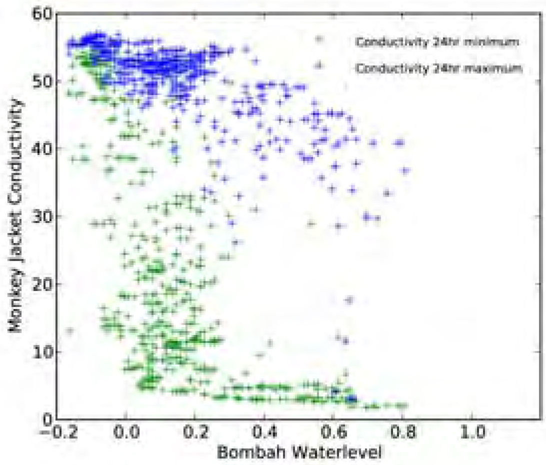


Figure 4: Conductivity vs Water Level - Monkey Jacket 1996/8

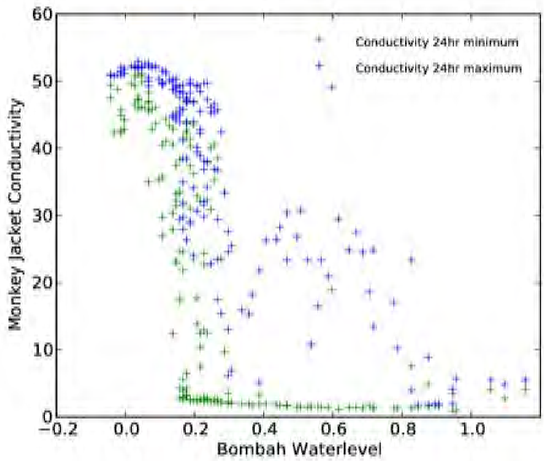


Figure 5: Conductivity vs Water Level - Monkey Jacket 2008

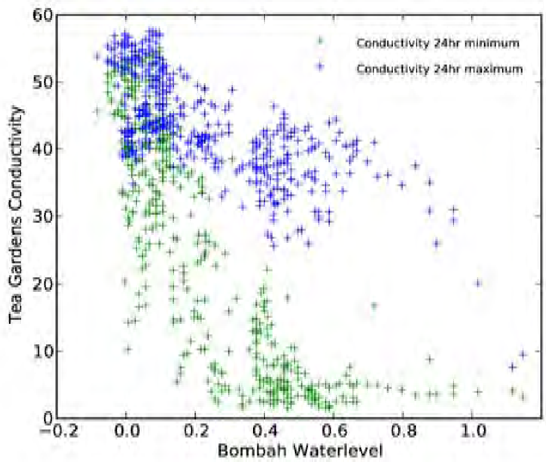


Figure 6: Conductivity vs Water Level – Tea Gardens 2009

Longterm Characteristics of Lake Levels

Are the monitoring deployments typical in terms of the lakes' water level behaviour? The Bombah Point water level and conductivity records are relatively short term, becoming a permanent recorder only in 2001. However Bulahdelah water level recorder has been installed since 1984, providing nearly 35 years of data. Figure 9 shows that except for the relatively short time period extreme flood levels, Bulahdelah follows the Bombah Point recorded levels very well. There using the Bulahdelah recorded levels, it is possible to construct water level exceedence plots.

Figures 8 and 9 show exceedence relations calculated from the Bulahdelah data. Figure 11 shows that in particular amongst the deployment periods, 2008 showed marked higher water levels then the other deployment years. However compared to the whole data set, the 2008 results were exceeded in the years 1990, 1999 and 2001. 1999 and 2001 relate to the period where longterm inundation in the lakes fringes created safety issues with Paper Bark Trees in the camping areas. Compared to the average exceedence conditions, 2008 has water levels approximately 0.1m higher for the same exceedences, which when compared against average water levels during the instrument deployments of around 0.2m is significant.

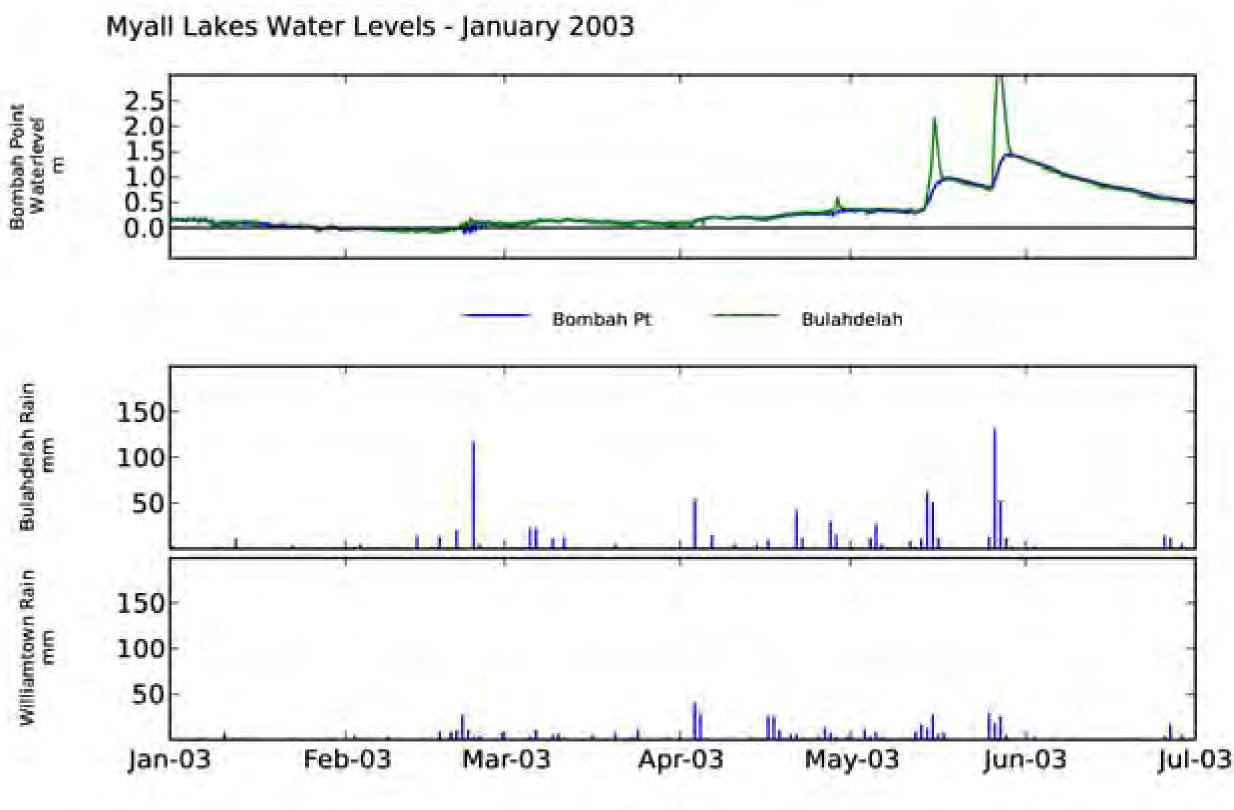


Figure 7: Example Bombah - Bulahdelah Water Level Relationship

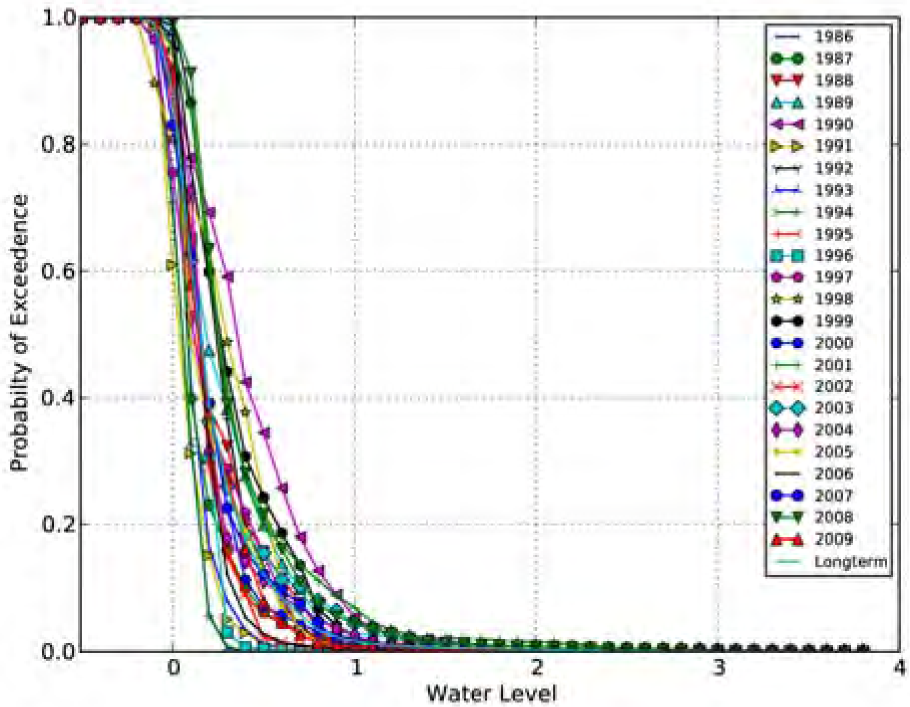


Figure 8: Bullahdelah Exceedence for All Data

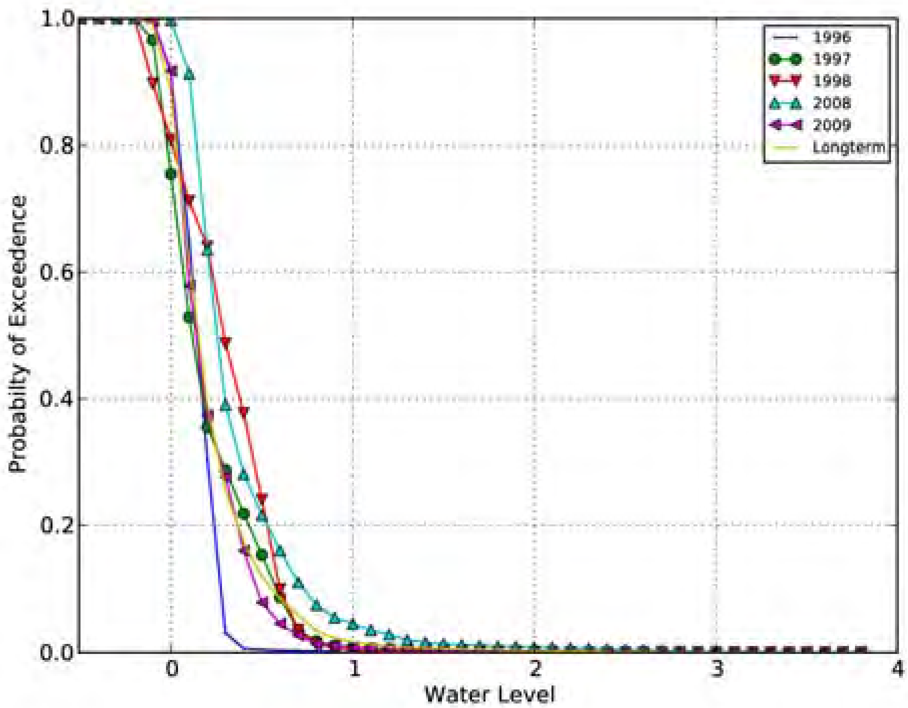


Figure 9: Bulahdelah Exceedence for Deployment Periods

Lake Levels Relationship to Recorded Rainfall.

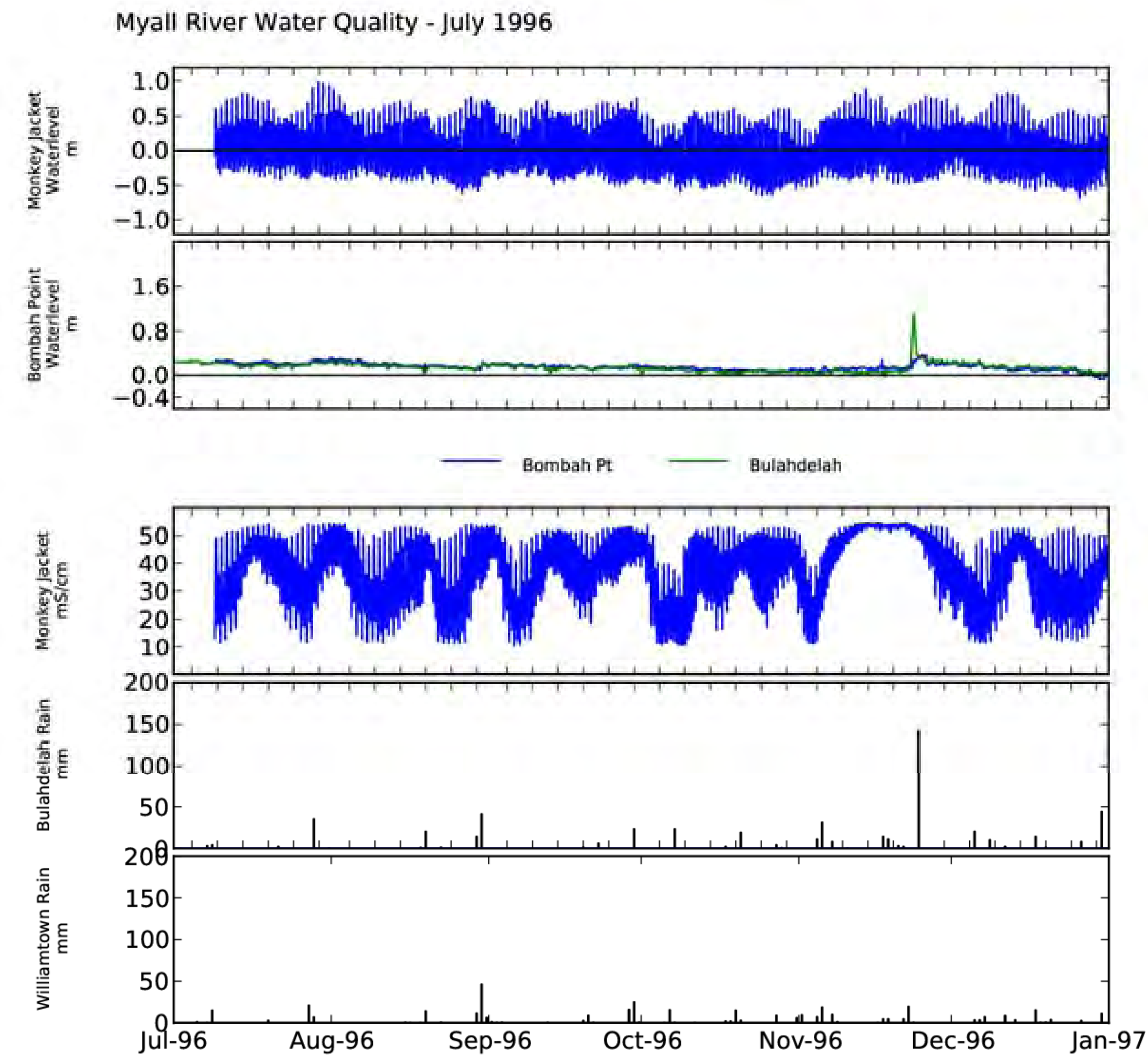
This distribution of rainfall across the catchment is difficult to quantify. There is evidence that the spatial variability of rainfall can be large. For example Figure 9 above shows that similar rainfall events recorded at Bulahdelah can result in negligible change in lake level (March 2003) or significant lake level increase (June 2003). Bulahdelah was believed originally to represent the major catchment of the Lakes. In most cases this appears true but other cases show that the lakes respond to rainfall recorded at Williamtown, when little or no rain was recorded at Bulahdelah, or even more local rainfall events that neither site records. It is beyond the scope of this study to determine the rainfall-runoff characteristics of the catchment.

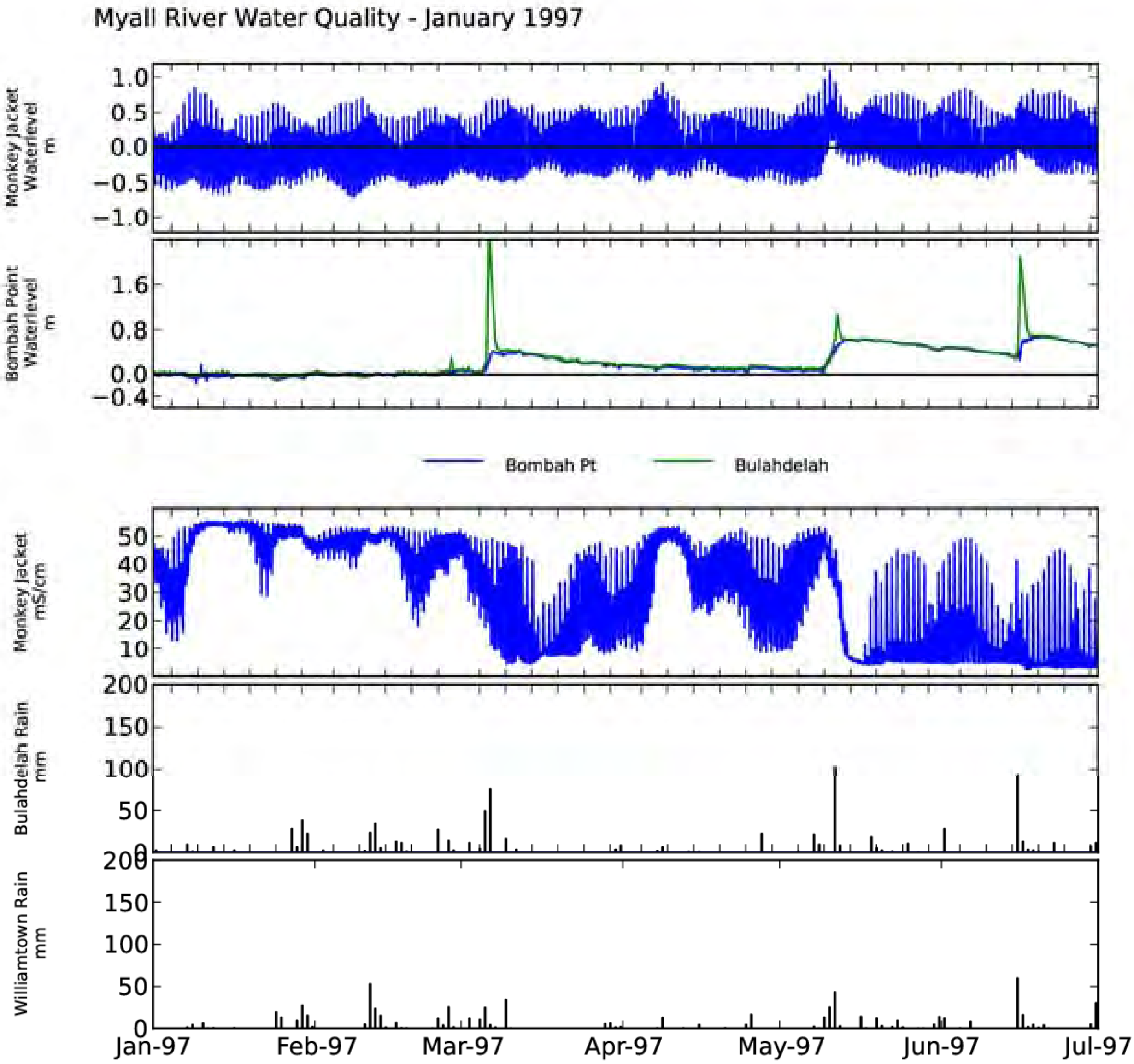
Appendix

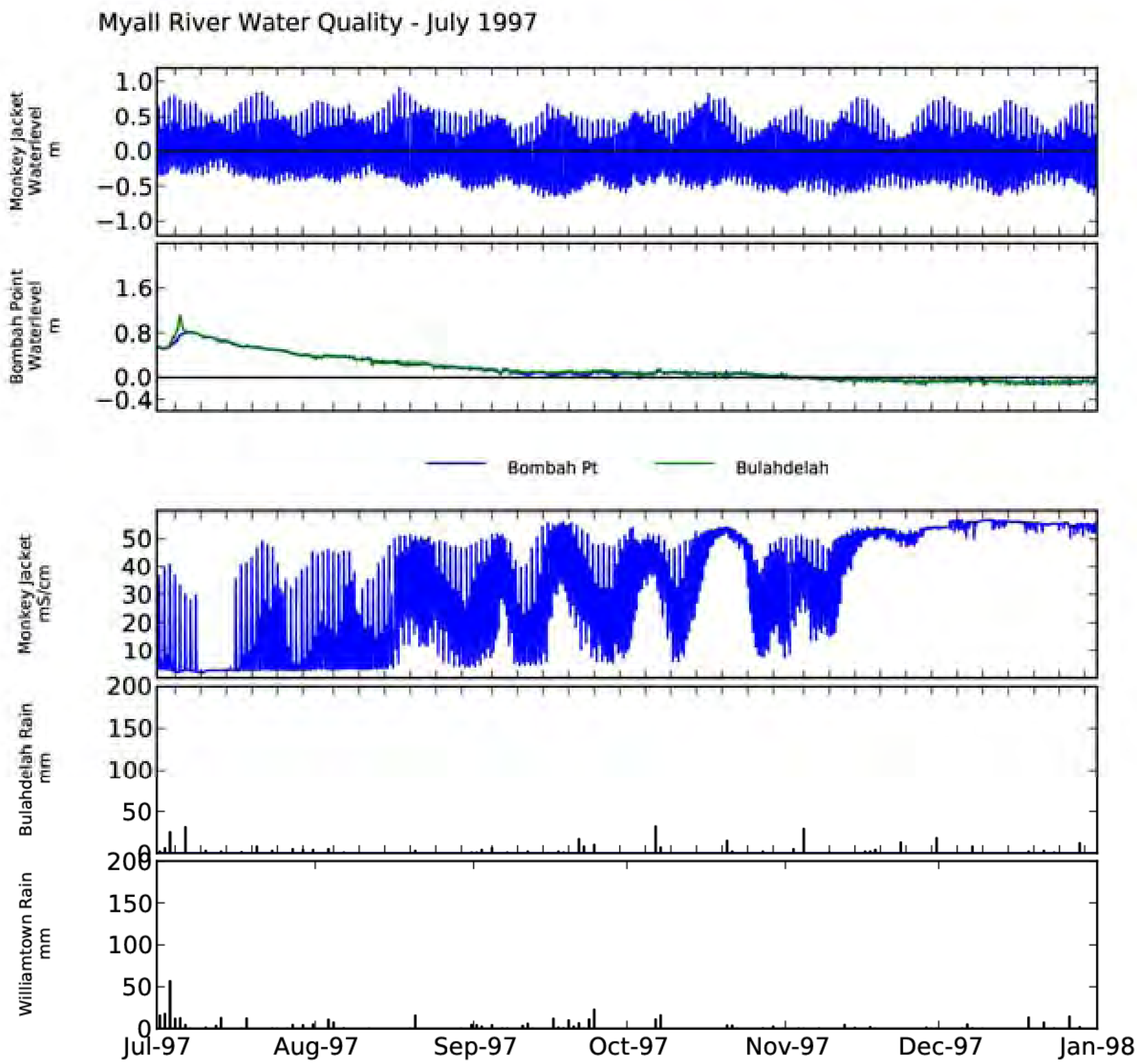
Plots of Historical Myall River Conductivity Data

Monkey Jacket	July 1996 to March 1998
Monkey Jacket	September 2008 to February 2009
Tea Gardens	February 2009 to June 2010

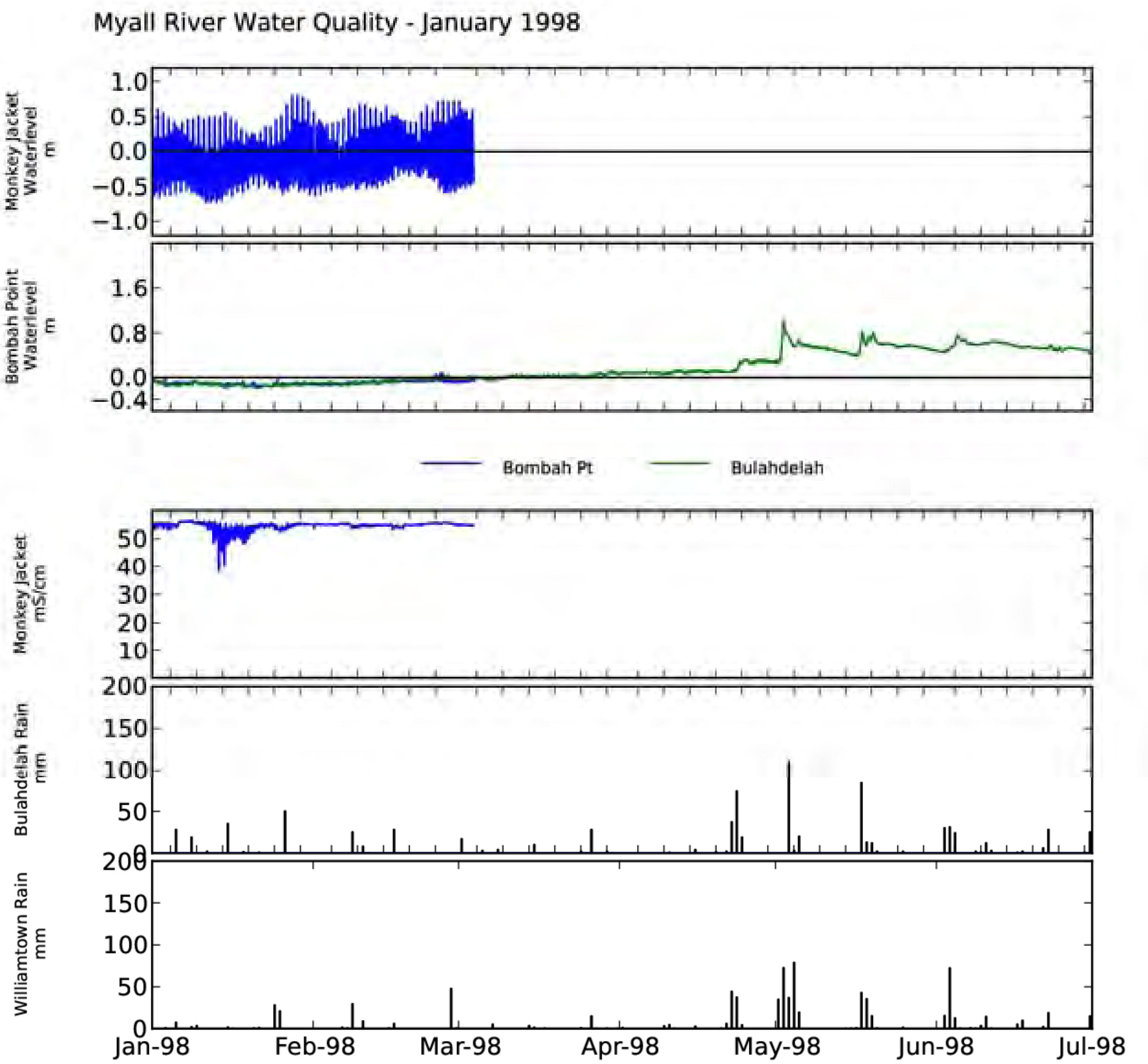
Plots include recorded Bombah and Bulahdelah Water Level, the relevant site Water Level and Conductivity and Bulahdelah and Williamtown BOM Rainfall.

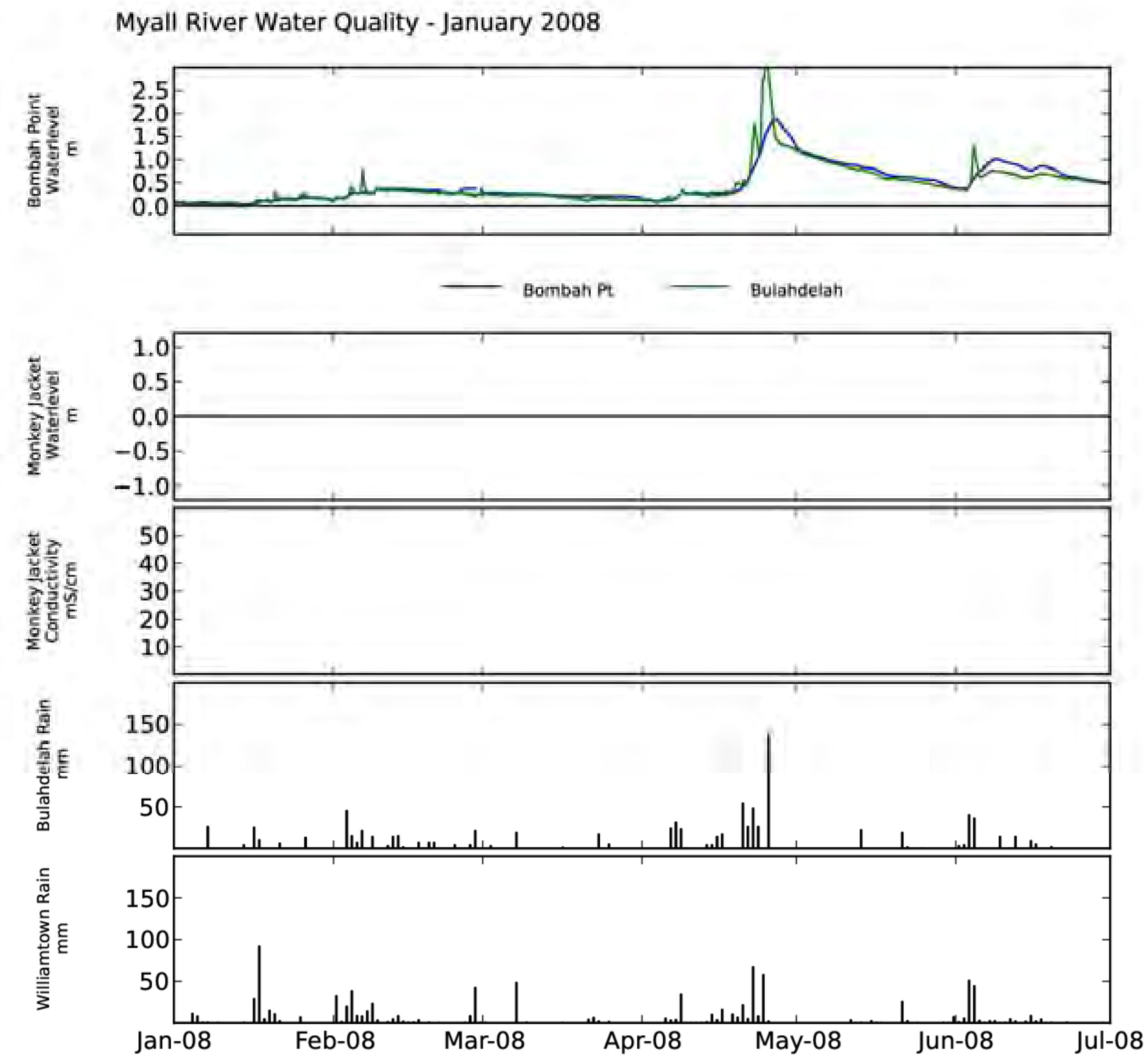

Myall River Water Quality - July 1996
Monkey Jacket Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Bombah Point Waterlevel m
1.6
0.8
0.0
−0.4
Bombah Pt
Bulahdelah
Monkey Jacket mS/cm
50
40
30
20
10
Bulahdelah Rain mm
200
150
100
50
0
Williamtown Rain mm
200
150
100
50
0
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Jan-97

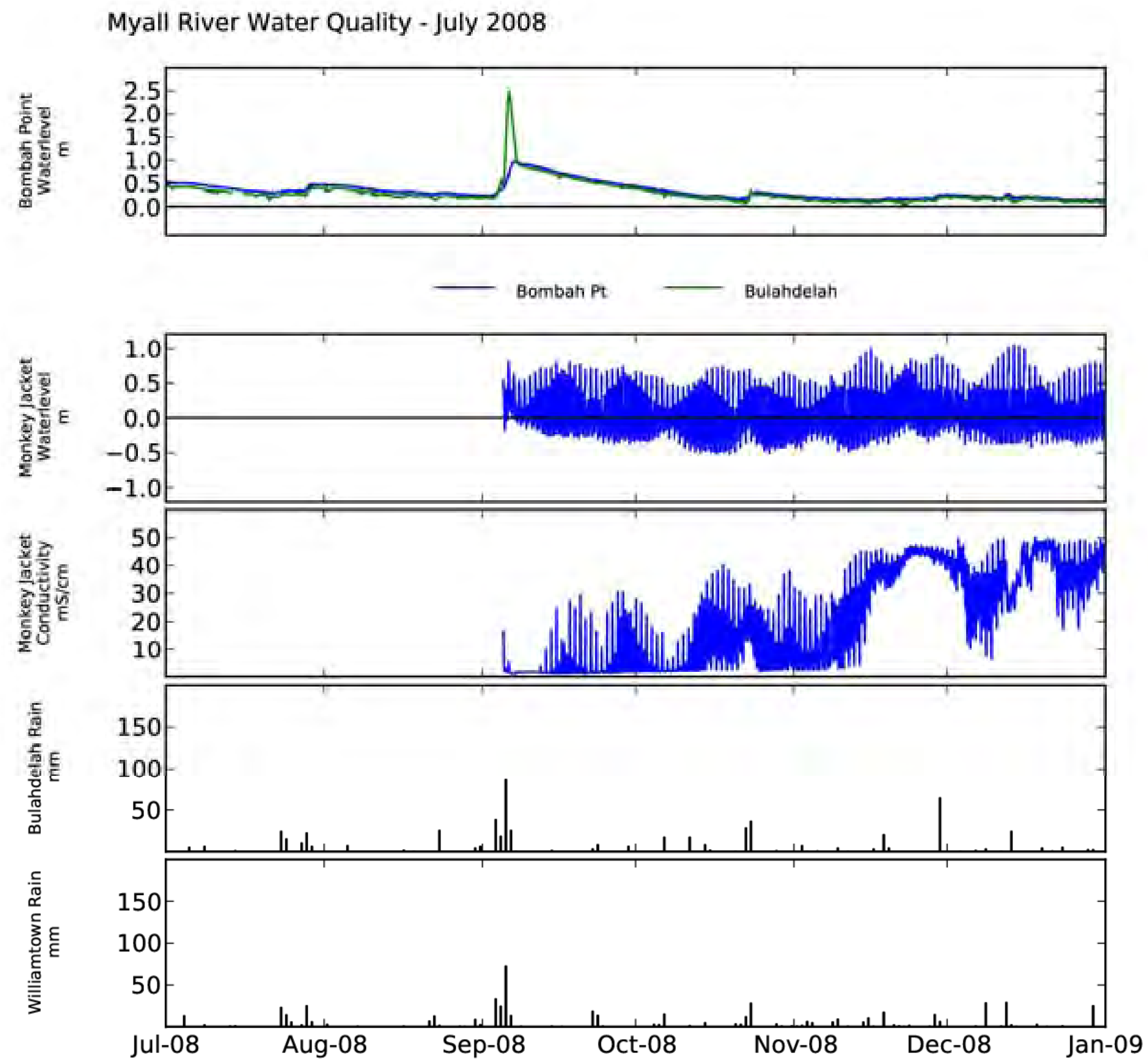

Myall River Water Quality - January 1997
Monkey Jacket Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Bombah Point Waterlevel m
1.6
0.8
0.0
−0.4
Bombah Pt
Bulahdelah
Monkey Jacket mS/cm
50
40
30
20
10
Bulahdelah Rain mm
200
150
100
50
0
Williamtown Rain mm
200
150
100
50
0
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97

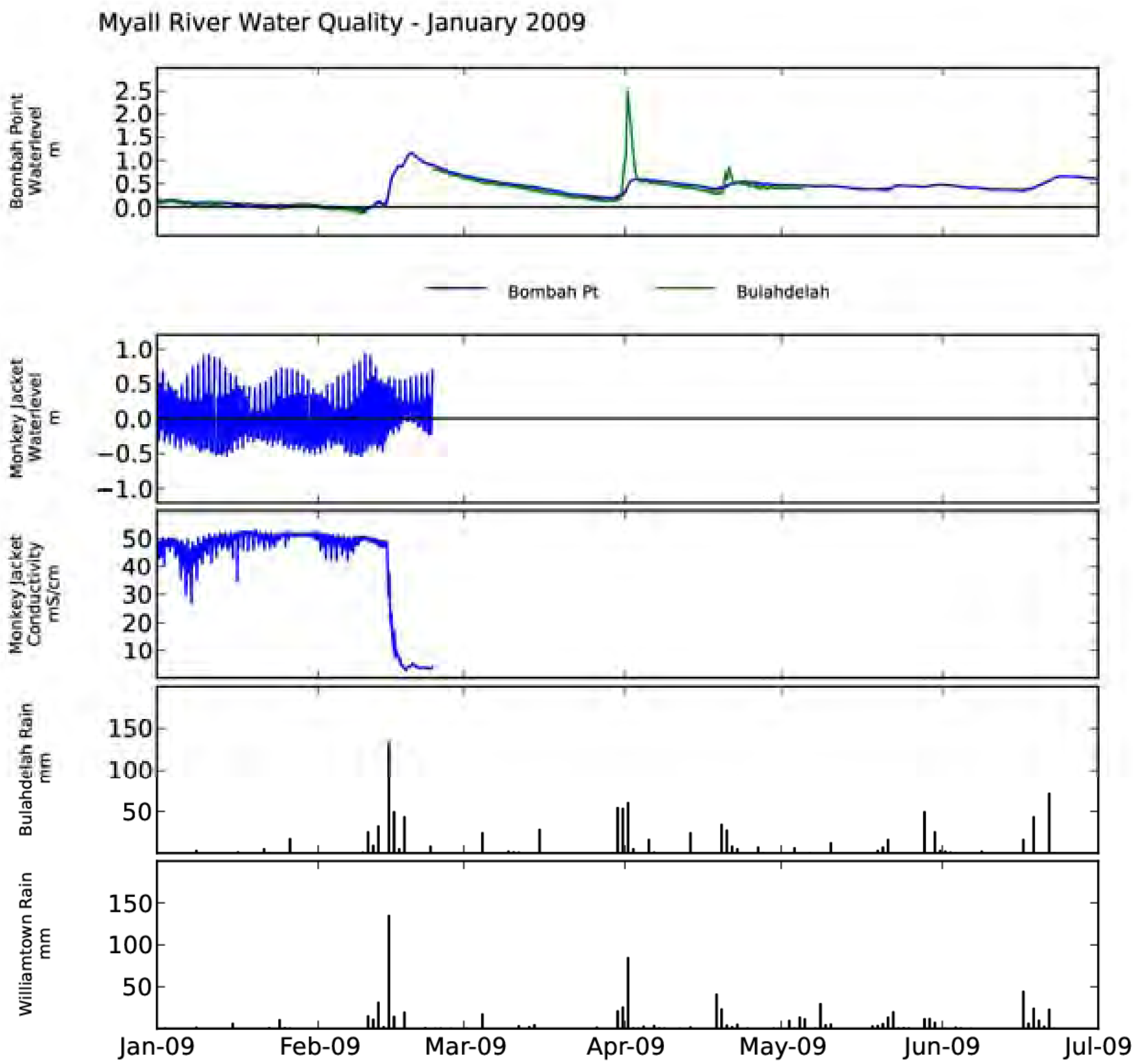


Myall River Water Quality - July 1997
Monkey Jacket Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Bombah Point Waterlevel m
1.6
0.8
0.0
−0.4
Bombah Pt
Bulahdelah
Monkey Jacket mS/cm
50
40
30
20
10
Bulahdelah Rain mm
200
150
100
50
0
Williamtown Rain mm
200
150
100
50
0
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
Jan-98

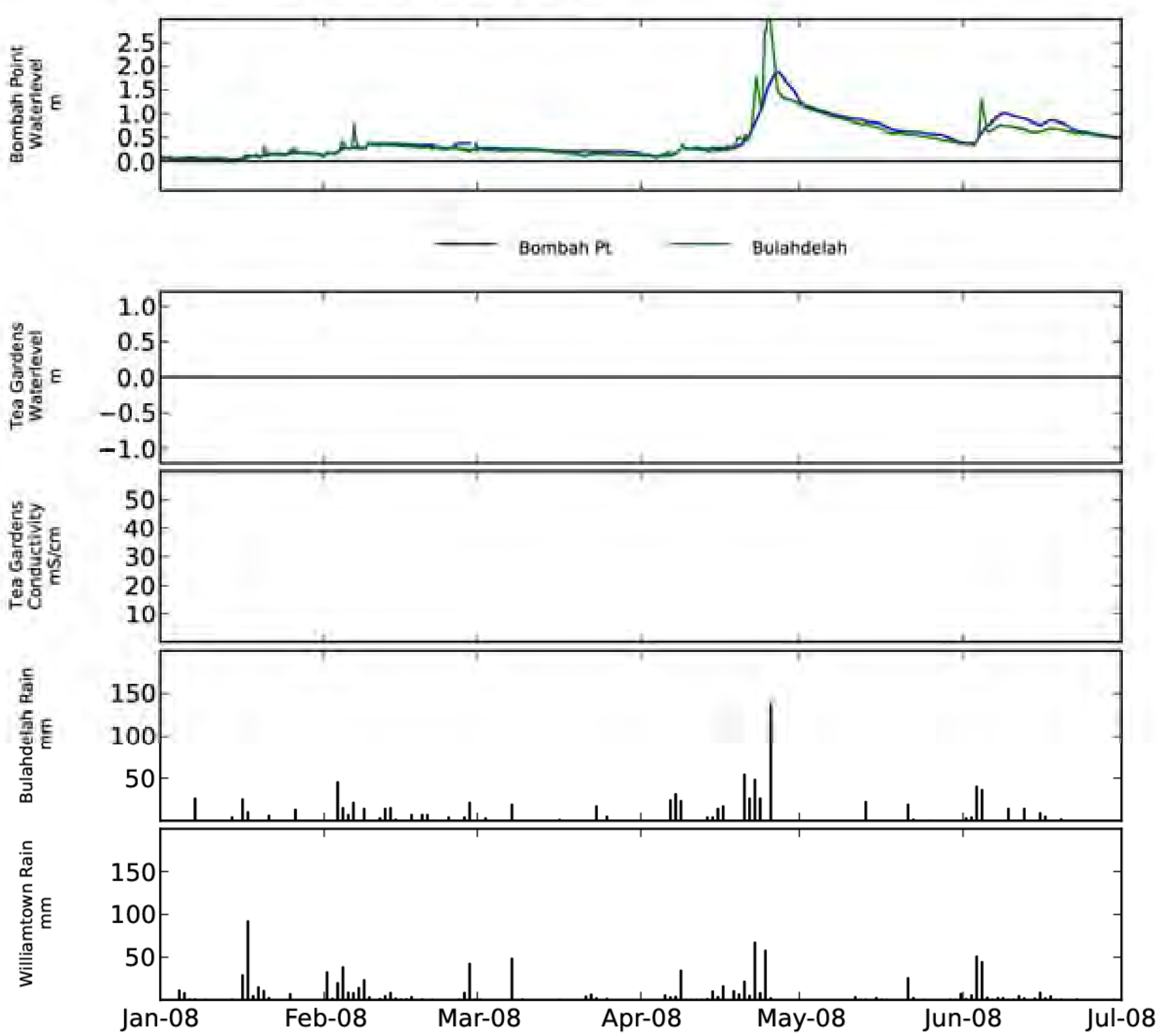

Myall River Water Quality - January 1998
Monkey Jacket Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Bombah Point Waterlevel m
1.6
0.8
0.0
−0.4
Bombah Pt
Bulahdelah
Monkey Jacket mS/cm
50
40
30
20
10
Bulahdelah Rain mm
200
150
100
50
0
Williamtown Rain mm
200
150
100
50
0
Jan-98
Feb-98
Mar-98
Apr-98
May-98
Jun-98
Jul-98

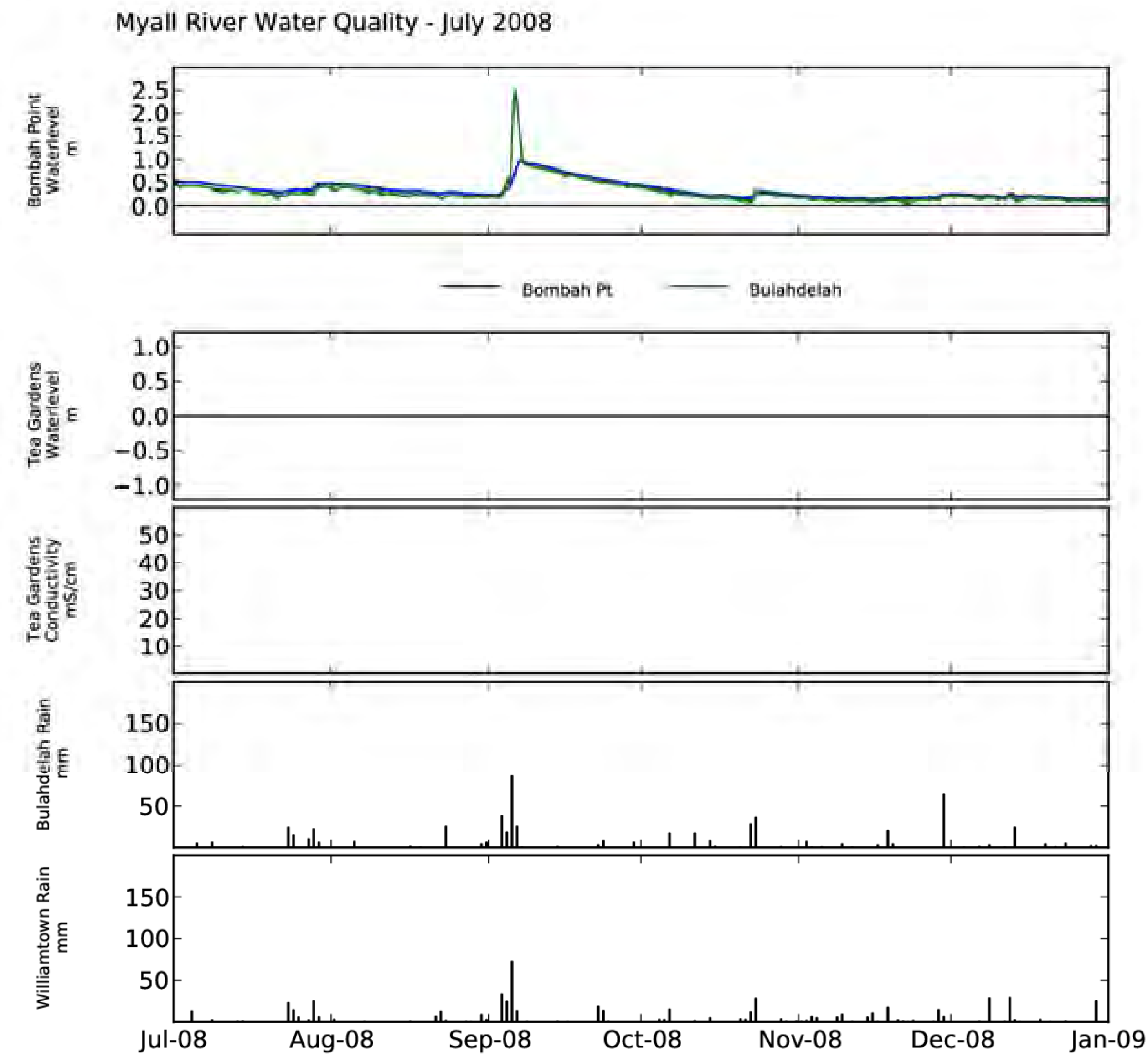

Myall River Water Quality - January 2008
Bombah Point Waterlevel m
Bombah Pt
Bulahdelah
Monkey Jacket Waterlevel m
Monkey Jacket Conductivity mS/cm
Bulahdelah Rain mm
Williamtown Rain mm
Jan-08
Feb-08
Mar-08
Apr-08
May-08
Jun-08
Jul-08

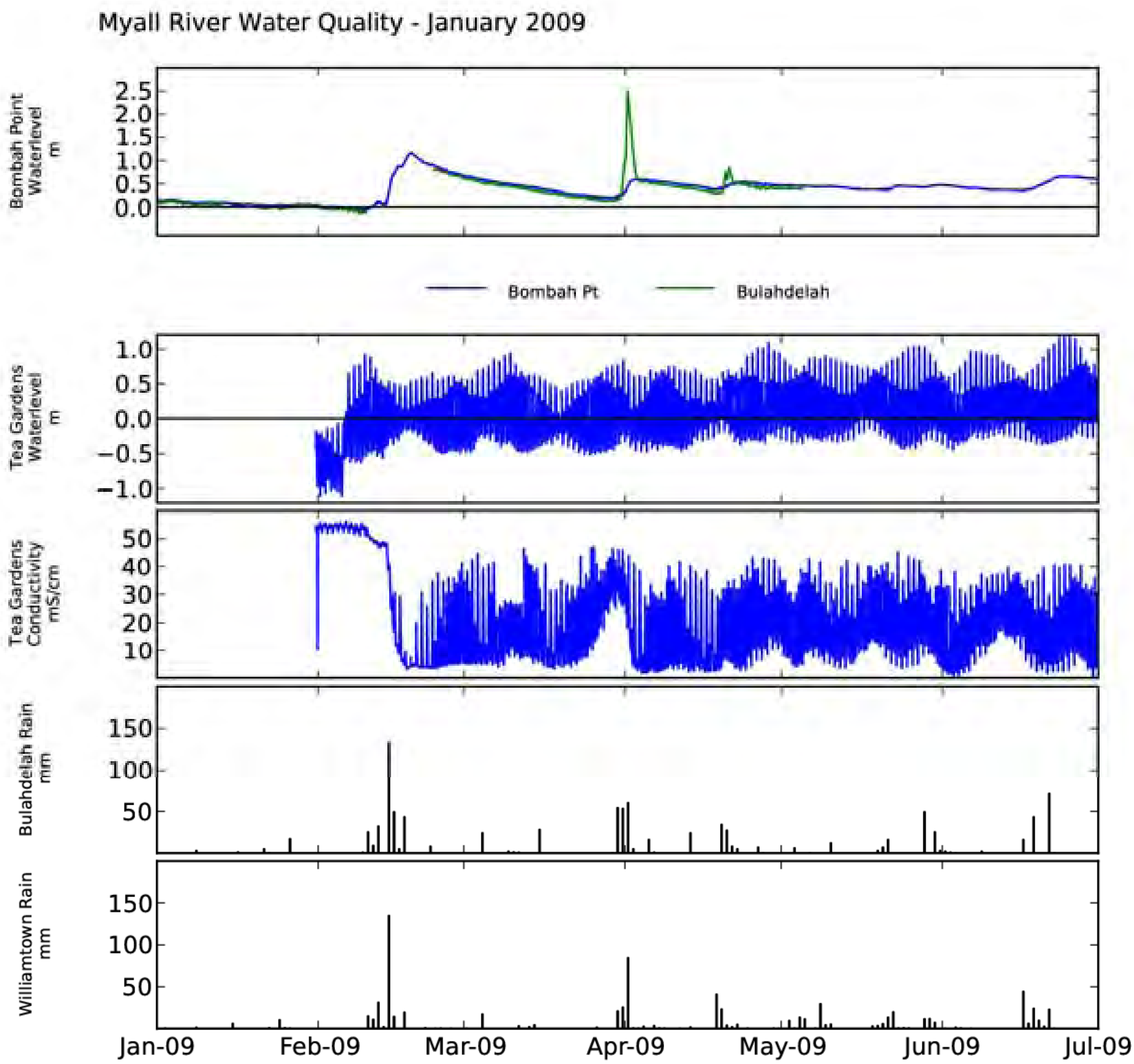

Myall River Water Quality - July 2008
Bombah Point Waterlevel m
2.5
2.0
1.5
1.0
0.5
0.0
Bombah Pt
Bulahdelah
Monkey Jacket Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Monkey Jacket Conductivity mS/cm
50
40
30
20
10
Bulahdelah Rain mm
150
100
50
Williamtown Rain mm
150
100
50
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09

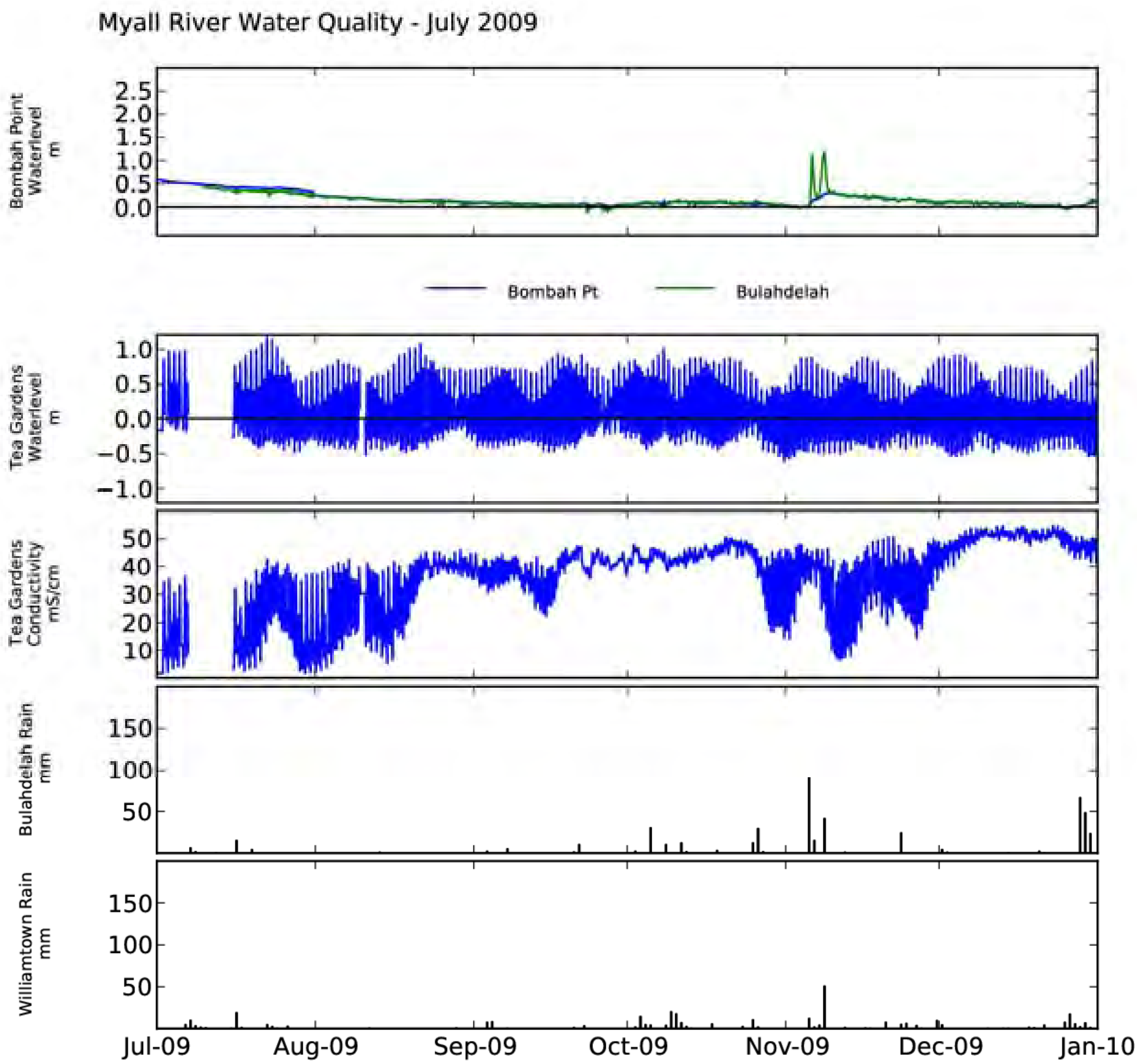

Myall River Water Quality - January 2009
Bombah Point Waterlevel m
2.5
2.0
1.5
1.0
0.5
0.0
Bombah Pt
Bulahdelah
Monkey Jacket Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Monkey Jacket Conductivity mS/cm
50
40
30
20
10
Bulahdelah Rain mm
150
100
50
Williamtown Rain mm
150
100
50
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09

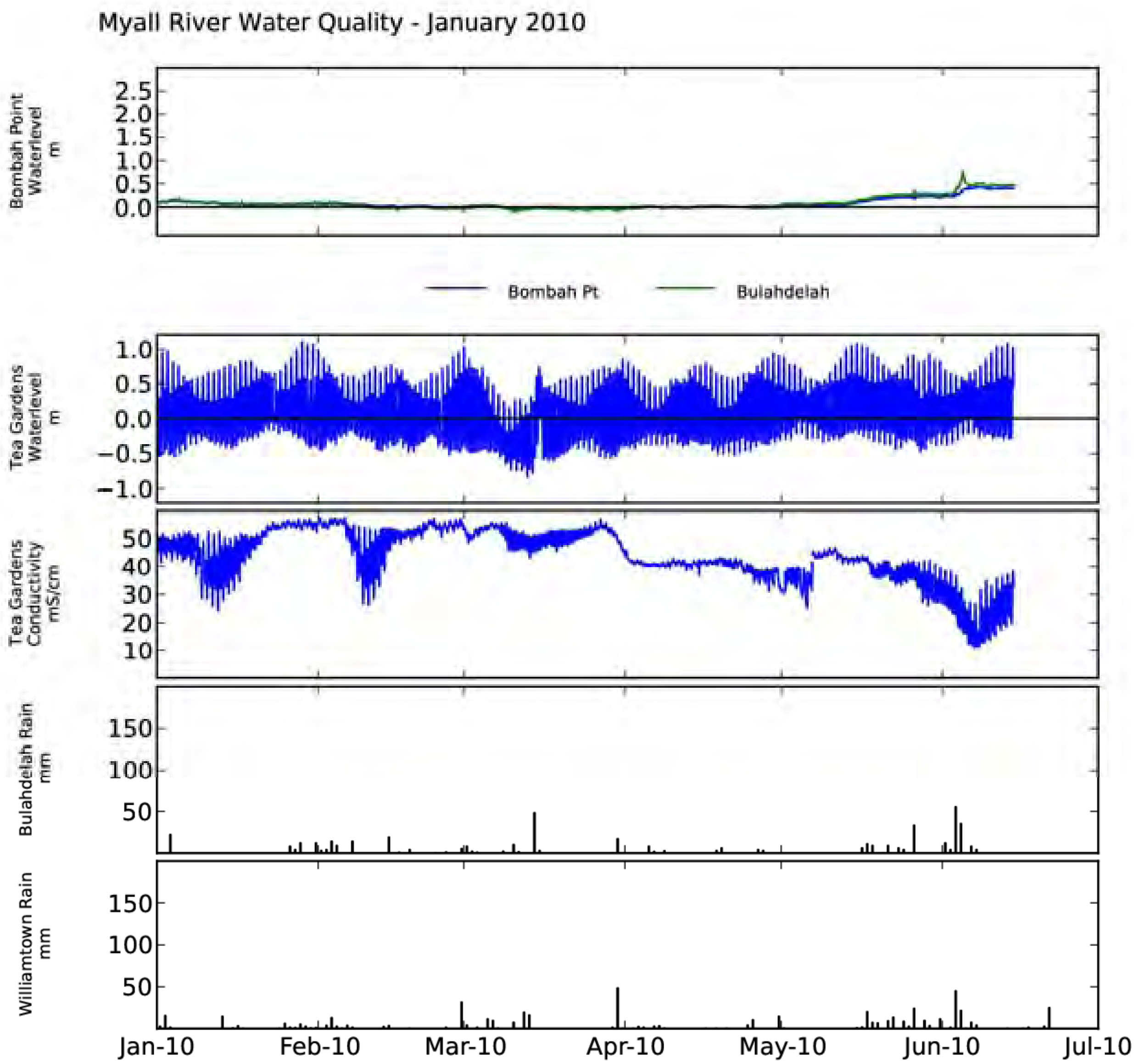
Myall River Water Quality - January 2008



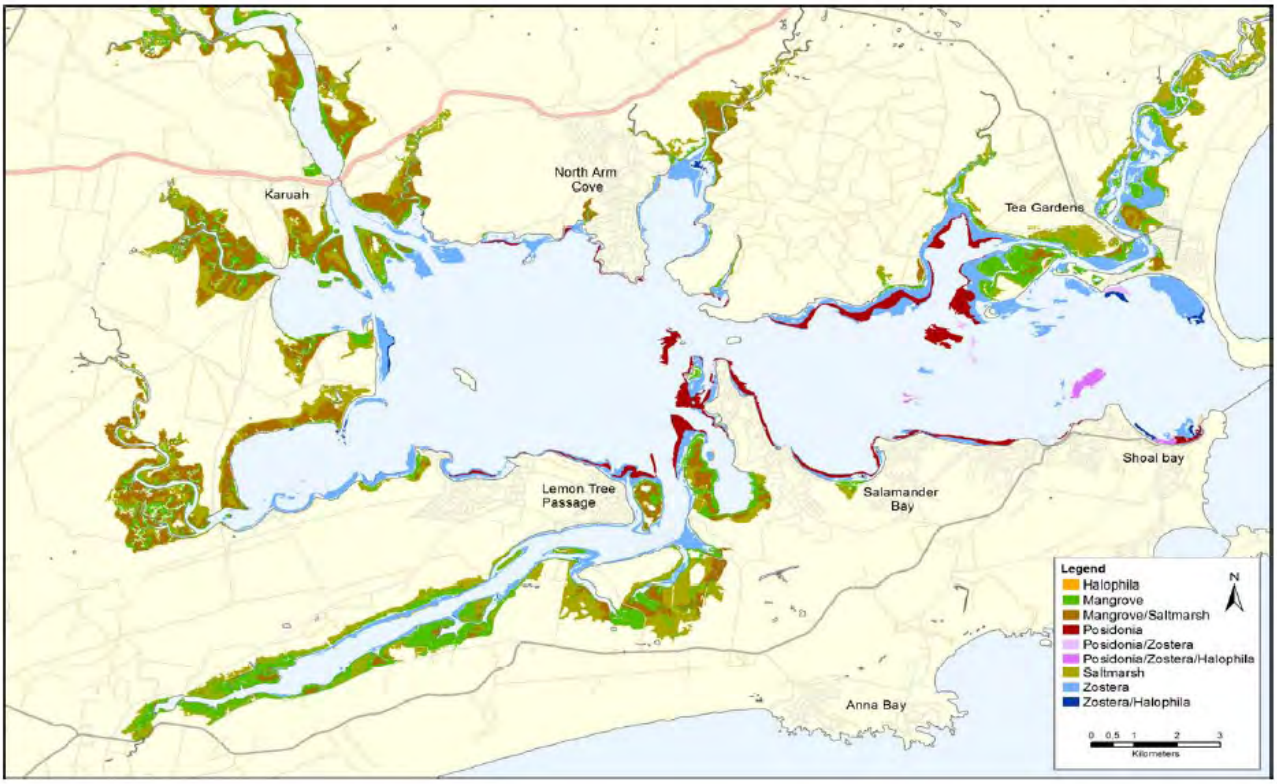

Myall River Water Quality - July 2008
Bombah Point Waterlevel m
Bombah Pt
Bulahdelah
Tea Gardens Waterlevel m
Tea Gardens Conductivity mS/cm
Bulahdelah Rain mm
Williamtown Rain mm
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09


Myall River Water Quality - January 2009
Bombah Point Waterlevel m
Bombah Pt
Bulahdelah
Tea Gardens Waterlevel m
Tea Gardens Conductivity mS/cm
Bulahdelah Rain mm
Williamtown Rain mm
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09


Myall River Water Quality - July 2009
Bombah Point Waterlevel m
2.5
2.0
1.5
1.0
0.5
0.0
Bombah Pt
Bulahdelah
Tea Gardens Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Tea Gardens Conductivity mS/cm
50
40
30
20
10
Bulahdelah Rain mm
150
100
50
Williamtown Rain mm
150
100
50
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10

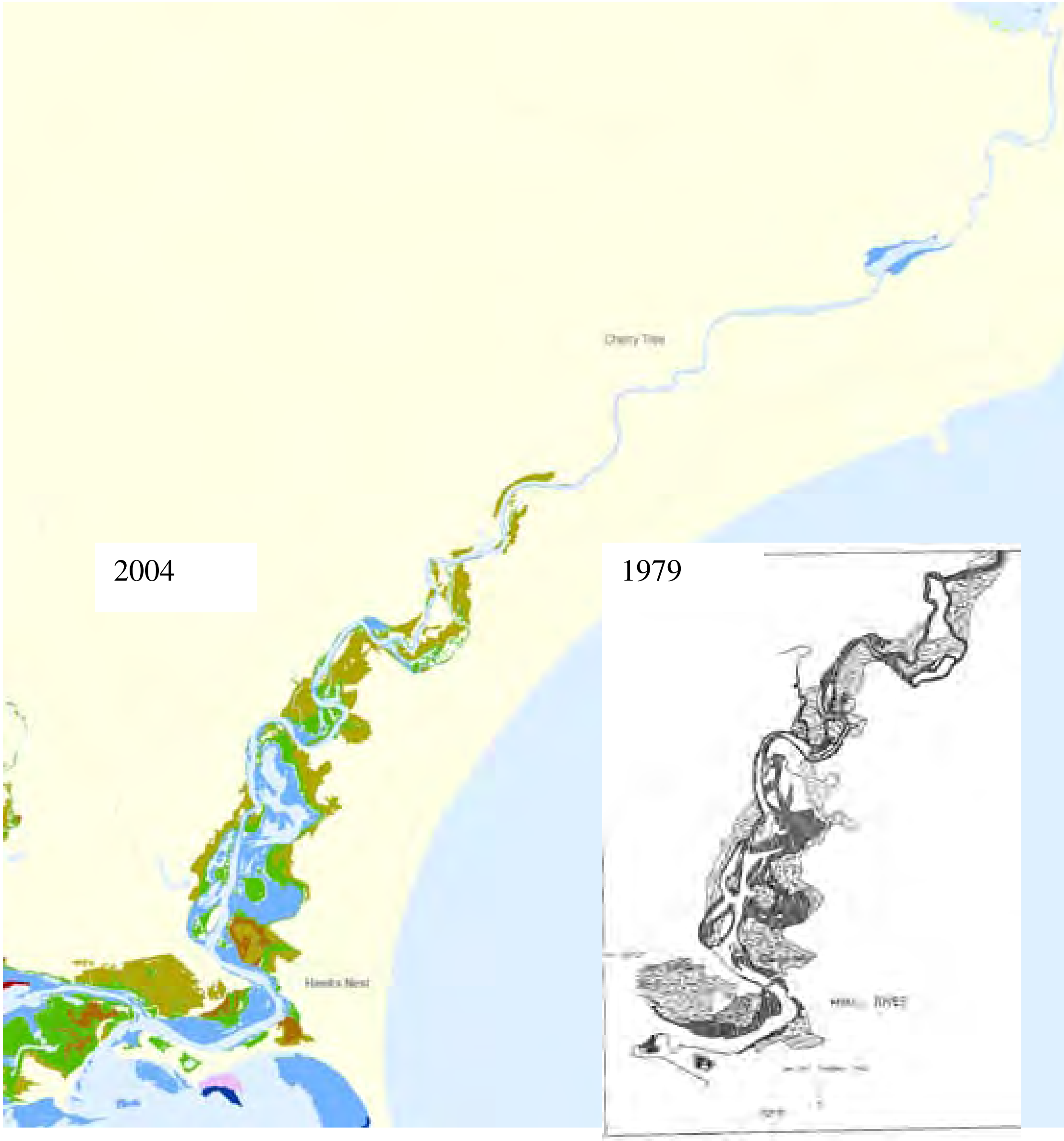

Myall River Water Quality - January 2010
Bombah Point Waterlevel m
2.5
2.0
1.5
1.0
0.5
0.0
Bombah Pt
Bulahdelah
Tea Gardens Waterlevel m
1.0
0.5
0.0
−0.5
−1.0
Tea Gardens Conductivity mS/cm
50
40
30
20
10
Bulahdelah Rain mm
150
100
50
Williamtown Rain mm
150
100
50
Jan-10
Feb-10
Mar-10
Apr-10
May-10
Jun-10
Jul-10

Appendix 3 - Aquatic Macrophytes – Port Stephens and Myall River

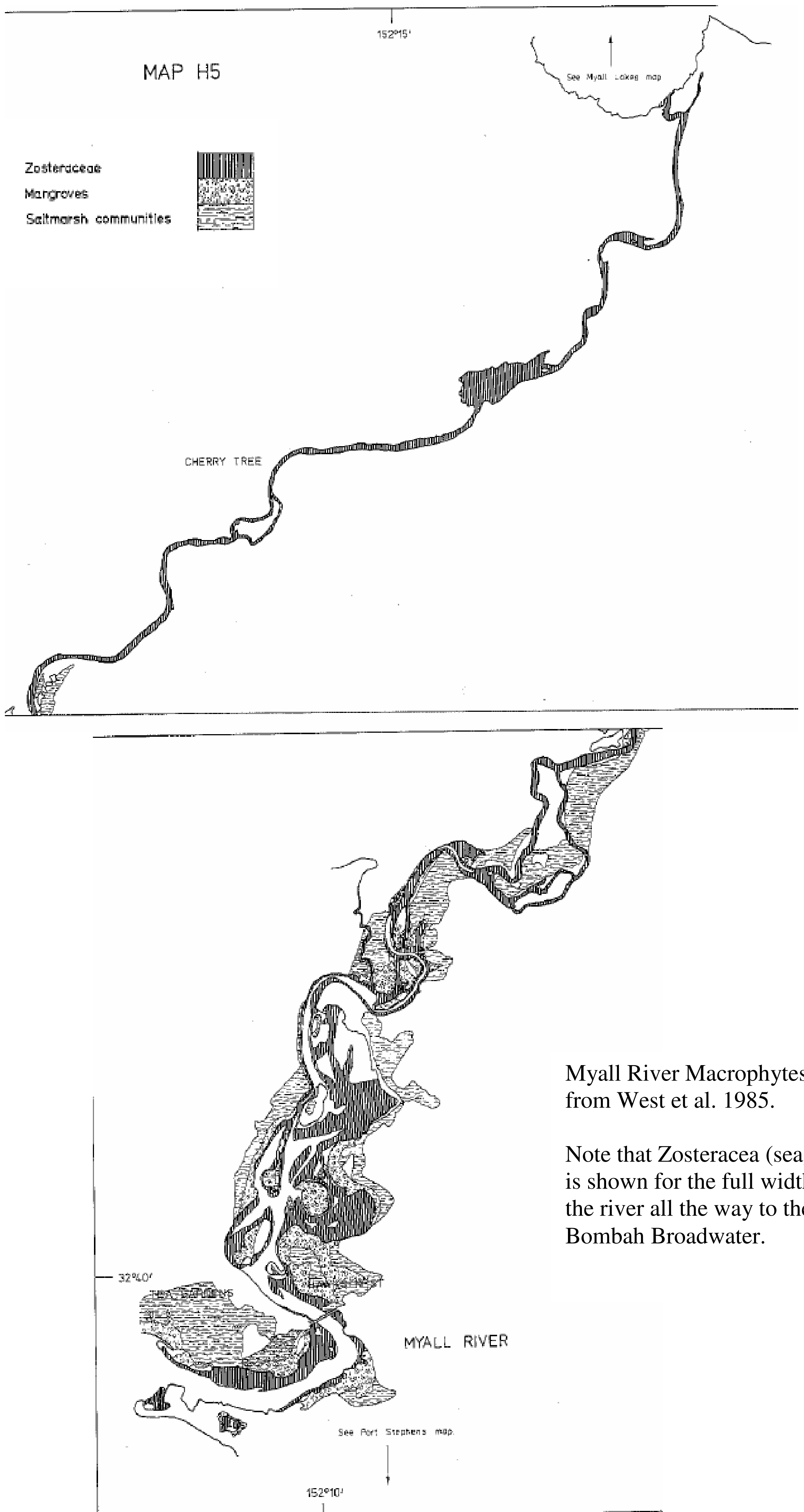


From:

Creese et al. (2009) Mapping the habitats of NSW estuaries



Comparison of macrophyte distributions in 2004 (Creese et al. 2009) and 1979 (West et al. 1985). Considering the limitations of the mapping and interpretation available in the 1980, it appears that there have been few major changes to seagrass beds



Myall River Macrophytes 1979 from West et al. 1985.

Note that Zosteracea (seagrass) is shown for the full width of the river all the way to the Bombah Broadwater.

Appendix - 4 Tea Gardens Secchi Data Analysis

Introduction

A number of data sets have been collected in the lower Myall River area since the middle 1990s. Those data sets include water level, conductivity and temperature. Recently a combined water level, conductivity and temperature gauge was installed at Tea Gardens on the Maritime NSW jetty. To compliment this data set, Secchi data has been collected manually nearby. To provide a basis for analysis of the lower Myall data, water level data from other sites has been used, namely Bombah Point in the Broadwater, Bulahdelah on the upper Myall River, Tomaree in Port Stephens and Sydney (Middle Head). Wind data from Williamtown has also been obtained. The following table shows the data sets used in this analysis.

Site	Type	Start Date	End Date
Tea Gardens	L,C,T	February 2009	Present
	Secchi	July 2009	Present
Monkey Jacket	L,C,T	July 1996	March 1998
	L	August 2001	October 2001
	L,C,T	September 2008	February 2009
Bombah		July 2001	Present
Bulahdelah	L	November 1984	Present
Tomaree	L	July 1996	Present
Sydney Middle Heads	L	July 1996	Present
Bulahdelah	L, R	1985	Present
Williamtown	W,R	July 2009	Present

Where L=water level, C=conductivity, T=temperature, W=wind, R=rainfall

Data analyses and presentations were undertaken to help show the relationship between the observed secchi readings and possible external events.

Monthly plots of the major datasets from July 2009 to June 2010 are presented in the following Figures 1 to 12.

The plots comprise of Secchi measured depth and relative depth (below AHD), Tea Gardens water level and conductivity and observed daily tide range, Bombah water level, Williamtown wind speed and direction. Conductivity is plotted in these figures, as a measure of salinity. As conductivity in milliSiemens/cm (mS/cm) varies with water temperature, it is common to reference the measured value back to a common temperature, usually 25 degrees Celcius. At this temperature, a conductivity of 53 mS/cm is equivalent to ocean salinity, and zero is freshwater conditions. The plotted tide range is based on the water level difference of the maximum and minimum water level recorded over the preceding 14 hours – hence the stepped nature of the plot.

The following explains the symbology of the plots. All times are in Eastern Standard Time, conductivity is at 25 degrees temperature and water levels are relative to AHD and with depths are in metres. The Secchi depth plots show the rising, lowering and mean depths, with high tide values marked in blue, low tide in green, others in black. Diamonds represent where the disk bottomed. Days when the secchi observations indicate cloud, showers or rain are marked with grey along the bottom axis. The Secchi observation points are marked on the associated plots as crosses for high and low tide and stars for other observations. The vertical gray bars are observations noted for turbidity. All other plots show a red cross at the associated time of the Secchi reading.

Secchi Analysis

Secchi disk readings provide a simple and generally repeatable method of determining light penetration through the water column. Secchi disk results have a basic assumption that turbidity in the water column is homogeneous and as such cannot adequately differentiate discrete layers of different turbidity. There may be a bias in the results, if a layer near the top of the water column is more or less turbid then lower down.

Secchi disk readings were taken generally twice daily, at the approximate high and low tides that occurred during daylight hours. This was undertaken when ever possible, and generally taken every day over nearly the whole year to date. Some days were missed, some tides were missed. The coverage is very good. In the following analyses, readings that were not near to the recorded high and low tides were ignored.

High and low tide readings relate closely to end of flood and end of ebb flows respectively. This is confirmed from the time series plots that show the secchi readings that occur at high and low tides also correspond to maximum and minimum conductivity values.

All data have been plotted with respect to Australian Eastern Standard Time (AEST). Secchi readings were recorded in local time. All other data were recorded in AEST

Discussion of Time Series Data

The following discussion is based on the plots of monthly data shown in Figures 1 to 12.

General

Over the whole record, secchi mean depth values varied between 0.8 to 2.88 metres, with a mean value of 1.68m. Over the first half of the record, secchi values would generally exceed 2.5m on high tide, with low tide values around the 1.0 to 1.5m.

In all cases there is generally a significant difference between high and low tide readings on the same and consecutive days of around 1.0 to 1.5m. Low tide readings (corresponding approximately to end of ebb flow) are generally the lower values (more turbid). This appears to indicate that the flood tide is bringing in cleaner water. This observation is partly why taking readings at the end of flood and ebb flows is preferred, as at other times in the tidal cycle it is possible that you are sampling water that is the result of the previous tide.

Secchi Depths Relative to Mean Water Level

Do the secchi readings show a layered response? The second plot in the figures show secchi readings adjusted for tide level, so that the values are relative to AHD (or mean water level). At the beginning of the secchi data collection (July 2009) when the secchi readings were low, it is interesting to note that the AHD secchi results form what looks like a layer that is varying slowly over the week. This is evident over many of the following months. However there is more variation between high and low water secchi AHD values where the secchi values are higher. This may be indicating that where the site is more influenced by marine water, the layering breaks down. Presented in this way, also shows that the reading marked as 'bottomed' vary by 0.5m, showing an indication of the repeatability of this measurement method. A number of readings not marked as ‘bottomed’ are possibly within a short distance of the bed, and could be located within a boundary layer close to the bed with higher turbidity and therefore not representing the true clarity of the water column.

Rainfall

The effect of rainfall in the Myall Lakes catchment is shown in the November 2009 plot. Around the 6th of the month, Bombah water level increased to around 0.3m. At this time low tide secchi readings were around 1.5m (a relatively high value for them). Over the course of another 5 days and the values had dropped to around 1.0m but after that then slightly improved to 1.3m even though Bombah remained elevated. Through December, low tide readings remained above 1.2m. For the rest of the period, Bombah remained low, and even went negative, due to evaporation dominating over rainfall. A lake level below zero results in a net flow from Port Stephens up the Myall River to balance the loss due to the evaporation. Bombah water levels only represent significant catchment rainfall.

Cloud/Overcast Effects

Looking at the secchi values collected on cloudy days shows no apparent effects on the readings. The cloud indicator has been based on comments in the readings indicating cloudy, showers or rain conditions at the time of the readings.

Observed High Turbidity

Comments attached to the readings indicate turbidity at the time of readings. Half of the noted turbidity observations at Tea Gardens occur on or near low tide. About a quarter each are attributable to each of high and mid tide observations. Few of these appear to correspond to associated wind events. Large numbers of these observations do appear to correspond to periods of higher daily conductivity variations (due to catchment flow), but high turbidity was also observed where conductivity was near ocean values.

Tide Effects

Tides dominate the local currents at Tea Gardens, except under large catchment events. The influence is readily seen in the comparison of conductivity with water level, where the conductivity extremes (highs and lows) correspond with the highs and lows of the water level. This linkage is due to the end of the flood tide flow corresponding with high tide and end of the ebb tide flow corresponding with low tide. Another possible effect is due to the fortnightly spring-neap tidal cycle. This cycle results in both higher high tides and lower low tides and associated increased flood and ebb flow and velocities. This spring-neap characteristic is represented in the plot of the measured tidal range. However from this data set there does not appear to be any dominant link between spring-neap tides differences and water column turbidity.

Some months, January, February and March 2010 (Figures 7 to 9), show short periods of increased conductivity variations, starting near the 'peak' of the neap tide and continuing through approximately the 10 days. During January and February, the conductivity at low tide drops to nearly half the high tide value which is near ocean water values. By March the effects are substantially smaller, with the conductivity varying by around 10%. This would appear to be a result of the location of the salinity gradient in the river, with the March result due to that gradient moving upstream, and having lesser effect on the Tea gardens site, as the system as a whole becomes more marine in nature. From observations from other NSW estuaries, the conductivity/salinity gradient can move around 5km longitudinally over a tide. Yet over a month move substantially upstream or downstream depending on the driving mechanisms at the time. The upstream movement of the salinity gradient is generally slow (being driven by tides over months) whilst the downstream movement is generally much quicker (driven by catchment events over just weeks or days).

It is difficult to separate the effects of the tidal currents on turbidity. In one case higher velocities will help lift sediment particles from the bed increasing turbidity, whilst at the same time, transporting it faster and further from the pickup site. However, depending on the sediment particle size, this pickup function is most likely to be more evident at mid tide, when velocities are greatest. Increased currents also emphasis flow patterns due to curved flow. The increased inertial component of the flow will force more flow to the outer edge of the flow paths, creating low flow depositional areas on the inside of the bend.

The influence of tides can also have an impact of other forcing functions. For example, the state of the tide and hence local depths at the time of peak wind gusts (which may only last for an hour) may be critical in the impact on turbidity.

Conductivity

Over the period of the secchi records, conductivity recorded at Tea Gardens shows significant variation from fresh water to ocean values, conductivity values of 2.1 to above 50 respectively. During periods of high fresh water flow down the river, the conductivity varies the most, as the downstream fresh flow is replaced during the flood tide, with ocean water mixed with fresh. When the river is dominated by tide processes, the conductivity value is up around 50, with small variation. The daily variation is the result of a number of factors, including tidal range on the day, and the preceding events which determine the longitudinal distribution of salinity gradient. The salinity can move approximately 5km along a river just due to the tidal velocities, in both upstream and downstream directions. Conductivity had values below 30 on approximately 100 days out of 330 days of this analysis period. This occurred predominantly through July, August and November 2009. All other months had on average 3 days under 30 mS/cm.

Wind Effects

Wind effects have been hard to isolate as a cause of increased turbidity with the data available. Although there were a significant number of wind events with average wind speed above 35km/hr, there does not appear to be any major changes in secchi readings during or the immediate periods after. For example an event around the 25/26th August 2009, where maximum wind speed exceeded 60km/hr, shows an immediate dip in the secchi reading but quickly returns to it previous values in the days following. A similar event around the 23rd September shows no appreciable effect, with most secchi depths remaining in the higher area. It was followed on 26th by a 60km/hr event with a single reading at 1.4m then returning to around 2.0m. The influence of wind on water column turbidity may be tightly linked to the tidal depths (that is the state of the tide) at the time and duration of the event. It is also possible that wind effects are not long lasting, and the turbidity created quickly settles out. On this basis major effects if they occur, may occur more around mid and higher tides and not at all at low tide, when tidal flats are exposed.

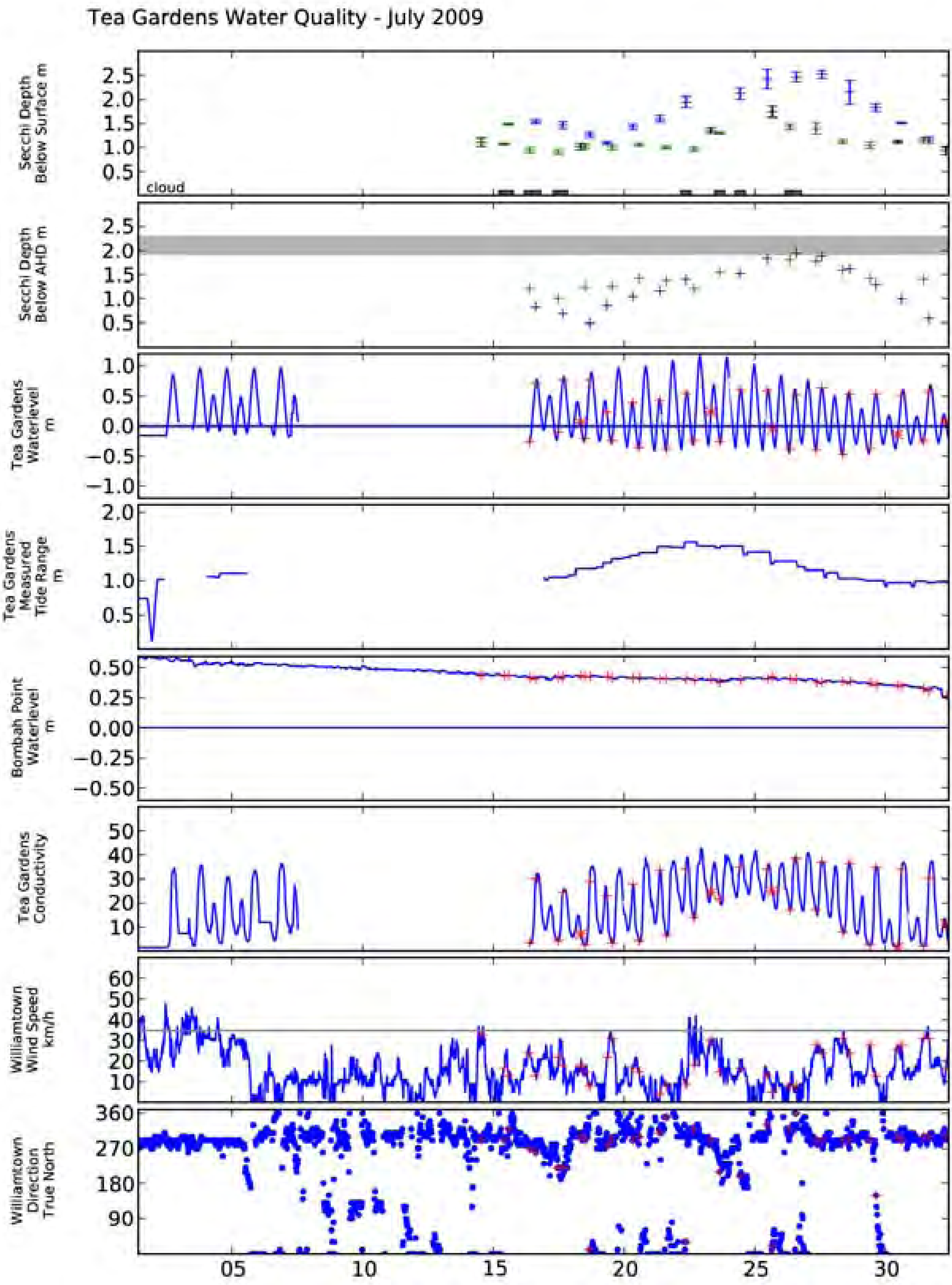


Figure 10 - July 2009

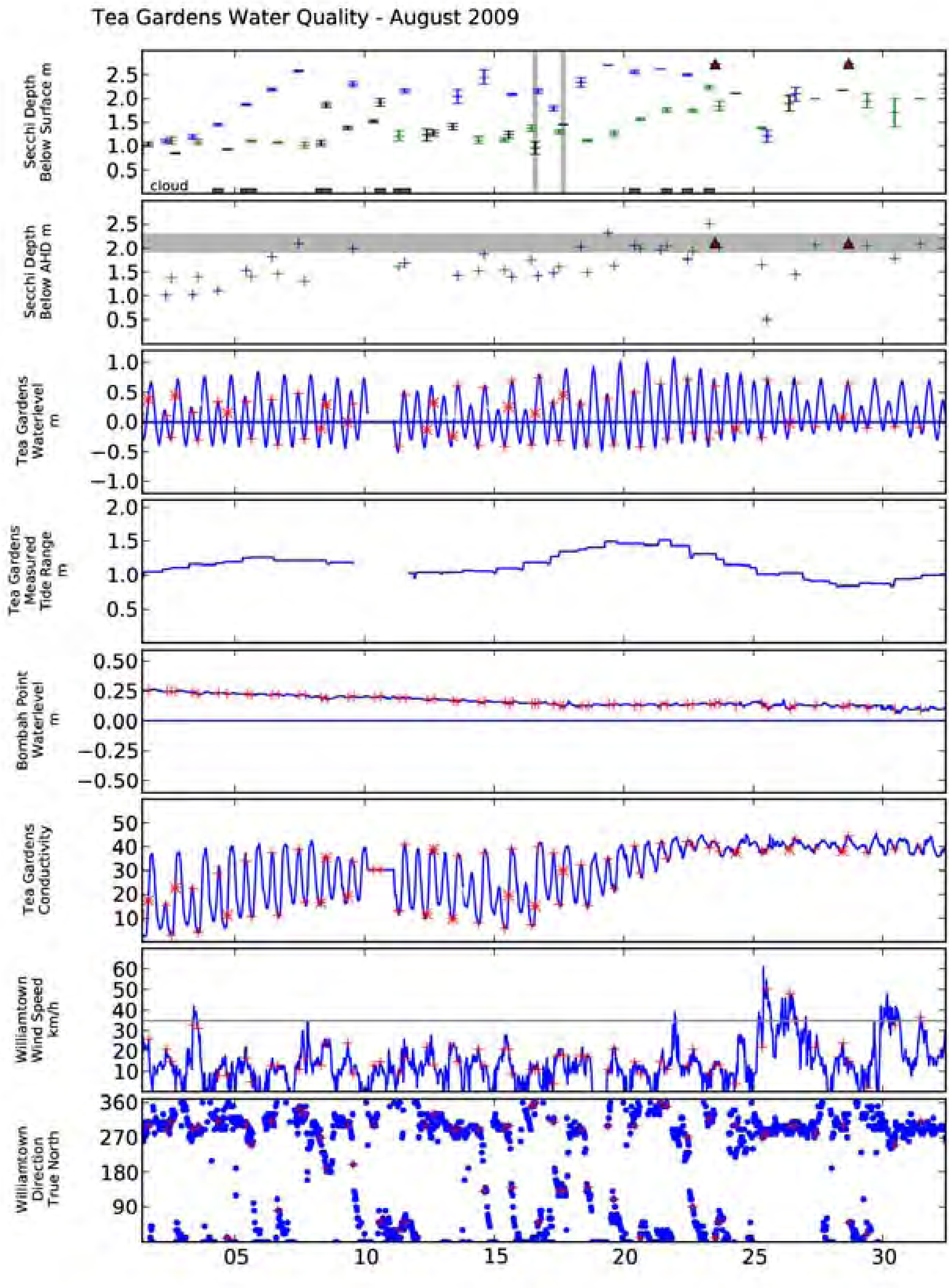


Figure 11 - August 2009

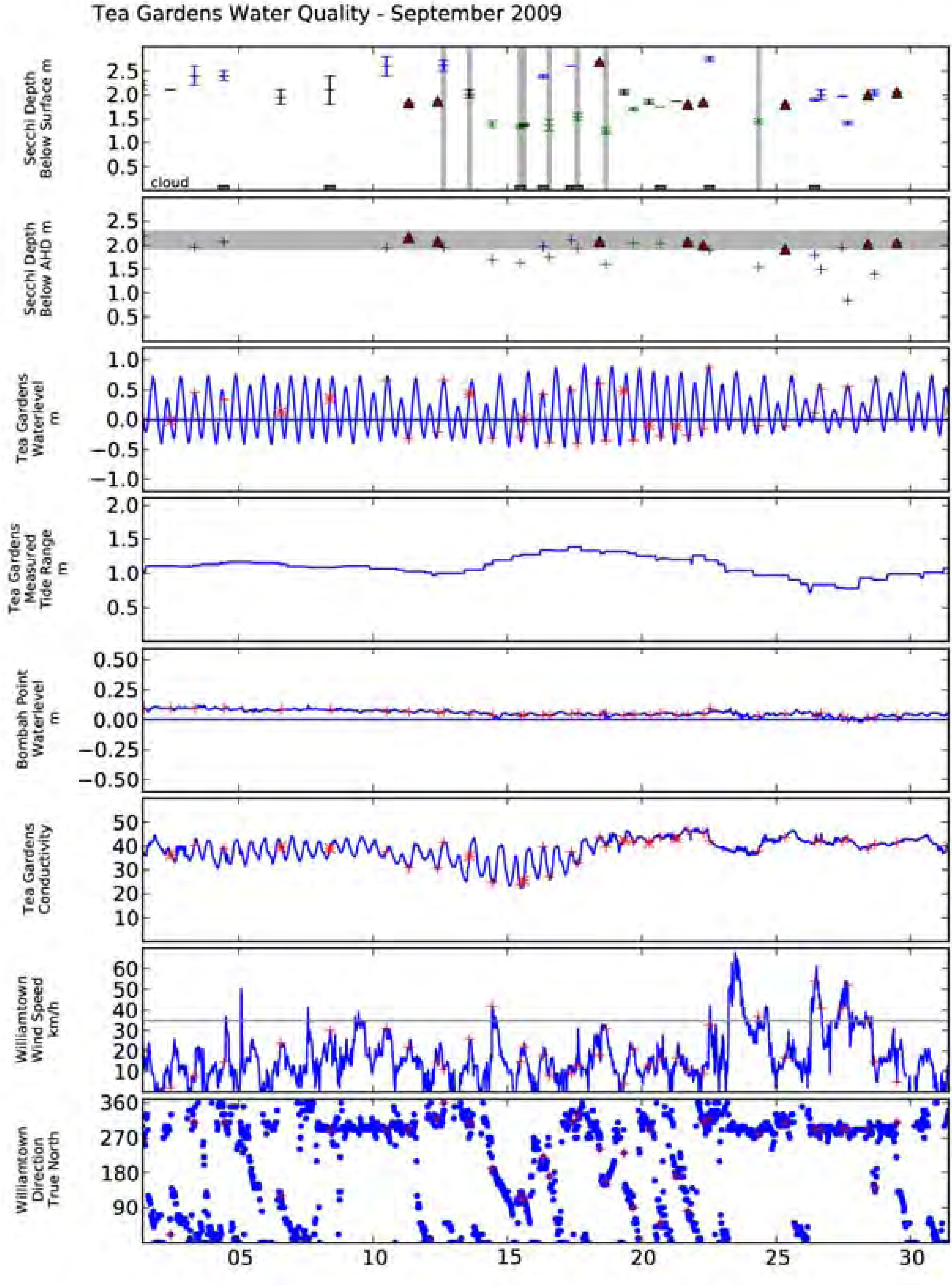


Figure 12 – September 2009

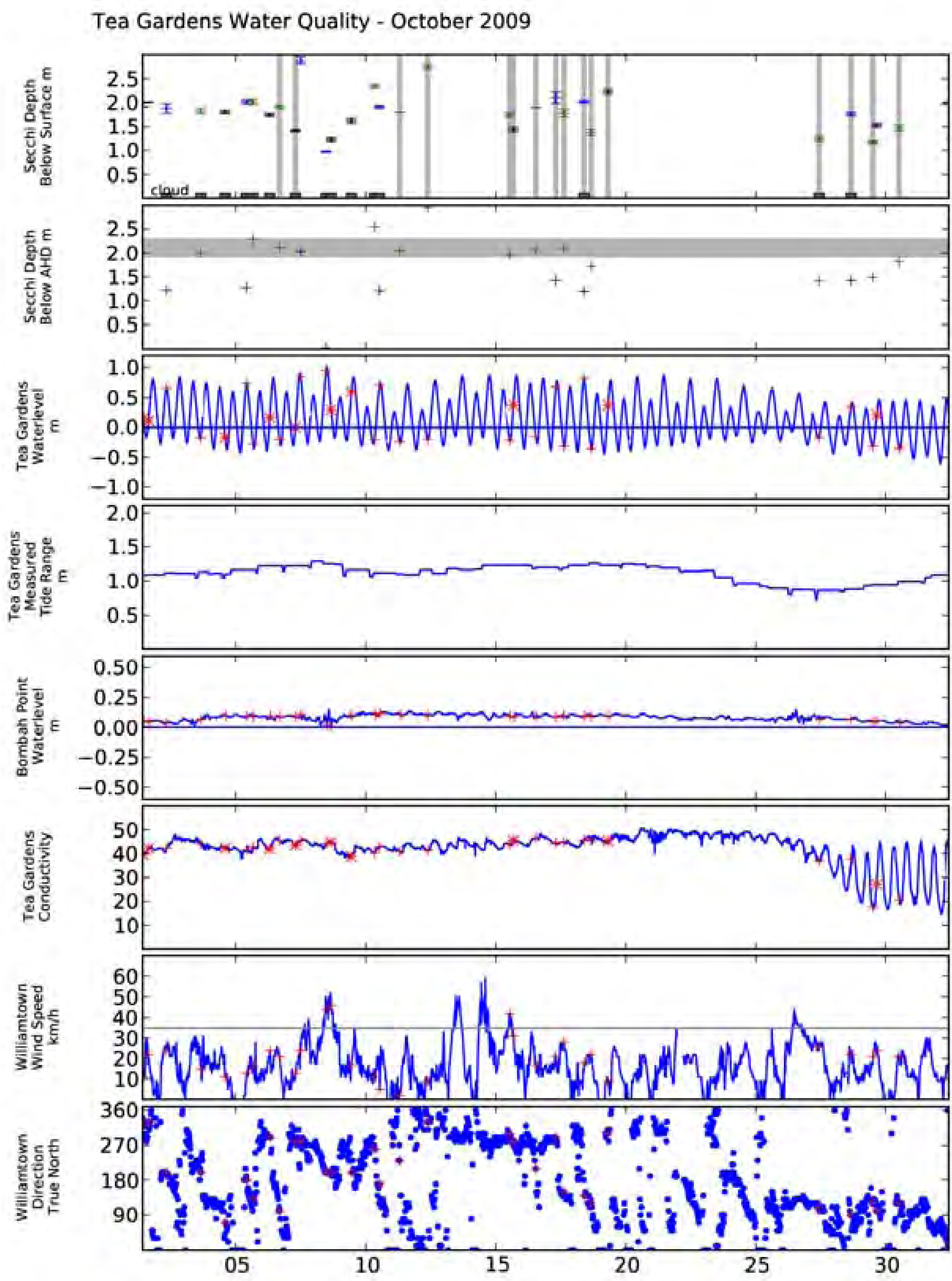


Figure 13 - October 2009

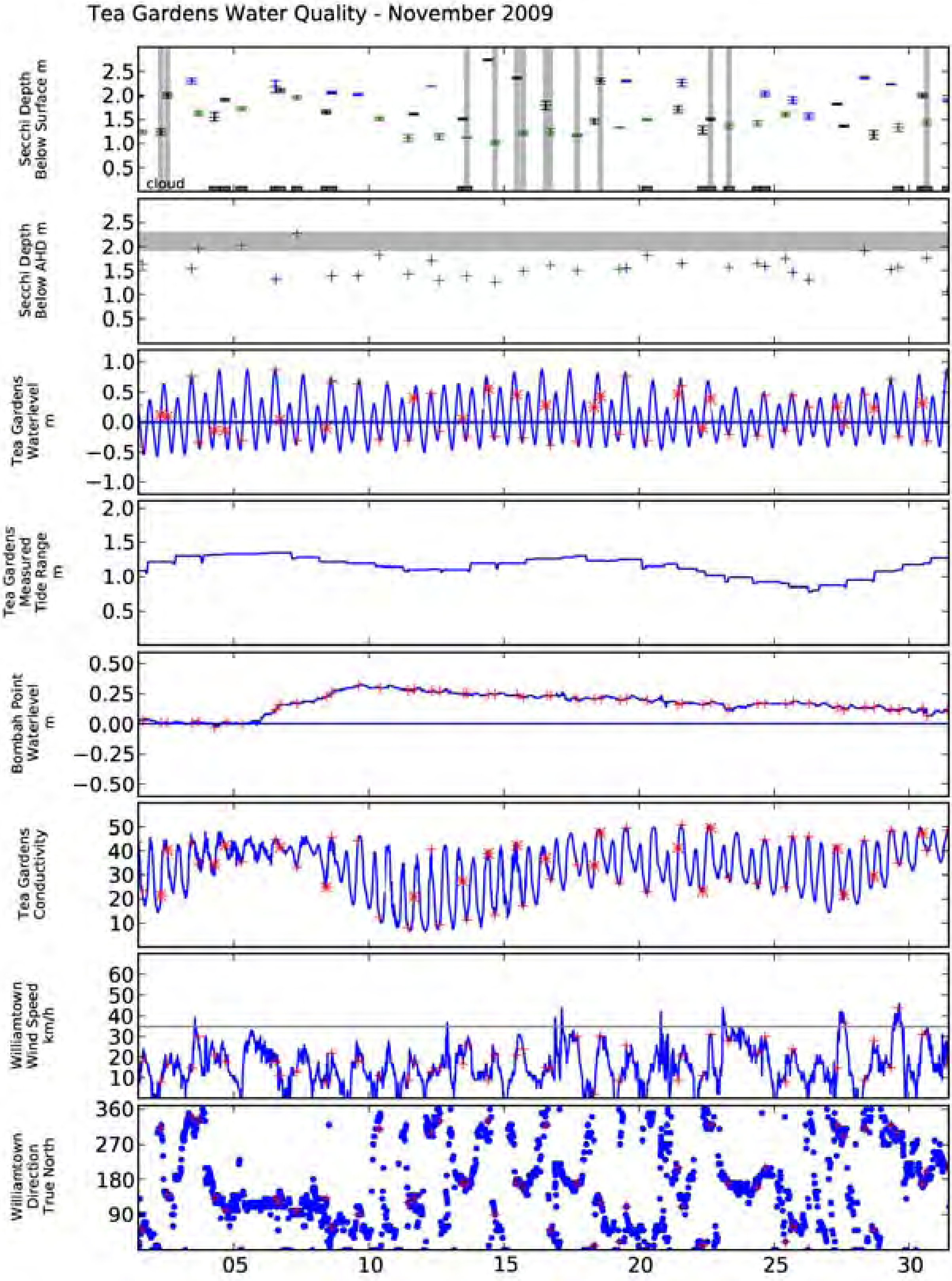


Figure 14 - November 2009

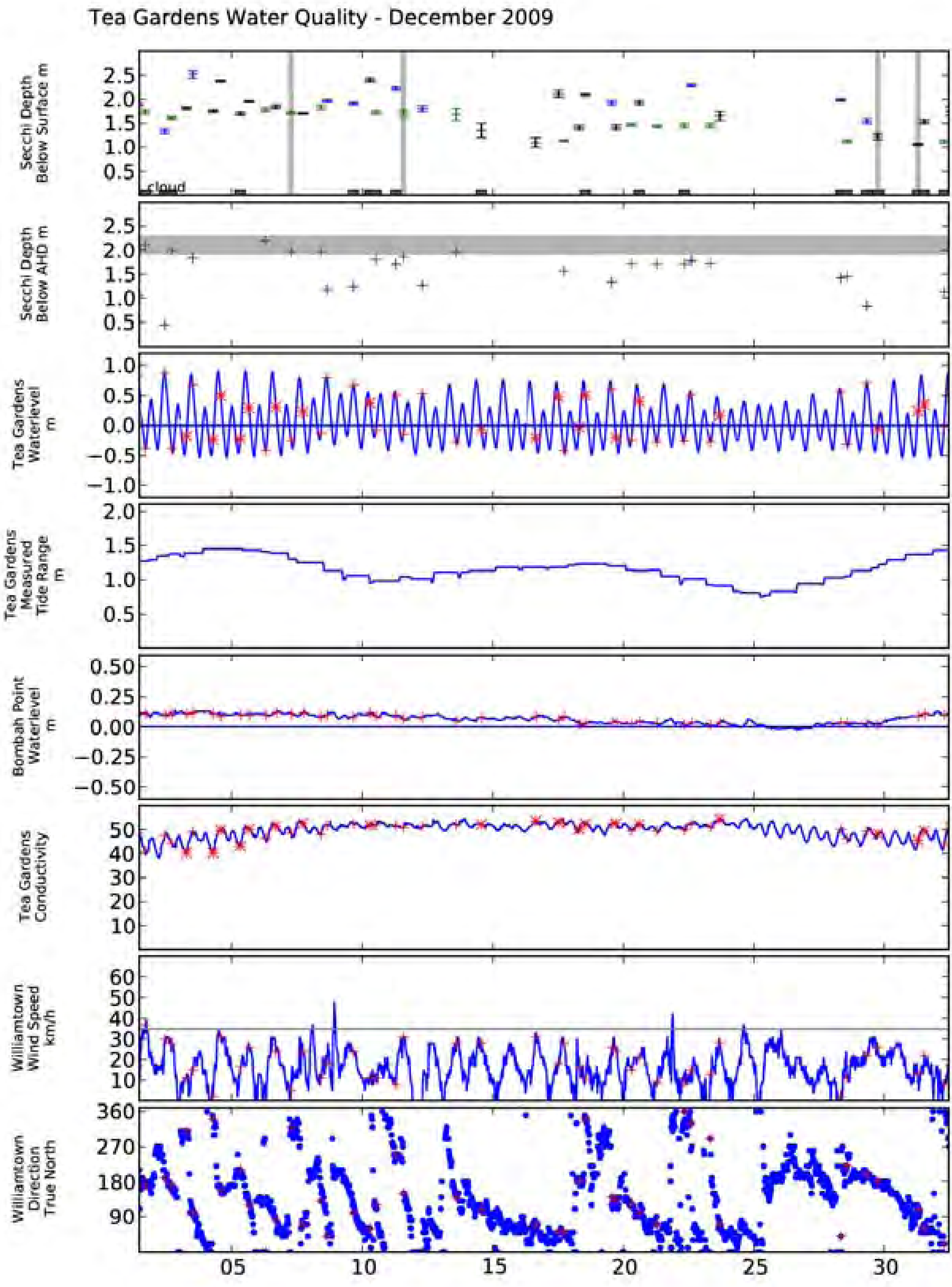


Figure 15 - December 2009

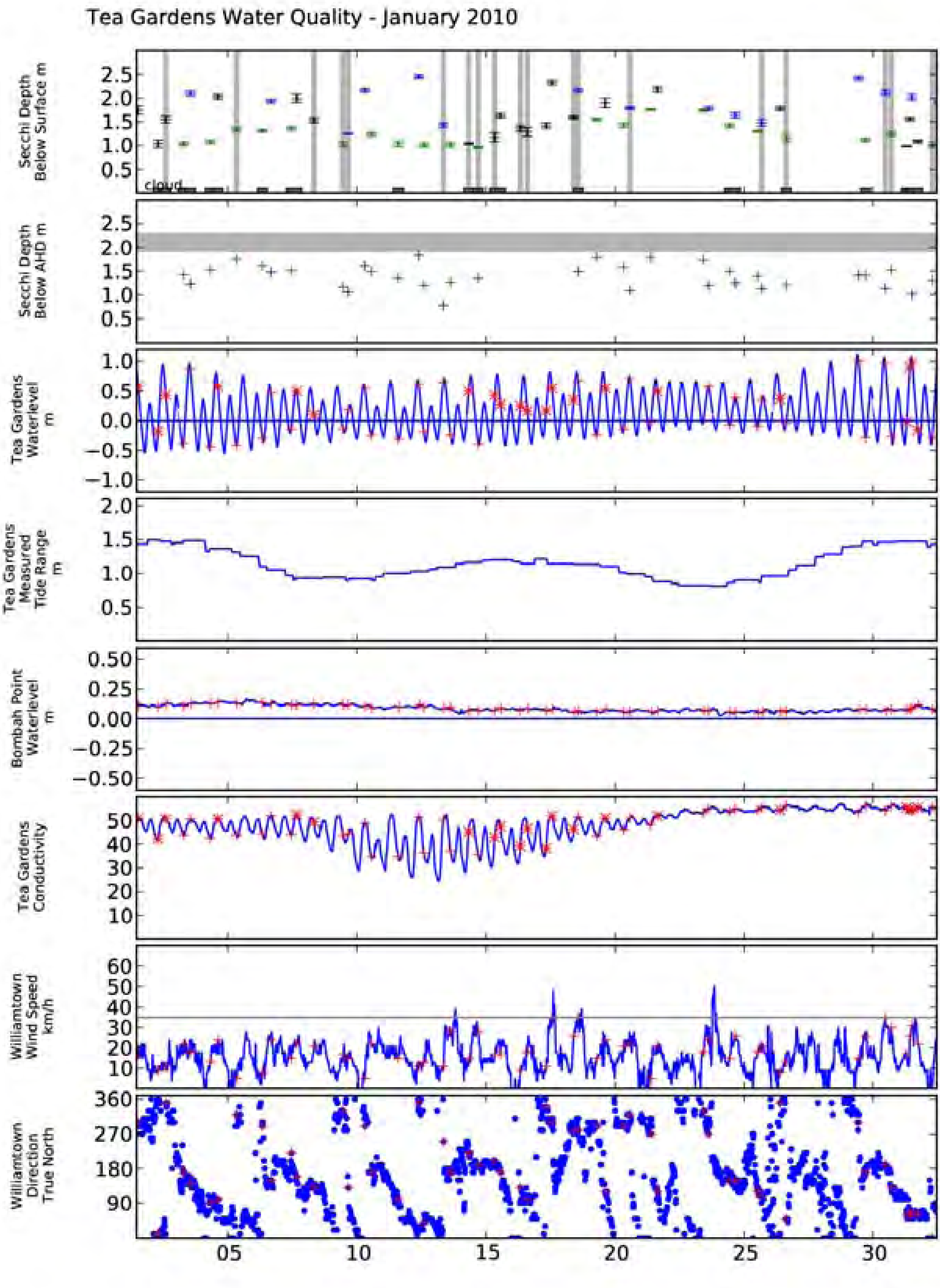


Figure 16 - January 2010

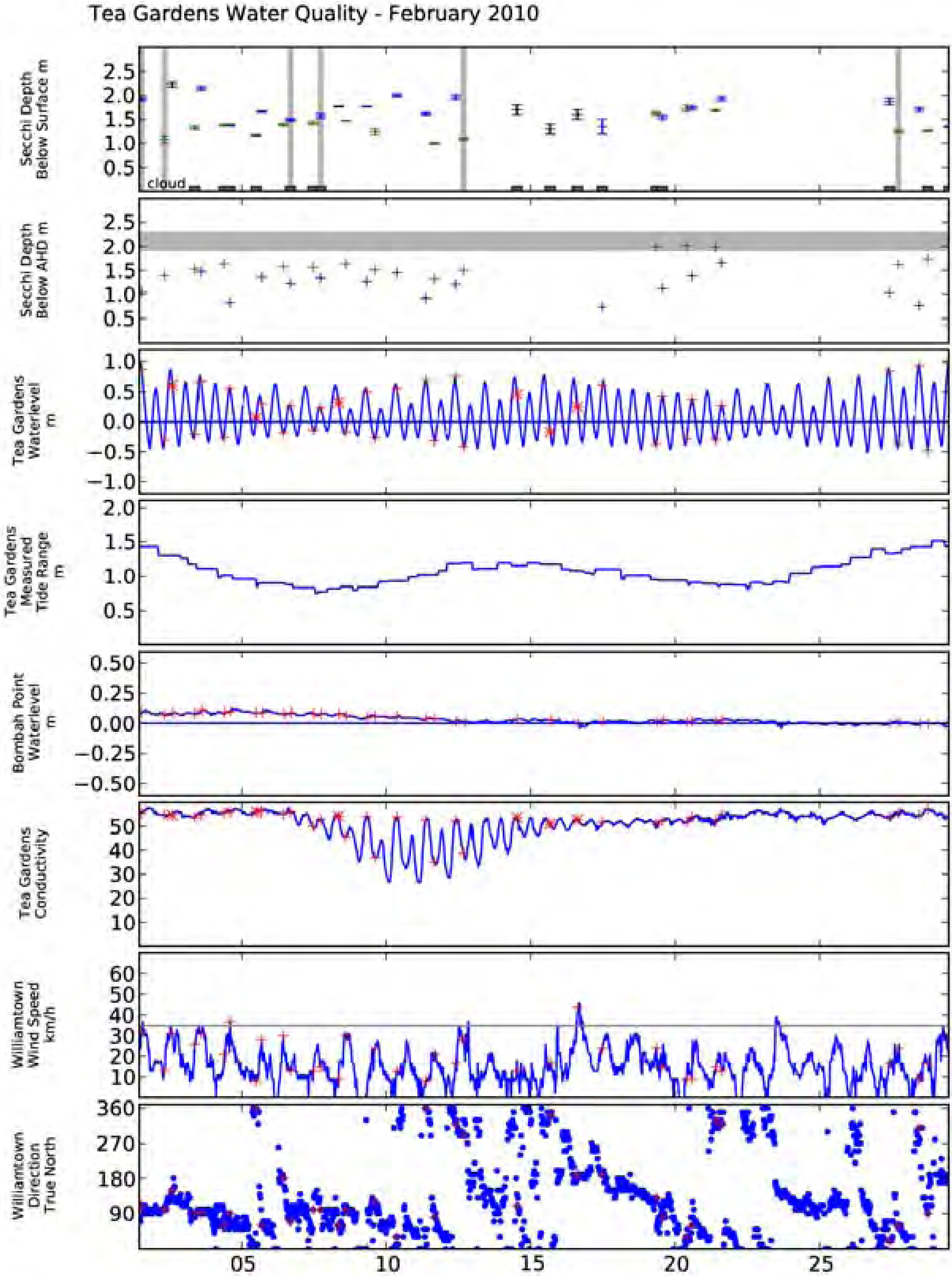


Figure 17 - February 2010

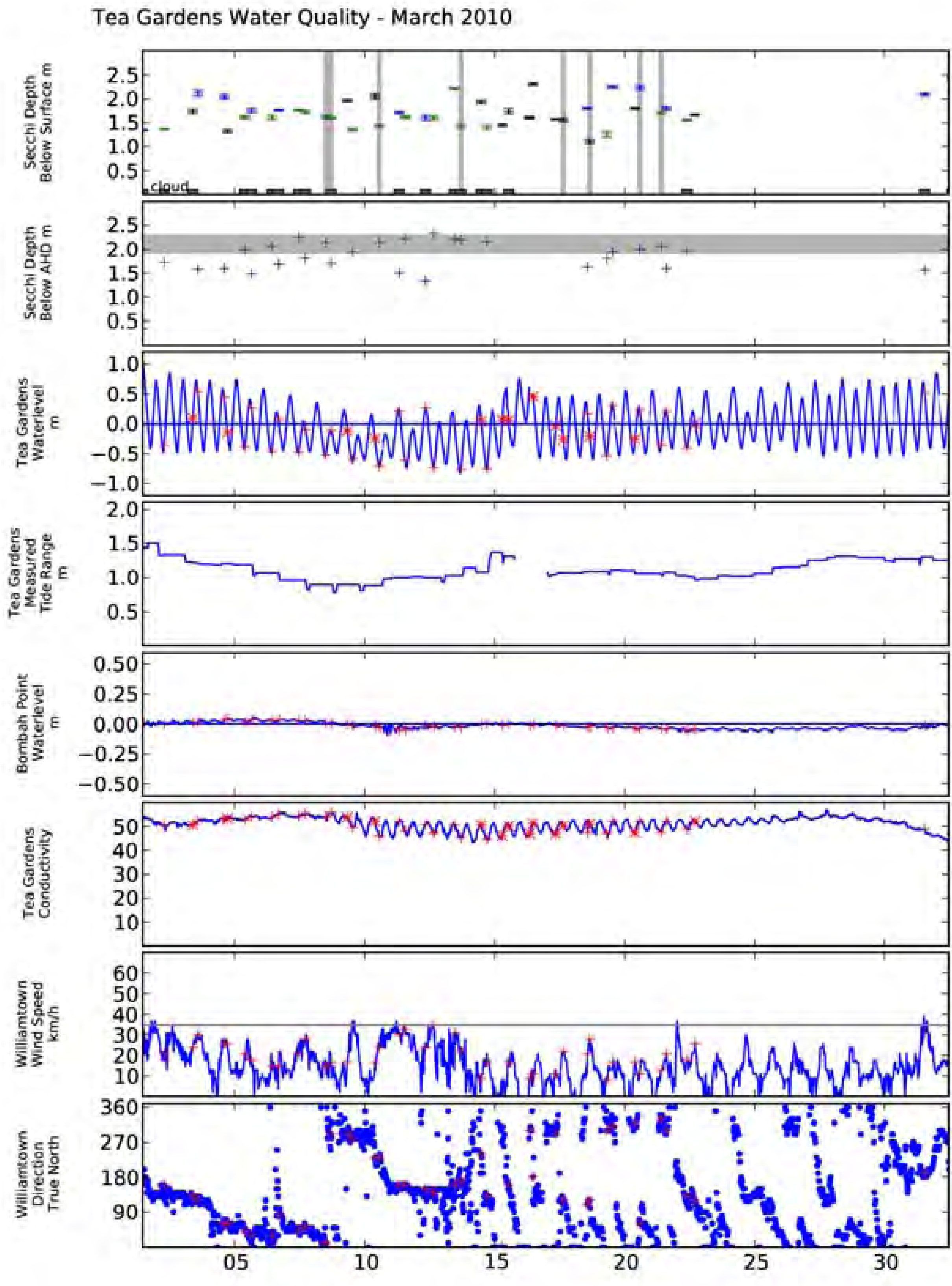


Figure 18 – March 2010

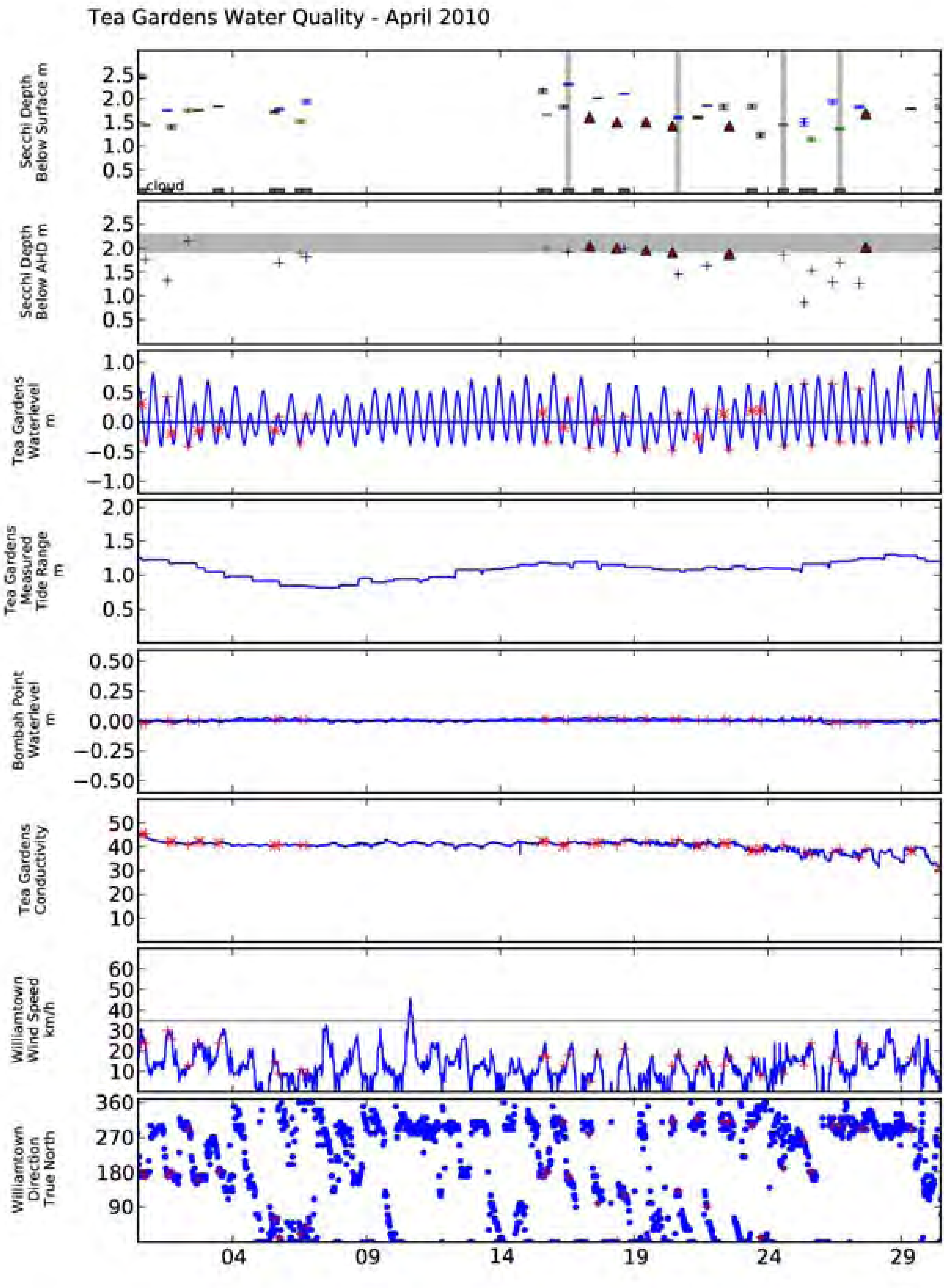


Figure 19 - April 2010

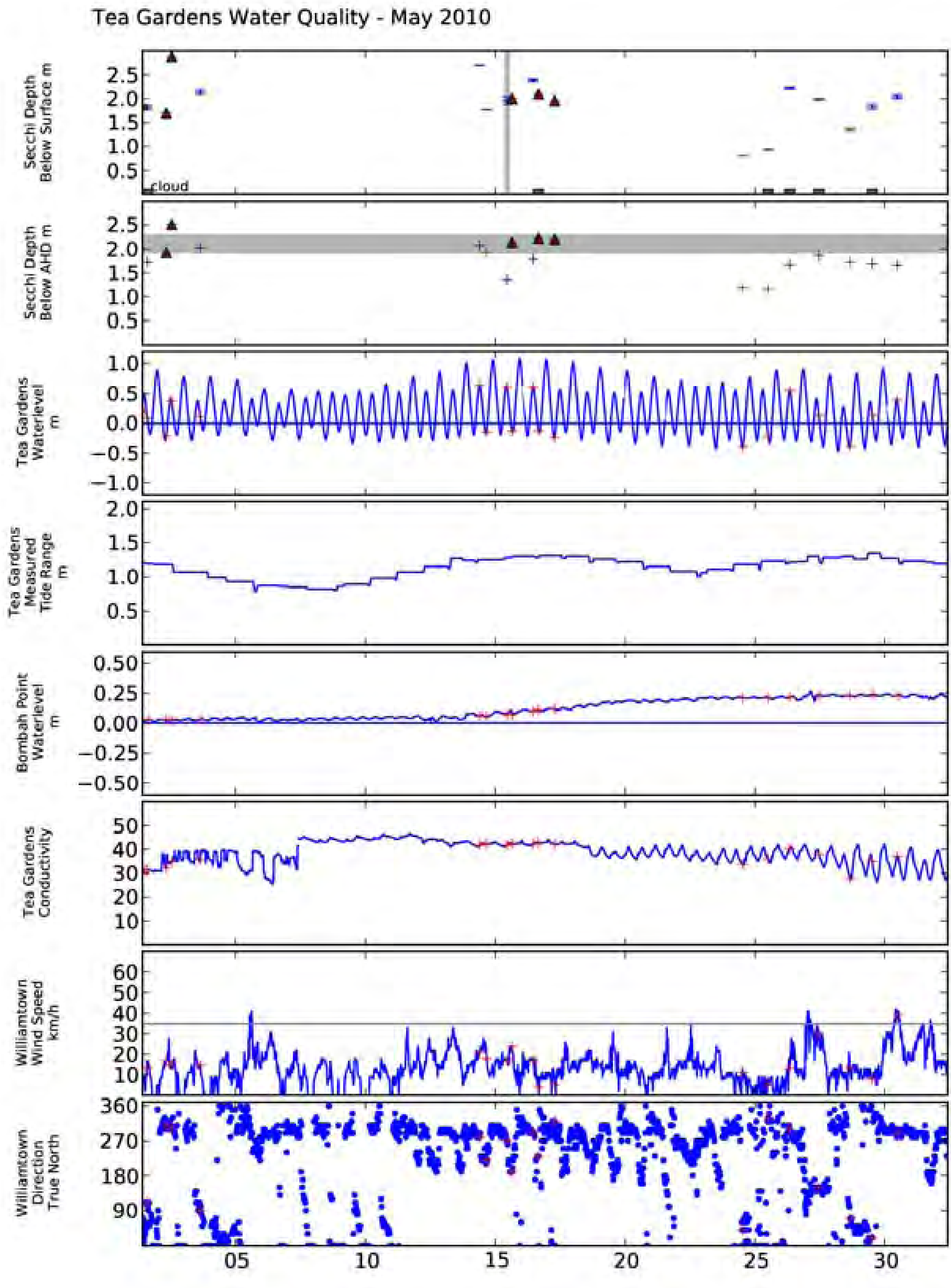


Figure 20 - May 2010

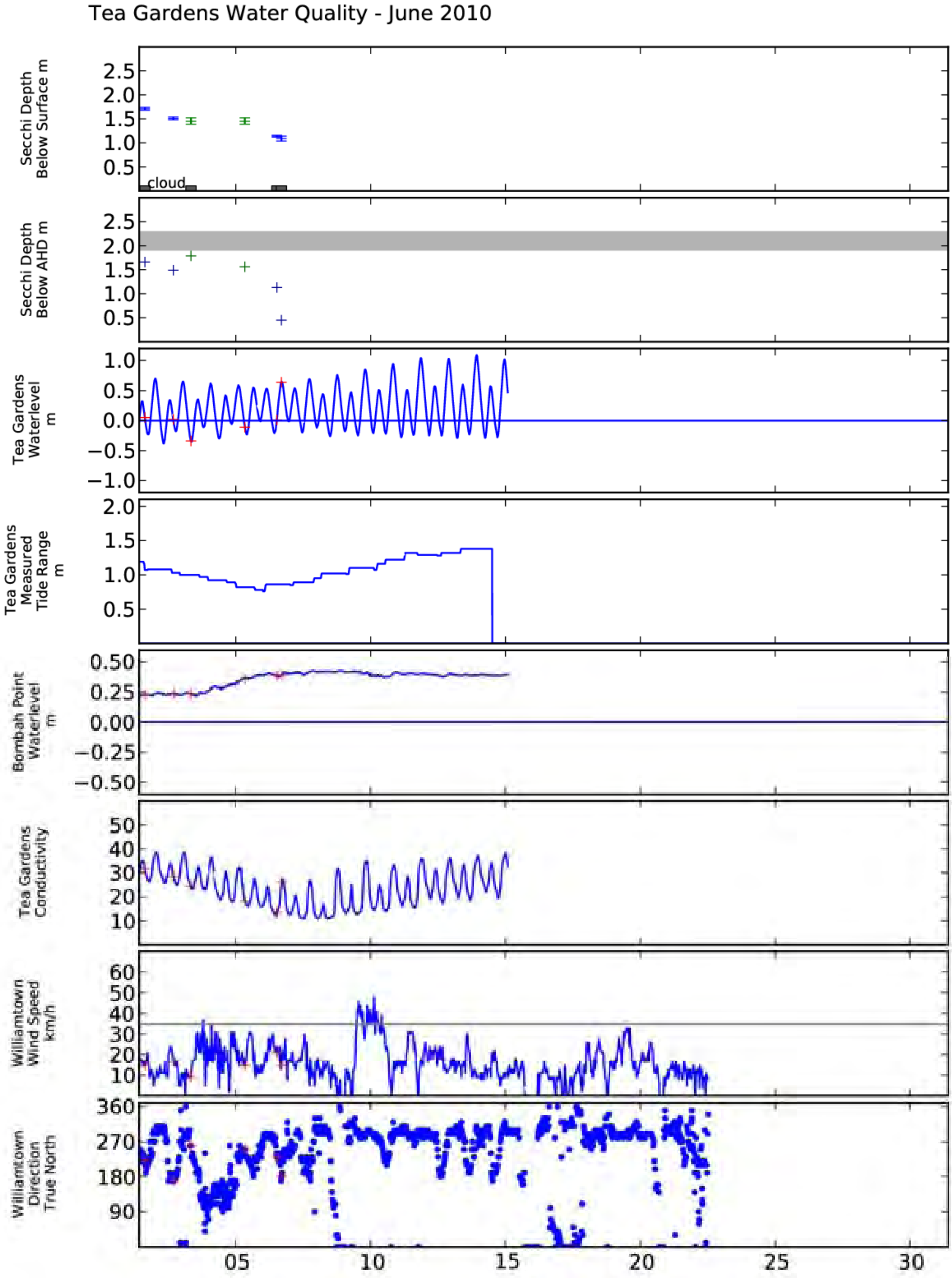


Figure 21 - June 2010

Secchi Depth Drivers

It is useful to directly compare the Secchi Depth values against other variables.

Figure 15 shows the comparison of Secchi Depths against Tea Gardens Conductivity. The figure is also highlighted with the state of the tide (high or low) for each plotted point. Secchi data that was mid tide was ignored for this comparison. This figure shows that for low conductivities, below 30 mS/cm, low secchi values below 1.5m can be expected. These values also occur predominantly at low tides. High secchi values will occur predominantly at high tides, with very few high tides producing low secchi values. High tide approximately corresponds to the end of the flood tide. This shows that the flood tide flushing of the Tea Gardens area is generally very good, with clear water brought in on the high tide. Low tide (at the end of the ebb tide flow) very rarely results in high secchi values, though results are frequent up to 2m secchi depths. This is indicative of the riverine nature of the system, with catchment effects being evident. This also suggests that the Tea Gardens area can be a major mixing zone and interface between the fresh river flow and the marine waters of Port Stephens.

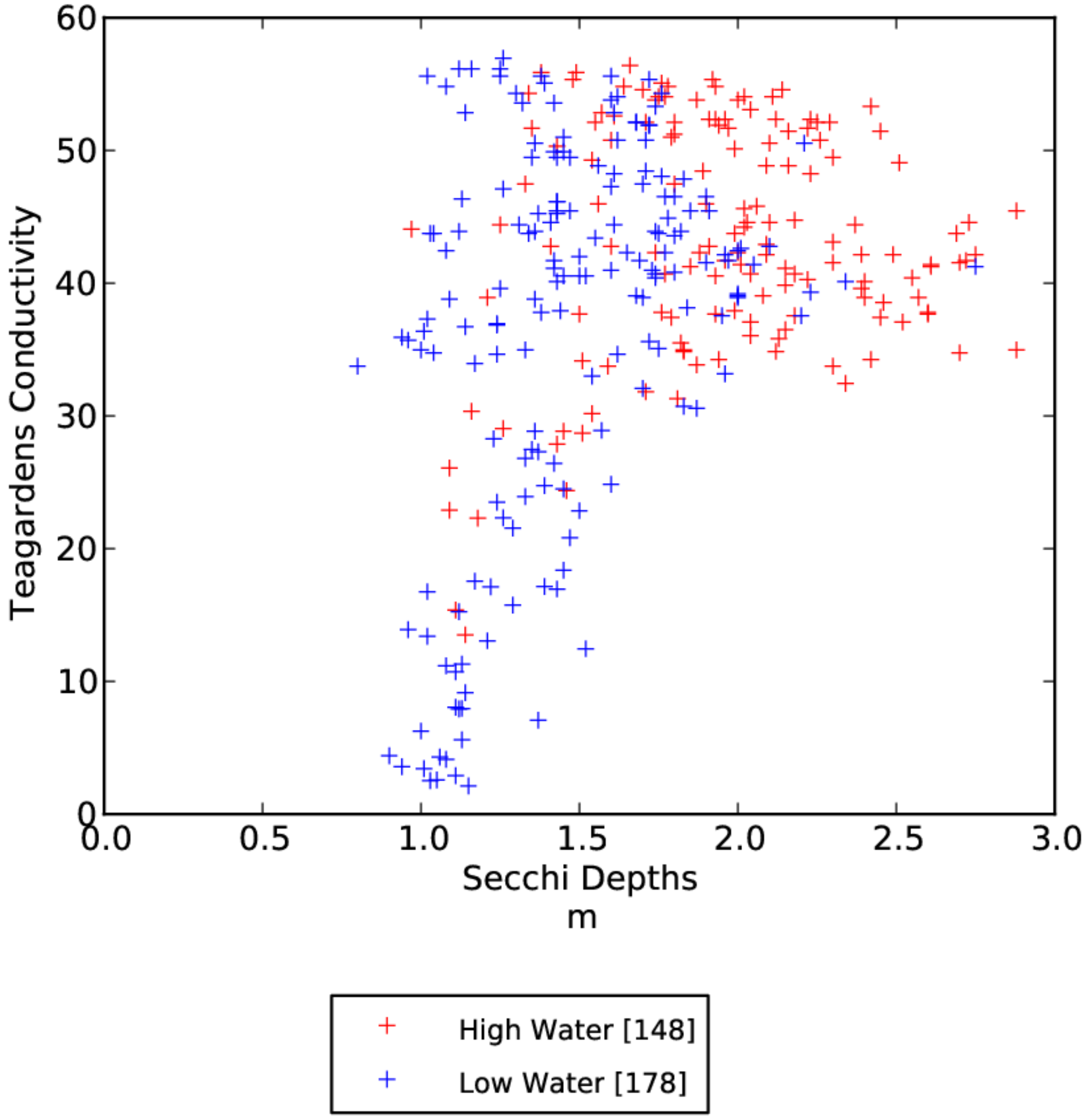


Figure 22: Secchi Depth versus Conductivity with Tidal State

A similar plot of Secchi values against conductivity, with plot points highlighted with the Lakes water level, as represented by Bombah Point water level data is shown in Figure 16. This figure clearly shows that low conductivity is driven by higher water levels in the lakes, which results in increased fresh water downstream. The higher lake water levels can generate increased downstream flows, which limit the penetration upstream of the saline marine waters. This water also has increased turbidity, most probably due to the catchment runoff which results in the low secchi depth values. However, high lake water levels do not guarantee low secchi values. Due to size of the lower Myall River, the lakes drain at a relatively fixed rate, with the river regulating that flow. Because of this the lake system has the characteristic behaviour of 'filling' quickly in significant events and draining slowly over the following number of weeks or months. Therefore given sufficient time catchment sediments generating turbidity may settle out in the Lakes, and high water levels may also result in clearer waters at Tea Gardens. There is most probably an influence from wind, where a large wind event may stir up bed material in the lakes, and if they are in a

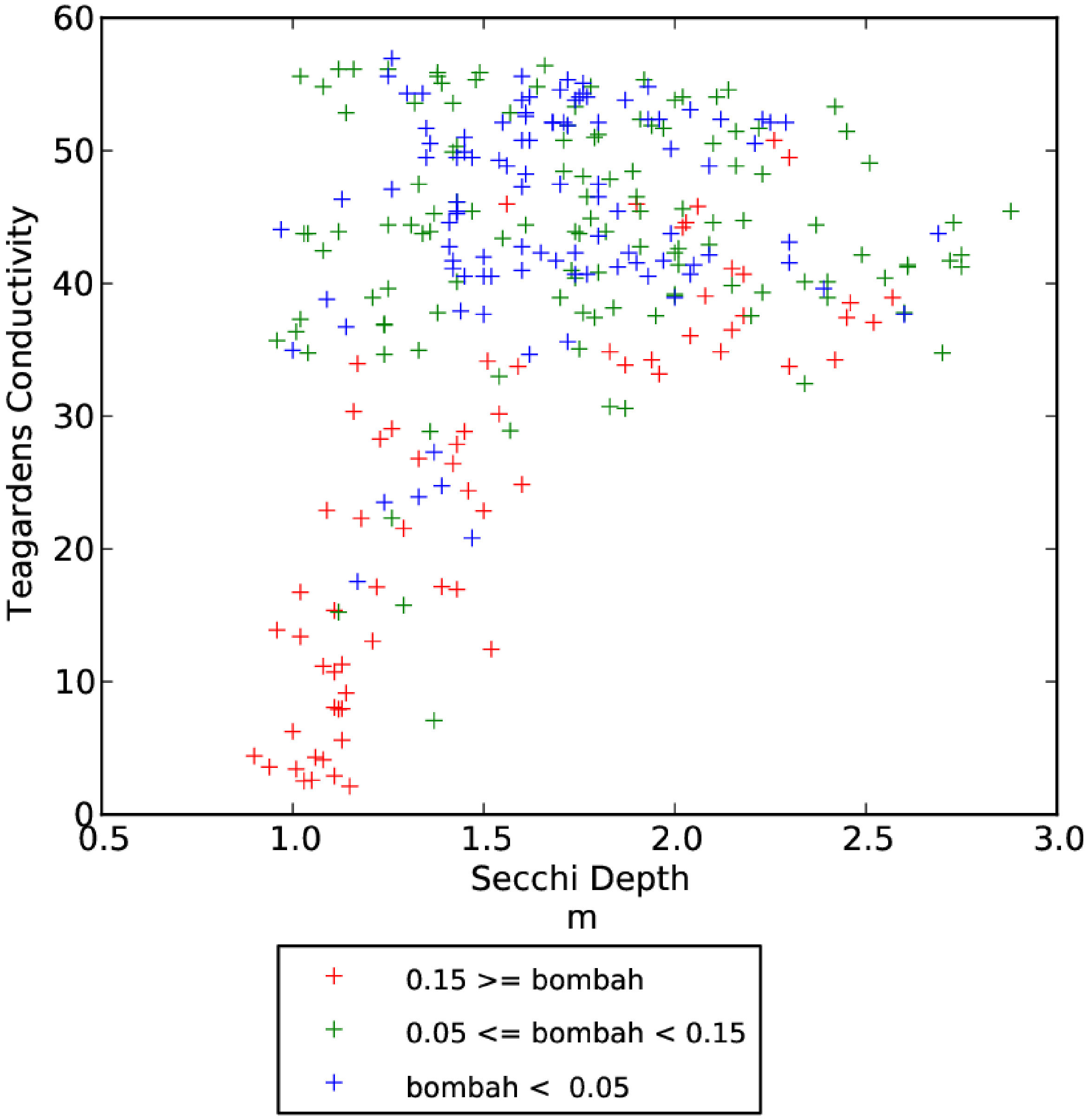


Figure 23 - Secchi Depth versus Conductivity with Bombah Water Level

'draining' mode, may influence downstream water quality.

There will be a lag between events in the lakes and their influence of water quality near the river entrance. The lakes appear to drain at rates of 1cm/day up to around 2cm/day. Given the lake surface area of approximately 100 sq km, this means the lakes are draining at a rate of approximately 11m^3/s (up to 23m^3/s). The channel size at Tamboy is approximately 100 sq m, which gives an approximate downstream velocity 0.1m/s. Therefore a very approximate estimate of the lag between a lake event and its subsequent observation at Tea Gardens is of the order of three days (assuming a travel distance of 25km). This estimate does not include changing channel sizes or the influence of tides, but does give an indication that the lag will be of the order of days (possibly a week) but not hours.

Appendix 5 - Invertebrate Taxa

species code	scientific name	common name/ other info
tryaus	Trypaea australiensis	Australian Ghost shrimp
micspp	Family Mictyridae	Soldier Crab
graspp	Family Grapsidae	Shore Crab
ampspp	Order Amphipoda	Amphipod
mysspp	Mysella spp	Bivalve (Family Montacutidae)
macspp	Family Mactridae	Bivalve
telspp	Family Tellinidae	Bivalve
psaspp	Family Psammobiidae	Bivalve
venspp	Family veneridae	Bivalve
lucspp	Family Lucinidae	Bivalve
lepspp	Family Leptonidae	Bivalve
natspp	Family Naticidae	Gastropod
nasspp	Family Nassariidae	Gastropod
nerspp	Family Nereitidae	Gastropod
capspp	Family Capitellidae	Polychaete
orbspp	Family Orbiniidae	Polychaete
sylspp	Family Syllidae	Polychaete
pilspp	Family Pilargidae	Polychaete
lumspp	Family Lumbineridae	Polychaete
owespp	Family Oweniidae	Polychaete
hesspp	Family Hesionidae	Polychaete
polspp	Class polychaeta	difficult to ID but is a polychaete

Appendix 6 - Fish Species

Tea Gardens/Myall River Sites

Species	Common name	Number Caught
Acanthopagrus australis	Yellowfin bream	16
Achoerodus viridis	Eastern blue groper	1
Afurcagobius tamarensis	Tamar River Goby	7
Ambassis jacksoniensis	Port Jackson perchlet (Glassfish)	1048
Arenigobius bifrenatus	Bridled Goby	20
Arenigobius frenatus	Half-bridled goby	486
Atherinomorus vaigiensis	Ogilbys hardyhead	4
Bathygobius krefftii	Kreffts goby	15
Centropogon australis	Eastern fortescue	26
Cryptocentroides gobioides	Crested Oystergoby	2
Dasyatis spp	Stingray	1
Dicotylichthys punctulatus	Three-bar porcupinefish	1
Dinolestes lewini	Longfin Pike	5
Favonigobius exquisitus	Exquisite Sandgoby	54
Favonigobius lateralis	Southern Longfin Goby	10
Gerres subfasciatus	Silver biddy	18
Girella tricuspidata	Luderick	104
Herklotsichthys castelnaui	Southern Herring	127
Heteroclinus spp	Weedfish	1
Hyperlophus vittatus	Sandy Sprat	19
Hyporhamphus regularis ardelio	Eastern River garfish	2
Liza argentea	Flat-tail mullet	26
Meuschenia freycineti	Six-spined leatherjacket	2
Meuschenia trachylepis	Yellowfin Leatherjacket	6
Monacanthus chinensis	Fan-bellied leatherjacket	21
Mugil cephalus	Striped mullet	59
Pelates sexlineatus	Eastern Striped Trumpeter	147
Philypnodon grandiceps	Flathead gudgeon	12
Platycephalus fuscus	Dusky flathead	10
Pomatomus saltatrix	Tailor	38
Pseudogobius olorum	Swan River Goby	13
Pseudorhombus jenynsii	Small-toothed flounder	1
Redigobius macrostoma	Large-mouth goby	37
Rhabdosargus sarba	Tarwhine	21
Sillago ciliata	Sand whiting	26
Sillago maculata	Trumpeter whiting	2
Siphamia roseigaster	Silver siphonfish	8
Tetractenos glaber	Smooth toadfish	4
Tetractenos hamiltoni	Common toad	100
Upeneichthys spp.*	Goatfish	1
	Total Number Caught	**2501**
	Total Number Species	**40**

Port Stephens Sites (Pindimar Bay)

Species	Common name	Number Caught
Acanthopagrus australis	Yellowfin bream	19
Afurcagobius tamarensis	Tamar River Goby	1
Ambassis jacksoniensis	Port Jackson perchlet (Glassfish)	37
Ambassis marianus	Estuary perchlet	2
Arenigobius bifrenatus	Bridled Goby	2
Arenigobius frenatus	Half-bridled goby	303
Atherinomorus vaigiensis	Ogilbys hardyhead	113
Bathygobius krefftii	Kreffts goby	29
Carcharhinus obscurus	Dusky Whaler Shark	1
Centropogon australis	Eastern fortescue	186
Dasyatis spp	Stingray	3
Dicotylichthys punctulatus	Three-bar porcupinefish	1
Dinolestes lewini	Longfin Pike	1
Favonigobius exquisitus	Exquisite Sandgoby	7
Favonigobius lateralis	Southern Longfin Goby	3
Gerres subfasciatus	Silver biddy	40
Girella tricuspidata	Luderick	9
Herklotsichthys castelnaui	Southern Herring	123
Heteroclinus spp	Weedfish	6
Hyperlophus vittatus	Sandy Sprat	9
Hyporhamphus regularis ardelio	Eastern River garfish	88
Leptatherina presbyteroides	Silverfish	5
Liza argentea	Flat-tail mullet	19
Meuschenia trachylepis	Yellowfin Leatherjacket	13
Mugil cephalus	Striped mullet	23
Mullidae spp.	Goatfish	1
Ophisurus serpens	Giant snake eel	1
Pelates sexlineatus	Eastern Striped Trumpeter	130
Platycephalus fuscus	Dusky flathead	3
Pomatomus saltatrix	Tailor	58
Pseudorhombus jenynsii	Small-toothed flounder	13
Repomucenus calcaratus	Spotted stinkfish	2
Rhabdosargus sarba	Tarwhine	31
Sarda australis	Australian Bonito	2
Sillago ciliata	Sand whiting	92
Sillago maculata	Trumpeter whiting	5
Tetractenos glaber	Smooth toadfish	2
Tetractenos hamiltoni	Common toad	2
Torquigener pleurogramma	Weeping toad	1
Trygonoptera testacea	Common Stingaree	1
Trygonorrhina fasciata	Southern fiddler ray	1
Upeneichthys spp.*	Goatfish	2
Vanacampus margaritifer	Mother-of-pearl Pipefish	1
	Total Number Caught	**1391**
	Total number Species	**43**

Wallis Lake Sites

Species	Common name	Number Caught
Acanthopagrus australis	Yellowfin bream	20
Afurcagobius tamarensis	Tamar River Goby	32
Aldrichetta forsteri	Yelloweye mullet	3
Ambassis jacksoniensis	Port Jackson perchlet (Glassfish)	1502
Ambassis marianus	Estuary perchlet	79
Arenigobius bifrenatus	Bridled Goby	161
Arenigobius frenatus	Half-bridled goby	52
Arenigobius spp	Goby	1
Atherinomorus vaigiensis	Ogilbys hardyhead	77
Bathygobius krefftii	Kreffts goby	3
Centropogon australis	Eastern fortescue	49
Chrysophrys auratus	Snapper	2
Cryptocentroides gobioides	Crested Oystergoby	3
Dasyatis spp	Stingray	2
Dinolestes lewini	Longfin Pike	4
Echeneis naucrates	Slender Suckerfish	1
Favonigobius exquisitus	Exquisite Sandgoby	14
Favonigobius lateralis	Southern Longfin Goby	6
Gerres subfasciatus	Silver biddy	117
Girella tricuspidata	Luderick	40
Herklotsichthys castelnaui	Southern Herring	327
Hyperlophus vittatus	Sandy Sprat	19
Leptatherina presbyteroides	Silverfish	1
Liza argentea	Flat-tail mullet	29
Meuschenia trachylepis	Yellowfin Leatherjacket	32
Monodactylus argenteus	Silver batfish	2
Mugil cephalus	Striped mullet	66
Pelates sexlineatus	Eastern Striped Trumpeter	194
Petroscirtes lupus	Brown sabretooth blenny	1
Philypnodon grandiceps	Flathead gudgeon	91
Platycephalus fuscus	Dusky flathead	3
Pomatomus saltatrix	Tailor	17
Pseudogobius olorum	Swan River Goby	37
Pseudorhombus jenynsii	Small-toothed flounder	1
Redigobius macrostoma	Large-mouth goby	40
Rhabdosargus sarba	Tarwhine	21
Scatophagus argus	Spotted scat	1
Sillago ciliata	Sand whiting	31
Siphamia roseigaster	Silver siphonfish	17
Synaptura nigra	Black sole	1
Tetractenos hamiltoni	Common toad	7
Urocampus carinirostris	Hairy pipefish	1
	Total Number Caught	**3107**
	Total Number Species	**42**

Appendix 7 - Red Spot or Epizootic ulcerative syndrome (EUS)

Taken from: http://www.dpi.nsw.gov.au/fisheries/pests-diseases/animal-health/wildfish-shellfish

Epizootic ulcerative syndrome (EUS) or 'red spot disease' is a disease that can affect many species of fish. Red spot disease is known to be endemic in a number of coastal waterways in NSW. In 2009 reports of red spot disease have been confirmed in Port Stephens and the Clarence River and reported from the Richmond, Manning, Macleay and Tweed Rivers.

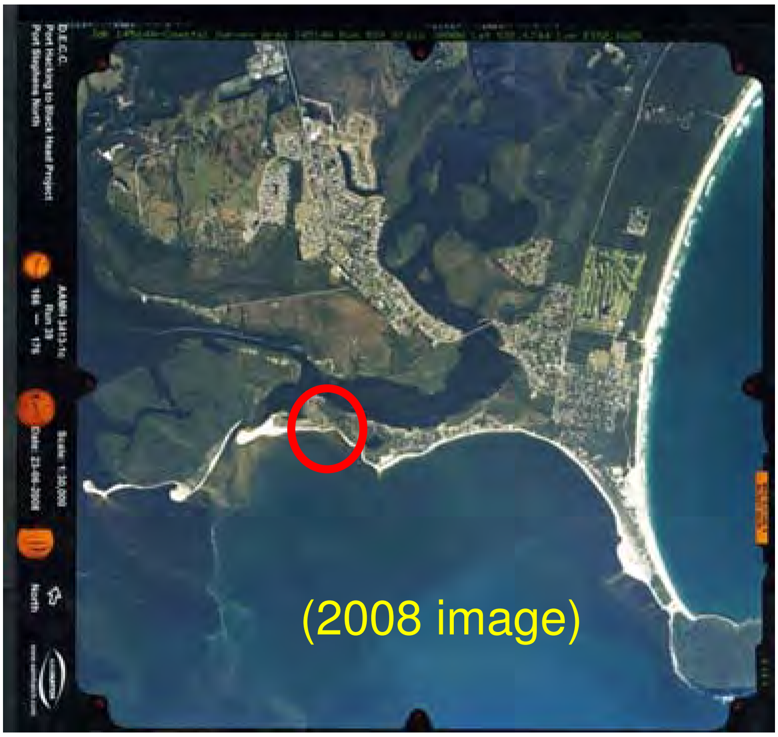
2008 was a particularly bad year for red spot disease, with reports of ulcerated fish and confirmation of this disease in a number of estuaries including the Manning River in February, the Wisemans Ferry area of Hawkesbury River in March and in Myall Lakes in September. Red spot disease was also reported from a number of mid-north coast NSW estuaries in 2008, including Macleay, Richmond, Clarence, Hastings and Wallamba Rivers. In addition to these coastal reports of red spot disease, fish sampled between Bourke and Brewarrina in the Darling River during May 2008 were also diagnosed with EUS.

EUS is caused by a fungus (*Aphanomyces invadans*) and shows as red lesions (sores) or deep ulcers. Secondary bacterial infections are often also associated with red spot disease.

Red spot disease is reasonably common in NSW coastal catchments and has been previously reported in many freshwater catchments and estuaries throughout Australia, including NSW, Queensland, Western Australia and the Northern Territory. Many fish species are known to be susceptible to the disease including bony bream, silver scat, sole, bream, mullet, whiting, dusky flathead, silver trevally, eels and catfish.

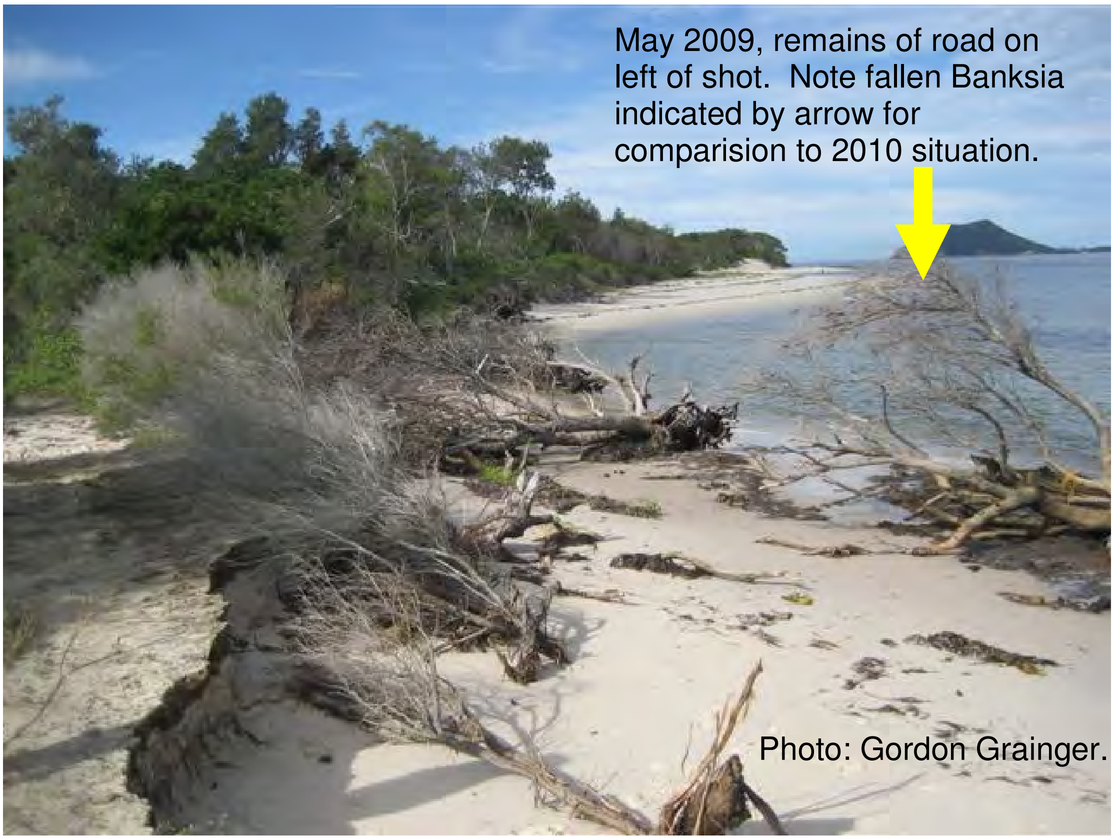
Previous outbreaks of red spot disease have been associated with acid water run-off, particularly after heavy rain following a prolonged a dry spell, as well as other factors such as prolonged cold temperatures, crowding, and conditions associated with drought.

Appendix 8 - Winda Woppa Erosion



May 2009, erosion back past road, high tide connection to mangrove forest on river side of spit.

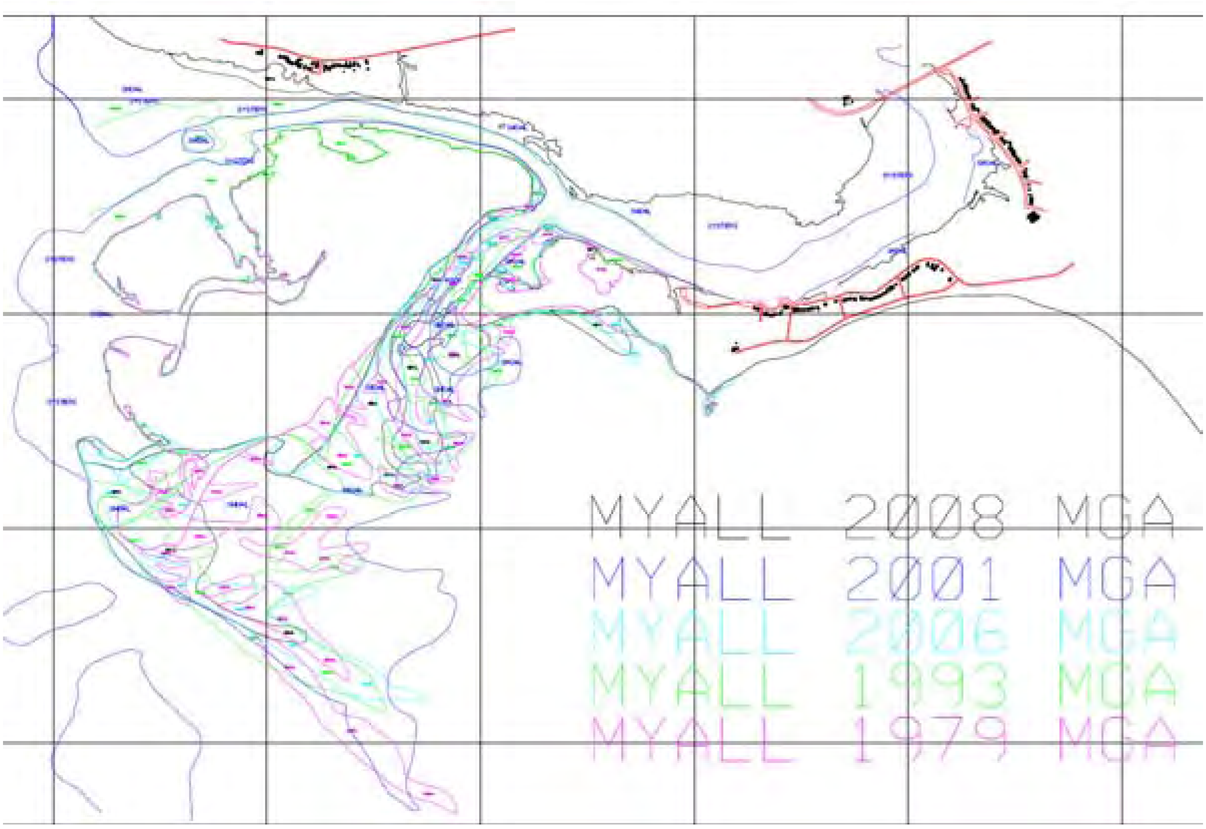
Photo: Gordon Grainger



May 2009, remains of road on left of shot. Note fallen Banksia indicated by arrow for comparision to 2010 situation.

Photo: Gordon Grainger.

11 am, 29 July 2010. Road is gone, small dune has formed. Considerable sand has washed over berm into saltmarsh fringe and mangroves behind. Note fallen Banksia indicated by arrow for comparision to previous photo.



Plots of shoreline position provided by Bruce Coates, Principal Data Specialist, Coast and Flood Policy, DECCWW