Report on condition and trends in water quality in central Queensland estuaries 1993 to 2015

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Contents

Executive summary

Since 1993, the Queensland Government, initially through the Environmental Protection Agency (EPA), then the Department of Environment and Resource Management, and now through the Department of Environment and Science (DES), has been undertaking a long-term program of water quality monitoring at around 80 sites in nine estuaries and two enclosed coastal waters in central Queensland, between Rockhampton and Tin Can Inlet. The program is known as the Central Queensland Ambient Monitoring Program.

The main aims of the program are to assess water quality in these estuarine and coastal waters with respect to both condition and long-term trend, although the data collected serves many other purposes, including input to environmental impact statements, input to licensing decisions, use by natural resource management bodies, including for regional reef report cards, and use as base data for deriving water quality guidelines.

This report describes the monitoring program, provides an analysis of available data up to mid-2015, and reports on the findings. The report also makes recommendations regarding the future direction of the program.

The nature of the monitoring program – routine monthly sampling – means that, while the data is suitable for assessing condition and trends in baseline or ambient water quality, it is not suitable for assessing the loads of pollutants entering estuaries or passing through estuaries into the coastal zone.

The program scope includes a range of basic water quality indicators that are the same as those employed in estuary monitoring in the Ecosystem Health Monitoring Program in south-east Queensland. It thus does not include indicators of any toxicants or heavy metals.

The main findings of the report are:

- While water quality condition in many of the estuaries in this region is impacted to varying degrees, for the most part these impacts can be described as minor to moderate. The most significant impacts are caused by point discharges, but there are some instances where impacts must be attributed to diffuse pollutants, although in most cases the actual causes cannot be precisely identified.
- The variation in climatic conditions during the program greatly increased the difficulties in the assessment of overall long-term trends. While climatic variation can to some extent be allowed for in the statistical analysis, this does not fully address the issue, and it was clear that statistically significant trends could not be simply accepted at face value. Therefore, all statistical trends were subjected to further assessment and expert opinion before being accepted as trends of real environmental significance.
- Overall, it was found that there were relatively few trends in water quality. Temporal variations that did occur were largely attributable to climate variation and, for the most part, water quality in most estuaries was remarkably stable over the 15–20 year period assessed. This in itself is a finding of some interest.
- Numerous small, statistically significant improving trends were detected, but it is thought that most of these had little real environmental significance. Of the really significant improving trends, most were related to upgrades in the quality of point discharges.

- Deteriorating trends were mostly minor, but there were some concerning decreases in clarity in the waters of the Great Sandy Straits. It’s possible that this relates to a very long-term water quality cycle.
- For the most part, it would appear that any changes in water quality related to changes in catchment management are very slow to take effect and it would take considerably longer than the span of this program to detect any such changes. There was some evidence from data in the Great Sandy Straits that very long-term cycles (~20 years) in water quality can occur.
- The extensive data collected in this program provides an excellent foundation on which to base future management of water quality in these estuaries.

The main recommendations of the report are:

- The ambient water monitoring program in central Queensland has been ongoing for over 20 years. It continues to address the main aim, to assess change over time, but the data has also been used for a wide range of other purposes. Having collected, and now analysed, over 20 continuous years of data, we are in a good position to make informed judgments about the design of the program and the nature and true value of the data. As with all long-term programs, it is important that this program be reviewed and, with the completion of this extensive data analysis, it is appropriate that such a review be undertaken at this time. Such a review should make recommendations about the future design of the program. However, there are an increasing number of factors which will constrain the extent to which the program can be modified. The main ones are described below:

    - Data from this and allied monitoring programs in north Queensland are increasingly being used as key inputs to the estuary component of regional reef report cards. This includes data from Fitzroy estuary sites used in the Fitzroy report card, and data from the Calliope and Boyne estuaries which both adjoin Port Curtis, currently a high priority report card area .
    - Many of the sites will need to be continued due to priorities associated with individual estuaries. These include:
        - Fitzroy – monitoring is associated with ongoing assessment of sewage treatment plants and other discharges, and receives some Receiving Environment Monitoring Program funding
        - Baffle Creek – this is a key reference estuary and, as such, maintaining a long-term dataset has high strategic significance
        - Burnett – DES receives funding from Bundaberg Regional Council to undertake monitoring, and so we need to continue the program here
        - Mary – a significant estuary with discharges from Maryborough and large catchment impacts
        - Great Sandy Strait – an iconic area which is also an important marine park.

    - Long-term water quality datasets are difficult to achieve, and become increasingly valuable over time. They are often used for purposes which may not be envisioned at the start of the program (e.g. tracking climate change effects). Interrupting or altering a long-term program, and thus creating disturbances to the dataset, should therefore never be implemented without very careful consideration.

- While there are important constraints, it is still timely that the program be reviewed and recommendations made about its design, even if this only confirms that the program should continue largely unchanged.

- While the current program is very much focused on monitoring of waterway condition, it is equally important to undertake parallel monitoring of the various pressures that impact on condition (e.g. land use and other anthropogenic catchment activities). This information can be used to address different types of questions:
  - Firstly, if a change in condition is recorded, then the immediate question is why? If there is information on parallel changes in pressures, then this question can be addressed and this also provides direction in terms of management needs.
  - Alternatively, if a change in condition is recorded but there are no changes in pressures, then this raises questions about indicators and methods and the possible need to revise them.
  - Thirdly, if no change in condition is recorded but pressures have changed, then this might similarly indicate a problem with indicators or, alternatively, that the particular changes in pressures are of no consequence for the water body.
  - Whatever the scenario, the possession of relevant pressure data allows a much more informed assessment of the condition data to be made.

- A further important reason for assessing pressures is that it allows informed judgments about monitoring priorities. Thus, where no changes in pressures have occurred, the risk would be assessed as low and monitoring resources could be directed to higher risk waters. Conversely, where major increases in pressures have occurred, this would indicate a higher priority for monitoring.

- The current program design is best suited to assessing estuary condition under base-flow conditions. However, over the 20 years of the program, a proportion of samples were collected in post-event periods, and it was clear that the poorest water quality mostly occurs in these periods. Monthly monitoring rarely captures these short-lived post-event periods, and does not in any case cover them adequately. However, technical advances in remote instrumentation are starting to allow us to acquire much more comprehensive data during these highly variable periods. It is therefore recommended that more effort be put into this type of monitoring, which allows us to acquire good data during post-event periods. This will provide a better understanding of the magnitude of short-term variation under base-flow conditions.

- The very significant data set now available will also provide a strong basis for modelling water quality in estuaries. Such models could be used to predict both ambient condition and to provide a better basis for understanding of the impacts of diffuse source pollutants on estuaries.

- The current program is very much focused on water quality issues. From other studies, it has become apparent that water quality is only one of a range of issues affecting Queensland estuaries and coastal waters. Issues such as habitat modification, reduction of inflows due to impoundments and the reduction in connectivity with freshwater reaches can all significantly impact on estuaries. To address these issues, monitoring programs need to have a broader ambit than just water quality. A framework for undertaking more broad-based assessments has been recently developed by the Coastal Cooperative Research Centre (Moss et al. 2006). It is recommended that consideration be given to applying this assessment framework to the monitoring of all estuaries in Queensland.

1 Introduction

Responsibility for managing Queensland's waters lies principally with the Queensland Department of Environment and Heritage Protection (EHP) and the Queensland Department of Natural Resources (NRM). To assess the success of their management activities, both departments undertake a number of water quality monitoring programs. One of these programs – the Central Queensland Ambient Monitoring Program (CQAMP) – covers the major estuaries and some inshore coastal waters of subtropical central Queensland. The region covered extends from the Fitzroy River estuary south to Tin Can Inlet. Figure 1.1 provides an overview of the estuaries and sampling sites. This program is undertaken by the Queensland Department of Environment and Science (DES).

The CQAMP is a long-term program, and its principal aims are to assess trends in the quality of these waters and to assess the quality against guidelines. The program also provides important base data for licensing, environmental impact statements, guidelines and general natural resource management use. The program commenced in 1993 and is still continuing. A report on the program results up to 2006 has been completed and is available on the Queensland Department of Environment and Science website (Queensland Department of Environment and Science 2012).

This current report covers all data up to mid-2015, and similarly reports on condition and trend. However, this second report does use some more advanced statistical methods to assess trends. The additional data up to 2015 also provides a better basis on which to make inferences about long-term trends.

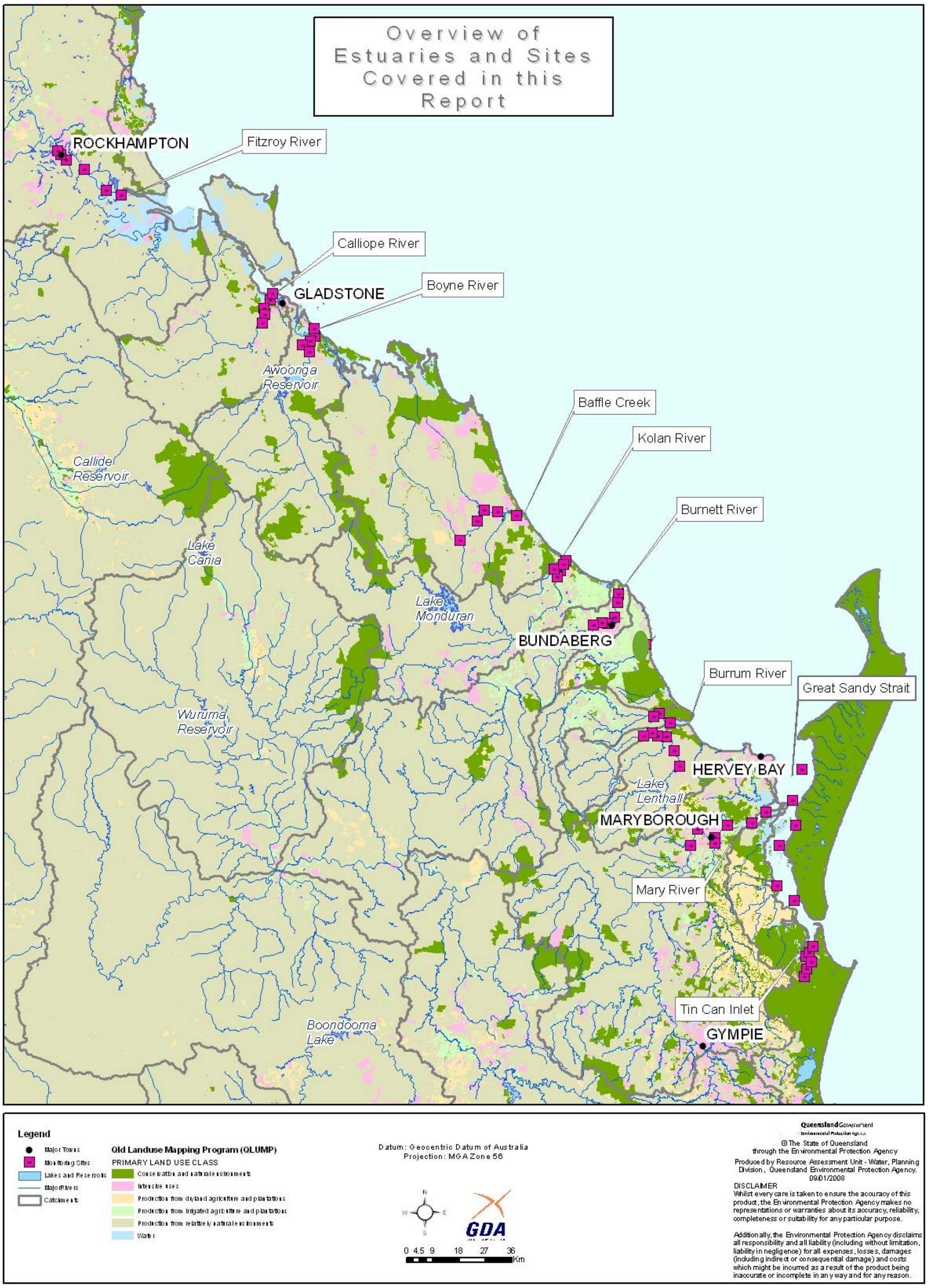

Figure 1.1: Overview of waters and sites covered in this report

2 Description of Central Queensland Ambient Monitoring Program

2.1 Scope of program

In 1993, a statewide Ambient Monitoring Program for water quality was initiated. In its original form, the Ambient Monitoring Program covered a selection of Queensland east coast waters from Daintree in far north Queensland down to the New South Wales (NSW) border. These included freshwaters, estuaries and coastal waters. A total of 426 sites were sampled on a monthly basis.

In 1999, due to resource limitations, sampling in the north of the state (i.e. from Mackay north) ceased. A report on the data from wet tropics streams between 1992 and 1999 is available (Queensland Department of Environment and Heritage Protection 2006).

From 2000 onwards, the South East Queensland component of the program (from Noosa south to the NSW border) was subsumed into the Ecological Health Monitoring Program (EHMP) of the South East Queensland Healthy Waterways program. It is now reported on as part of that program (http://hlw.org.au/report-card/monitoring-program).

These changes resulted in the Ambient Monitoring Program being reduced to its present form that covers estuaries and sheltered coastal waters in central Queensland (see Figure 1.1). The program is now called the Central Queensland Ambient Monitoring Program (CQAMP).

2.2 Aims of program

As a long-term (i.e. ongoing over many years) program, one of the principal aims of the CQAMP is to assess long-term changes or trends in water quality. In other words, the program was designed to address the general question: ‘Is water quality getting better or worse or staying the same?’ Trends might be negative due to increased development, or positive as a result of improved management of point or diffuse pollutant sources.

In addition to meeting the main aim, the data from the program can be used to address questions about current condition, although an ongoing long-term program would not be required if this was the only aim of the program.

The data collected also represents a valuable information resource and is used for a number of other related purposes. These include use as baseline data for the *Queensland Water Quality Guidelines*; as background for undertaking and assessing environmental impact statements; for licensing discharges to waters; and as a general data source for members of the public, particularly catchment and land care groups, to gain an understanding of water quality in their area. The data is also used in State of the Environment reporting (EHP, 1999, 2003, 2007). Additional unforeseen uses may also arise.

2.3 Sampling strategy

The CQAMP was designed as an ongoing program that principally aimed to detect long-term trends in water quality. To address this aim, the sampling strategy adopted was to undertake regular (monthly) sampling at a set of fixed sites over as long a period as possible. In most estuaries, the sites were distributed to cover the full length of the estuary. Thus the range of data from each estuary is comparable. A partial exception to this was the Fitzroy estuary, which was too long to allow us to readily sample the lower reaches of the estuary within a day. However, the main interest in the Fitzroy is in water quality in its upper reaches.

In order to reduce the effect of tidal variation to a minimum, sampling was always undertaken under similar tidal conditions i.e. on a falling tide.

With this type of routine monthly sampling, most samples are collected during base-flow conditions. This approach therefore provides a reasonable assessment of water quality under base-flow conditions and thus allows an assessment of trends under these conditions.

In Queensland streams (and therefore in downstream estuaries and coastal waters), high flow events tend to occur infrequently and at unpredictable intervals, although they predominantly occur during the summer months. They are also usually short-lived (a few days), and during that time water quality is highly variable and quite different to base-flow quality. Typically, monthly sampling will pick up only one or two such events over a 12-month period. Given the small number of events sampled and the fact that quality during such events is in any case highly variable, routine monthly sampling cannot provide more than a general characterisation of water quality under high flows. Nevertheless, where sampling is continued over a period of years, as was the case with this program, it becomes possible to make some general inferences about quality under high flow conditions.

2.4 Indicators

The CQAMP is aimed at assessing basic water quality characteristics and includes the indicators below. More detail on these indicators is provided in Appendix D.

Field measurements

- Conductivity
- Temperature
- pH
- Dissolved oxygen
- Turbidity
- Secchi depth

Laboratory measurements

- Organic nitrogen
- Ammonia
- Nitrate plus nitrite (oxidised nitrogen or NOx)
- Total nitrogen
- Total phosphorus
- Filterable reactive phosphorus
- Chlorophyll *a*

Temporal variations in estuary water quality can occur related to the tidal cycle, and there is also the well-established diurnal variability in indicators such as dissolved oxygen (DO) and pH. In this monitoring program, tidal-related variation was addressed as far as possible by always undertaking the surveys on or around the mid-ebb period. The high tide would have been easier from a logistical point of view (deeper water), but this would have meant that in effect we would be sampling seawater in the lower reaches of the estuary, when the main aim was to assess what was happening in the estuary itself.

Diurnal variation in indicators could only be addressed in so far as surveys were always carried out during the day. This is not ideal, but logistically there was little alternative. More recent data collected with continuous monitoring instruments has shown that DO does not in fact exhibit a large diurnal variation in most estuaries (usually less than 5% saturation change during the day). Turbidity is a different matter, and does vary significantly, although this is much more pronounced where turbidity levels are above 10–20 nephelometric turbidity units (NTU). Despite these issues, values of these indicators were for the most part relatively consistent over time.

Field measurements were taken at all sites but, due to resource limitations, nutrients (i.e. all forms of nitrogen and phosphorus) and chlorophyll *a* were only sampled at a subset of sites. A tabulation of all sites and indicators monitored at each site is provided in Appendix A.

2.5 Site names and locations

Site names in estuaries are denoted by distance upstream from the mouth of the estuary (e.g. site 17.1 in the Burnett estuary is 17.1 kilometres from the mouth). These distances are based on the Adopted Middle Thread Distances (AMTD) established by the Queensland Water Resources Commission in the 1950s for all major streams in the state.

Site names in the coastal waters are denoted as abbreviated Australian Mapping Grid (AMG) coordinates. The site names are six digits long and are based on the last three digits of the full easting and northing of the site.

2.6 Quality assurance

Quality assurance (QA) is an important component of any water quality monitoring program, but becomes particularly important in programs that are seeking to detect relatively small changes over long time periods. Simply because long time periods (many years) are involved, there are inevitably changes in field instrumentation and laboratory methods. These can result in changes in sensitivity, accuracy or detection limits. When dealing with low levels of an indicator or very small variations of an indicator, such changes can confound attempts to detect underlying trends. The changes in methods are nearly always improvements, but the effect in some cases is to make it problematic to validly combine the pre- and post-change data into one time series.

Where changes in detection limits occurred, the approach used was to maintain the earlier detection limit as the minimum value. Where results were recorded as less than this value, the detection limit value was used for assessing condition or trend. Using this approach, instead of using half the detection limit as is often employed, in fact makes little difference to condition (these low values are below guidelines in either case) or trend assessment.

A number of QA or change of analysis issues arose in the early years of the CQAMP. These were discussed in detail in the first report on this program (Queensland Department of Environment and Heritage Protection 2013) and are not repeated here. To varying degrees, these issues confounded our ability to detect small trends. Most of the issues were rectified or otherwise allowed for in the analysis of the data, so that false identification of trends was avoided. Nevertheless, the issues affected the power to detect trends. These issues were identified and very largely rectified by 1999. For this updated report, a decision was made to undertake the primary trend analysis on data post mid-1999. However, for indicators that were largely un-impacted by early QA issues (Secchi depth, turbidity, oxidised nitrogen and chlorophyll *a*), trends calculated from 1993 onwards were also taken into consideration whenever there were significant differences from the post mid-1999 trends. Conclusions in these cases were based on both sets of trend analyses.

3 Overview of the report study area and its estuaries and coastal waters

3.1 Description of estuaries and coastal waters

The region covered by this report is located in the subtropics, extending from the Fitzroy River south to Tin Can Inlet (Figure 1.1). Its catchments range in size from the Fitzroy, which is over 140,000 km^2 in area and extends far inland, to smaller coastal catchments such as the Kolan, just north of Bundaberg. Land use in the region is predominantly grazing, but there are significant areas of cane cultivation in some catchments and some smaller areas of intensive irrigated agriculture.

This report covers 80 sites in 11 estuarine and inshore coastal waters in central Queensland between Rockhampton and Tin Can Inlet. Figure 1.1 provides an overview of site locations, while more detailed maps for individual waterways are provided in the trend results section of this report. The main water bodies sampled are listed below in Table 3.1, while Appendix B provides a complete list of sites, their locations (expressed either as AMTD or AMG locations), together with the indicators that were monitored at each site. Note that, for the purposes of this report, the data analyses do not include every single site, but are restricted to a representative set of sites in each waterway. Similarly, only a representative set of indicators has been analysed in detail.

Table 3.1: Water bodies monitored in this program

Fitzroy River estuary	Burnett River estuary
Calliope River estuary	Burrum/Isis/Gregory River estuary
Boyne River estuary	Mary River estuary
Baffle Creek estuary	Great Sandy Straits (inshore coastal)
Kolan River estuary	Tin Can Inlet (inshore coastal)

The estuaries selected for the program include all the major estuaries in this region. Some are adjacent to urban areas and receive treated discharges, while others are relatively pristine. There are also a considerable number of smaller estuaries in this region, but these could not be included in the program due to resource limitations.

The two coastal water bodies are the Great Sandy Straits, tidal waters enclosed by Fraser Island, and Tin Can Inlet, which is a southward extension of the Great Sandy Straits and is enclosed by Rainbow Beach and Inskip Point. Both are relatively pristine, but at times the Great Sandy Straits are impacted by flood events in the Mary River.

3.2 Overview of estuary water quality behaviour in central Queensland

The climate in this region is characterised by long periods of dry weather with intermittent and generally short-lived periods of heavy rainfall, which mainly occur in the December to March 'wet season'. However, there is a high degree of annual variability in the extent of rainfall during the wet season, and there are also occasional large rainfall events at other times of the year.

The rainfall climate is reflected in freshwater stream flows, which are very low or nil for much of the time, with occasional short-lived, high flow events. These flow patterns in turn affect the hydrology of the region's estuaries. Thus, in most years, estuaries experience extended periods of low or nil inflows, during which time their hydrology is dominated by tidal water movements. Mean tidal range in this region varies from ~2 metres in the south to ~3.5 metres in the Fitzroy at the northern end. Tidal exchange with coastal waters can be quite rapid in the lower reaches of estuaries, but in the mid and upper reaches exchange rates may be very slow, and water residence times can typically be in the order of months. Water residence time is a key issue in determining the magnitude of impact of human-induced stresses. The longer the residence time, the greater the impact is likely to be.

Following a high flow event, large quantities of freshwater enter the estuary, and for a short period this dominates estuary hydrology. However, as high flows are generally short-lived, tidal effects resume a dominant role, usually within days in the lower reaches or weeks in the upper reaches. In ensuing dry periods, freshwater is gradually flushed out of the estuary by tidal exchange. Figure 3.1 illustrates a typical estuary conductivity (used in this report as a measure of salinity) cycle using data from a mid-estuary site in the Burrum estuary, with low values occurring immediately after flood events, and then conductivity gradually increasing during subsequent dry months due to tidally driven exchange with coastal waters. Note that in some years, the wet season rainfall can be very low (e.g. from 2004 to 2007).

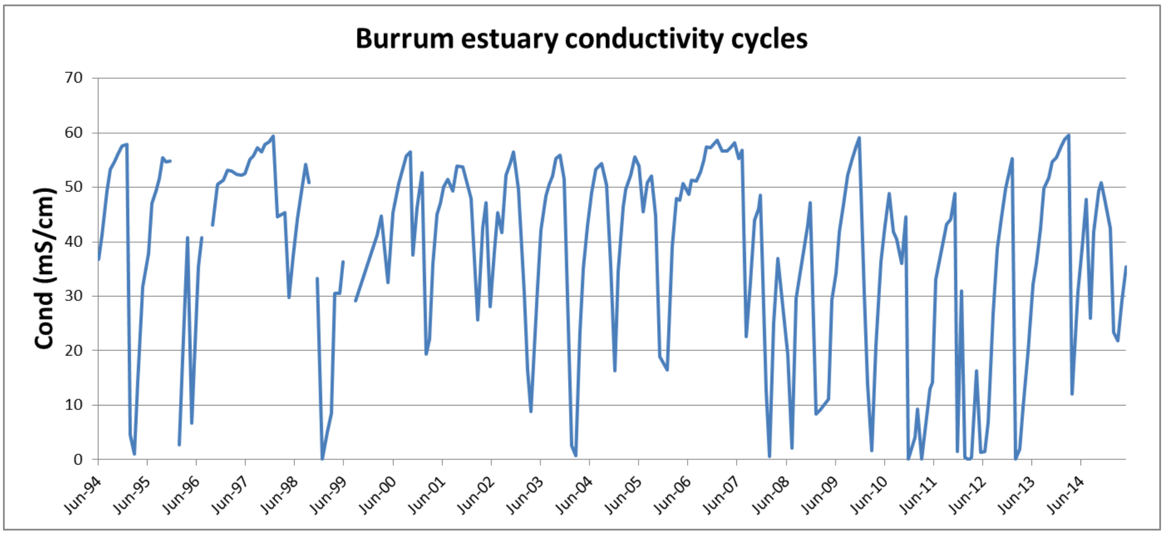

Figure 3.1: Conductivity cycles in the Burrum River estuary

During the extended low flow periods, estuary water quality remains relatively consistent apart from the steadily increasing conductivity. High flow events dump diffuse source loads of fine sediment, organic matter and nutrients into estuaries causing short-lived but usually quite major changes in water quality. These include increased turbidity and nutrients and reduced DO levels. Once turbidity levels fall, there is often a burst of algal activity due to the increased nutrients, leading to increased chlorophyll *a* concentrations. Pollutants that enter with the freshwater inflow may be gradually flushed out along with the freshwater, or alternatively may be assimilated within the estuary.

Freshwater inflows are a natural feature of estuaries, and play an important role in their ecology, for example, in the breeding cycles of fish and invertebrate species, and in generating primary production which fuels the estuary food chain. However, clearing and development of catchments over the past 200 years has meant that the loads of natural pollutants associated with inflows (sediment, nutrients, organic matter) have significantly increased, with consequent intensification of their impacts. DO sags become larger, turbidity becomes more prolonged and extensive, and algal blooms are larger. Most of these effects are deleterious to the estuary. The magnitude of the diffuse source pollutant loads (and hence the magnitude of their impacts) is related to the extent of change to land use in the catchment, and also to land management practices in the catchment.

The monthly sampling protocol of the CQAMP is well suited to characterising the relatively stable water quality during extended dry periods. However, it is much less suited to assessing the rapidly changing water quality that occurs following infrequent large freshwater inflows. Nevertheless, over the period of the program, a number of high flow events have been captured, and some assessment of their impacts can be undertaken.

4 Climate effects on water quality

4.1 Characterisation of flow climate effects

The main aims of this report are to assess condition and underlying long-term trends in water quality. However, as outlined in the previous section, water quality in estuaries is strongly influenced by the extent and magnitude of antecedent freshwater inflows. Some more detailed examples of this are provided in Figures 4.1 to 4.4, plots of water quality indicators vs conductivity. Conductivity in Queensland estuaries is a useful surrogate for freshwater inflows, with low conductivities being indicative of recent significant inflows.

The data in all the plots is from Baffle Creek. This has a relatively undisturbed catchment, and so the effects of inflows are related to general catchment run-off, but are unaffected by any intensive anthropogenic activities (e.g. feed lots) or point sources of pollutants.

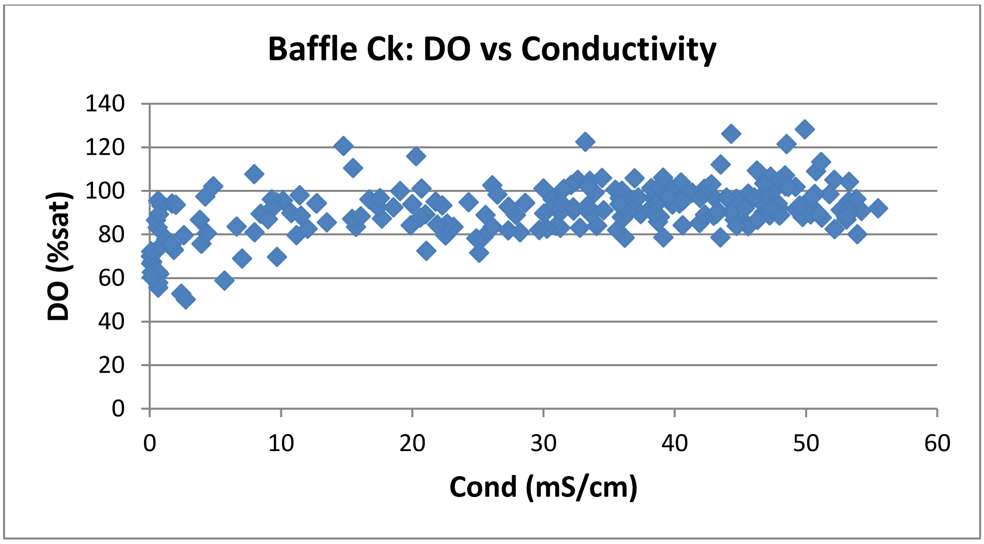

Figure 4.1: Effects of freshwater inflows on DO

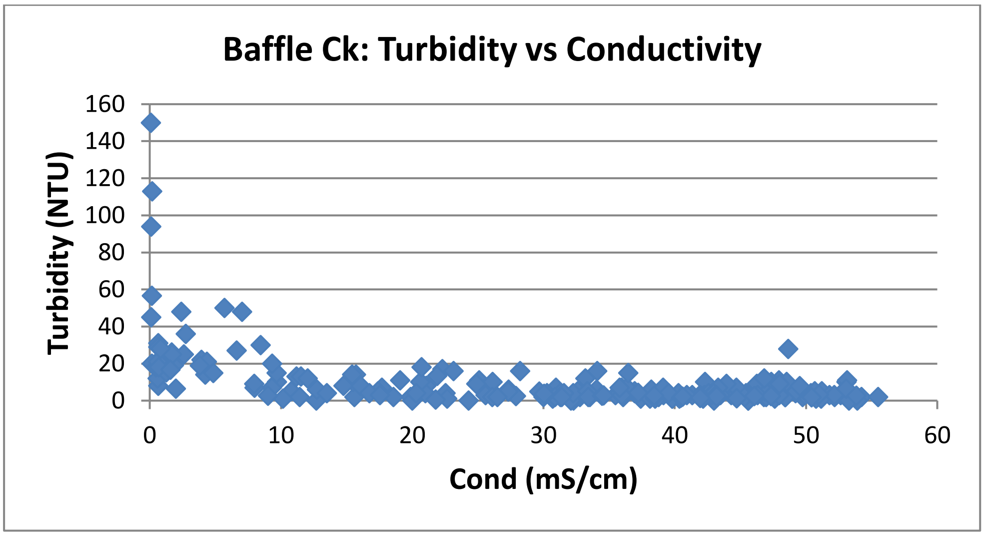

Figure 4.2: Effects of freshwater inflows on turbidity

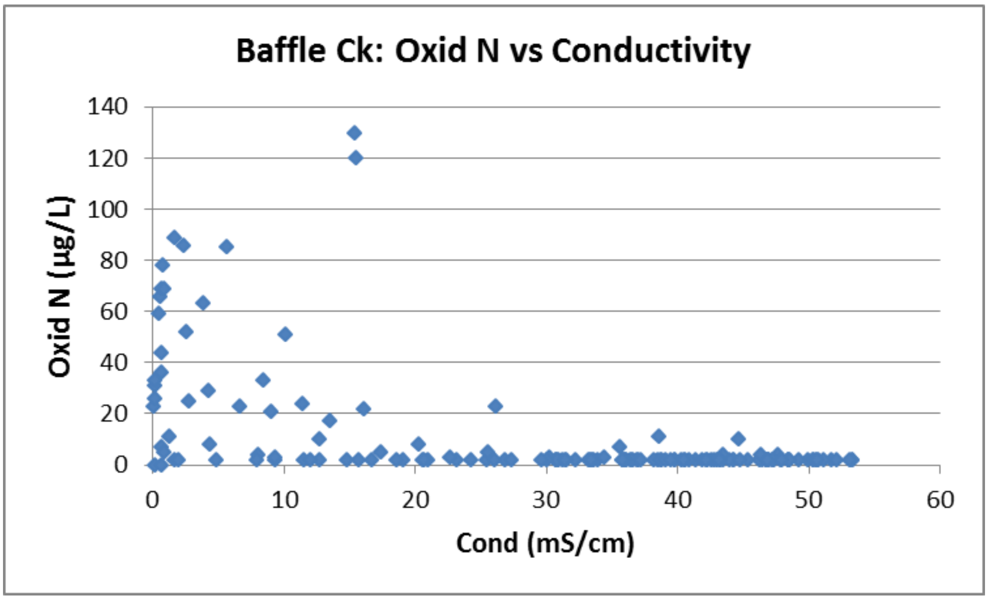

Figure 4.3: Effects of freshwater inflows on oxidised nitrogen

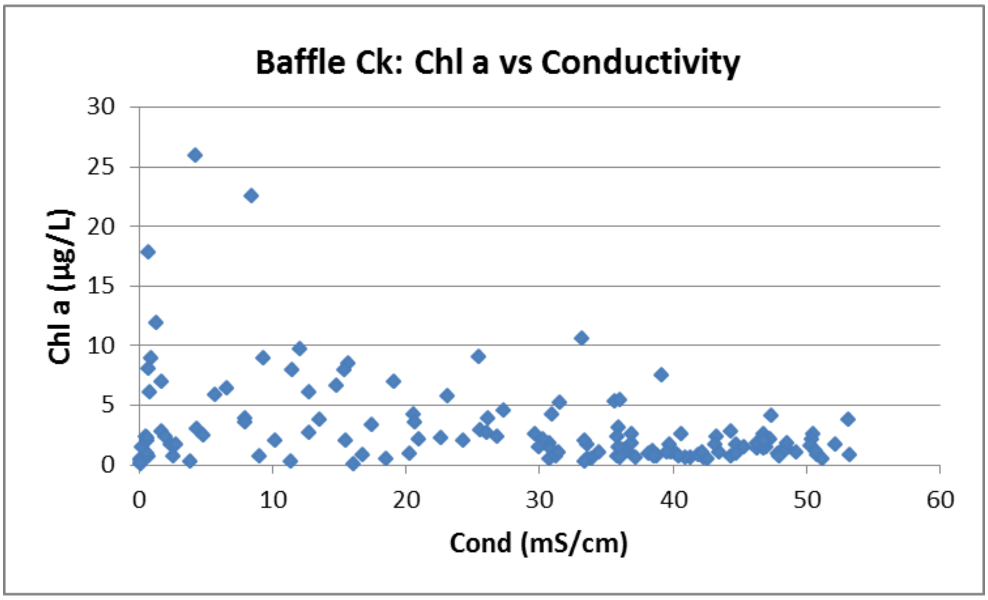

Figure 4.4: Effects of freshwater inflows on chlorophyll *a*

All the plots show a similar pattern, with water quality indicator concentrations relatively consistent at high to medium conductivity values (i.e. periods of moderate to low freshwater flows), but more variable and with higher concentrations (or lower in the case of DO) at low conductivity. The effects of significant freshwater inflows on estuary water quality are clearly evident in these plots.

This flow related variability has obvious consequences for condition and trend assessment. Condition may be reported as poor in wet years and good in dry years, even though underlying condition is unchanged. Similarly, uncorrected trend analysis is more likely to reflect wet–dry climate cycles than any underlying trend. Thus, any assessment of condition, and particularly trend, must take account of inflows and allow for their impacts on water quality.

A theoretical issue to be considered here is that, following flow events, estuary water quality is fundamentally different to water quality in dry weather, being related to quite different environmental conditions. It could therefore be argued that statistically, high flow and base-flow water quality should be considered as separate populations rather than as a combined dataset. This is a valid argument, but it introduces other difficulties such as the question of what is and is not a high flow situation, and how to deal with the grey area in between.

Due to these difficulties, separate assessment of the high and low flow datasets was not the approach used here. However, the issue has to be addressed, and the approaches used in this report for condition and trend assessment are detailed in sections 4.3 and 4.4.

4.2 Description of flow climate 1993–2016

The flow climate over the study period is illustrated in Figure 4.5, which shows monthly freshwater flows in rivers at the south (Mary) and north (Baffle) of the study area (NRM 2016). A more direct indication of the actual impacts on estuary salinity is provided in Figure 4.6, which shows the annual (lower) 20th percentile conductivity values for a mid-estuary site in Baffle Creek. The variation between years in these figures provides a measure of the likely extent of the impact of inflows on water quality in each year.

The figures demonstrate a consistent pattern, with variable but not extreme high or low flows up to 2005, a very dry period between 2005 and 2008, an extreme wet period from 2009 to 2013, and then a return to more average conditions in 2014 and 2015. This degree of variability is sufficient to impact significantly on both condition and trend assessments.

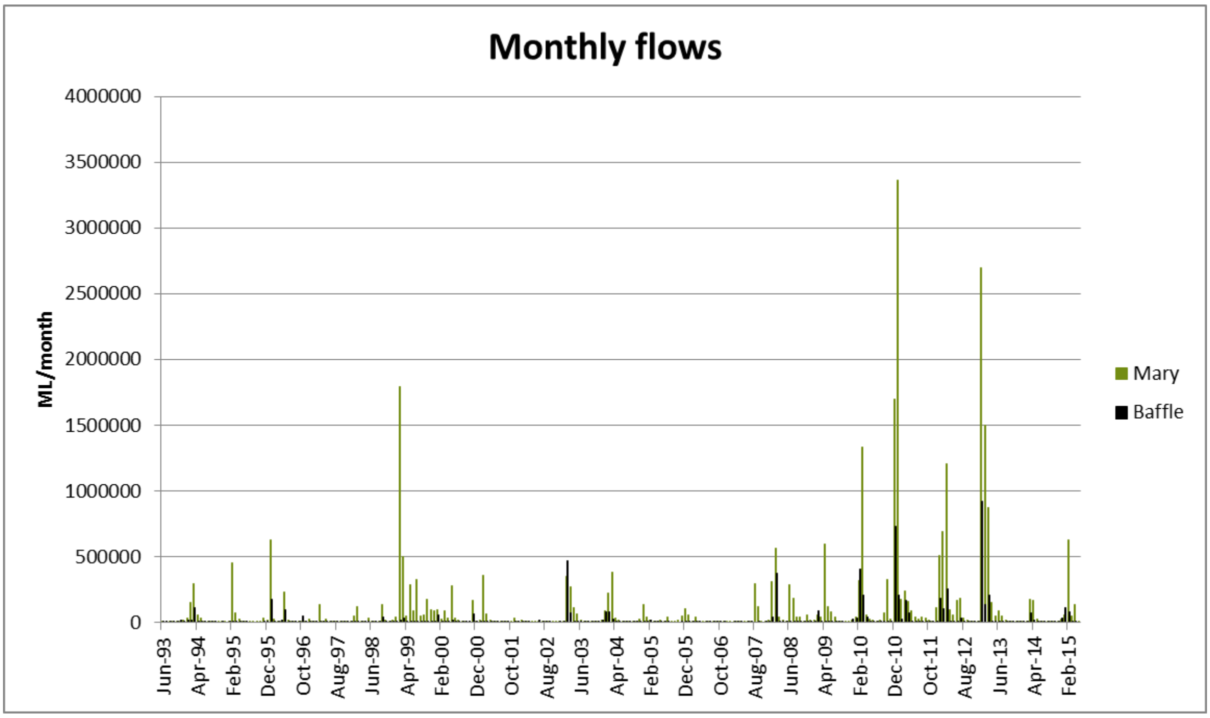

Figure 4.5: Monthly freshwater flows in two central Queensland streams (NRM data)

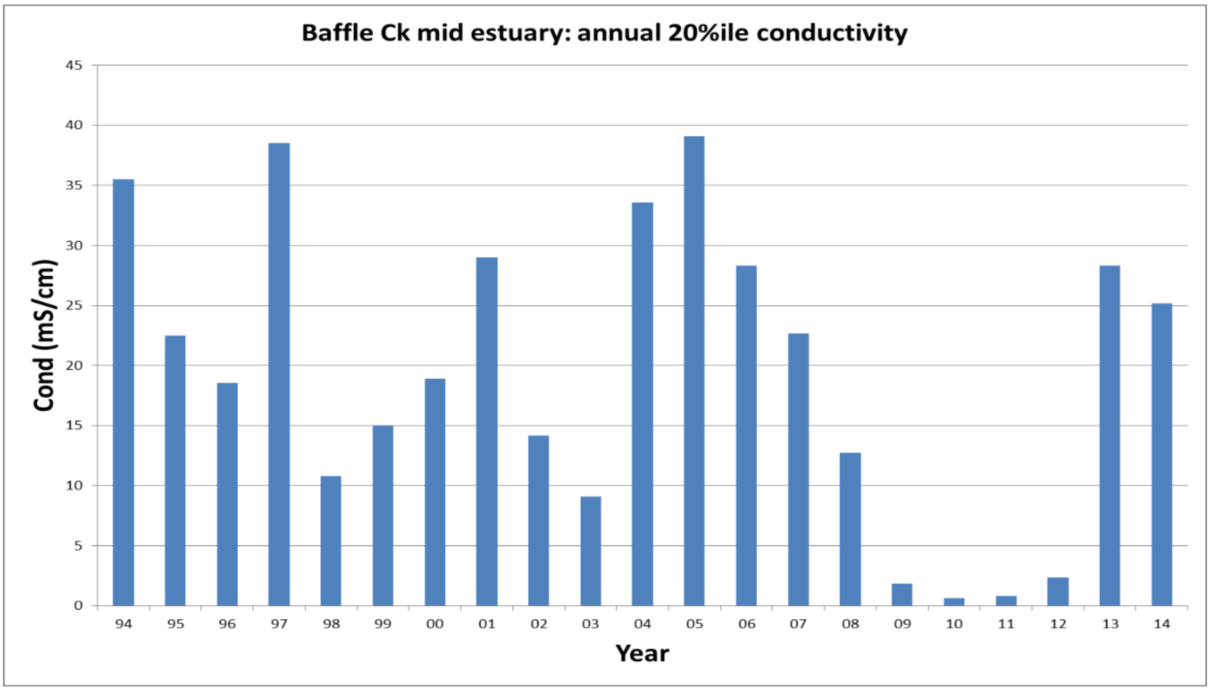

Figure 4.6: Annual conductivity data (20%ile) for the Baffle Creek estuary
(Year annotation: e.g. 94 ≡ 6/94 to 5/95)

4.3 Condition assessment: allowing for flow variation

With regard to condition, flow effects have been assessed using qualitative approaches. Firstly, condition assessment outcomes for individual years can be evaluated against the flow history in Figures 4.5 and 4.6. Where non-compliance with a guideline occurs in a wet year, this would generally be deemed to be of less significance than a similar non-compliance in a dry year.

A second approach has been to extend condition assessment to cover a five-year period as suggested by MacBride (2016). This would nearly always ensure the inclusion of both wet and dry years, so that a comparison between the two can be made. In this report, condition assessment is undertaken over the most recent five years (i.e. 2010–11 to 2014–15). As is apparent from the results in section 5, instances of non-compliance were more frequent in the initial three wet years.

4.4 Trend assessment: allowing for flow variation

With regard to trend, the effects of flow variation have been compensated for through the use of a flow related covariate within the Seasonal Kendall test, which is the trend assessment test used in this report. This test is described in detail in Section 7.3.

The flow-related covariate used in this report is conductivity, which in Queensland estuaries is a good measure of freshwater inflow history. The covariate is modelled against each indicator at each site to determine the best fit model. An example, based on the data in Figure 4.7, shows the covariate modelled against oxidised N using a Logarithmic Model.

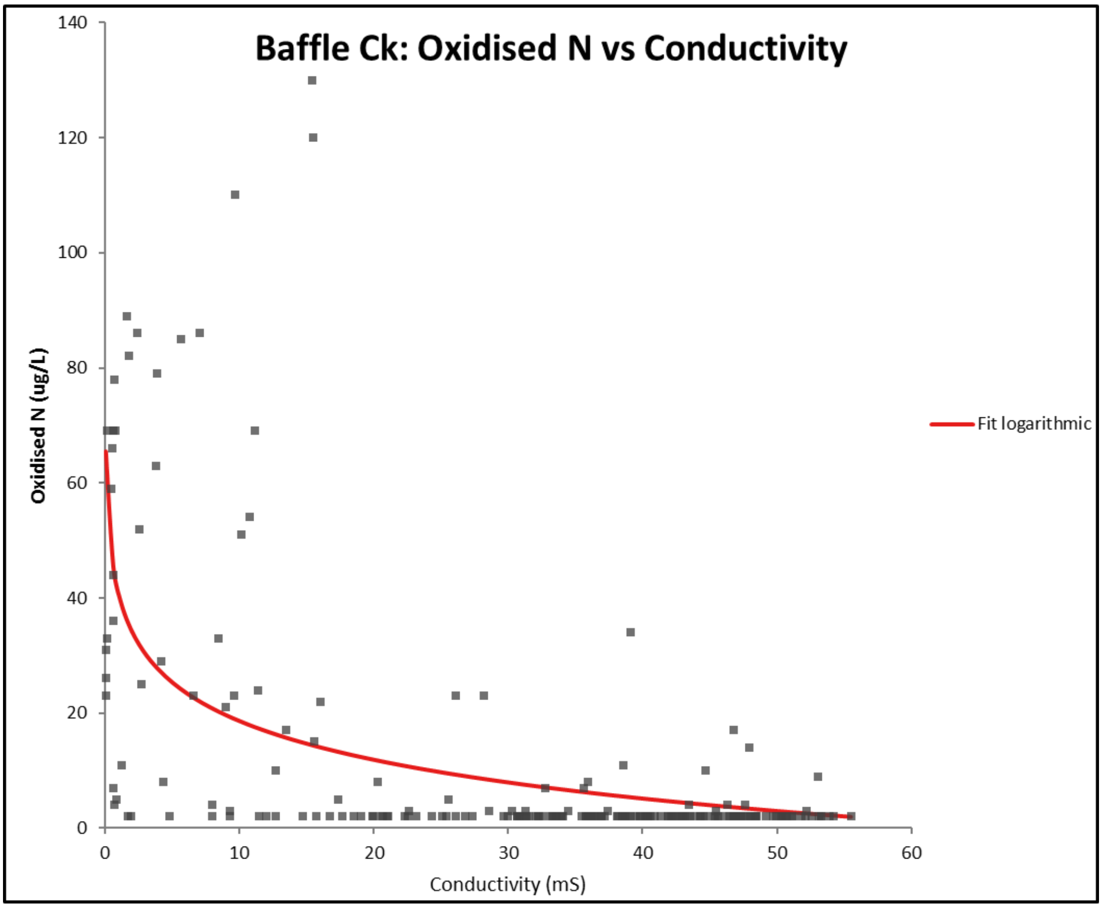

Figure 4.7: Conductivity covariate modelled against oxidised N (Log fit)

Based on the best fit model, residual values are calculated within the Time Trends software, and the seasonal Kendall test is run using these residual values rather than the raw data.

This approach has the merit of being quantitative. However, it is important to understand that the underlying complexity and temporal variation of flow impacts on water quality, and the fact that the modelled relationship between flow and water quality relies on a single covariate measurement in each month, means that even these quantitative adjustments are only approximate.

Given the fundamental differences between high and base-flow water quality, and also the issues involved with the use of covariates, a post-statistical assessment of trends based on expert opinion becomes a vital step in overall trend assessment. The combination of statistical testing and expert opinion will lead to a more balanced assessment of the real environmental significance of trends. This is discussed further in section 7.4.

5 Condition assessment methodology

5.1 Assessment criteria

The main aim of condition assessment is to determine if water quality is suitable to support one or more environmental values. For the purpose of this report, the environmental value of interest is ‘ecosystem protection’. The approach used to determine whether this value is protected is through comparison of existing water quality with the appropriate water quality guidelines for ecosystem protection.

Available water quality guidelines are designed to be compared with median values at a test site. Therefore, the main condition assessment method used in this report is to compare median values of selected indicators with recognised guideline values. While there are 20 years or so of data available for most waterways, condition assessment has been restricted to the five most recent years of data – i.e. 2010–11, 2011–12, 2012–13, 2013–14 and 2014–15 (years based on, e.g. June 2010 to May 2011). The use of a five-year period for assessment has been recommended in a report by MacBride (2016). In order to obtain a measure of annual variability, guidelines are compared with the median values (of the 12-monthly data values) for each individual year, rather than with median values of the pooled data for all five years. The guideline values used in this report are taken from the *Queensland Water Quality Guidelines* (EHP 2013) and are listed in Table 5.1.

Because different water types have naturally different water quality, separate guidelines need to be derived for each water type. There are a number of recognised water types but in this report, which is focused on estuaries and enclosed coastal waters, only three need to be considered:

- enclosed coastal/lower estuary (ECLE) – reaches near the mouth of the estuary and adjacent nearshore coastal waters
- mid-estuary (ME) – the main body of the estuary
- upper estuary (UE) – the poorly flushed most upstream reaches of estuaries.

These water types are defined more fully in Appendix B. There are separate sets of guideline values for each of these water types (see Table 5.1). All the sites reported on in this report have been classified into one of these categories (see Appendix A), and this determines which set of guidelines is used to assess each site.

While comparison of median values with guidelines provides a good guide to general condition, it takes no account of extreme values. For some indicators, extreme high or low values can have an important bearing on condition, even if they are relatively short-lived (e.g. very low levels of DO or pH). For this reason, the condition assessment also considers these values. As noted earlier in this report, these extreme values are usually associated with post-inflow event periods, when diffuse source pollutants are impacting on water quality.

There are no formal guidelines against which these extreme values can be assessed, and therefore no detailed quantitative assessment of the extreme data values has been made. However, a set of interim min/max guidelines has been derived for this report based on the expert opinion of the author, and are included in Table 5.1. These guidelines should be viewed as indicative of levels that are 'of concern' rather than having any more formal implication.

Table 5.1: Indicators and guidelines used for condition assessment

Indicator	Statistic	Rationale	Guideline values for water types
DO **(% saturation)**	Annual median	This represents a mid-range (daytime) value of DO under base-flow conditions.	ECLE 85 – 105 % saturation [2]ME 85 – 105 % saturation [3]UE 80 - 105 % saturation
	Annual minimum	Minimum values are nearly always associated with the introduction of organic matter during large inflows from the catchment. Subsequent bacterial breakdown of this matter causes reduced DO.	Values <50% saturation are of concern Values <30% saturation may be lethal to some fish spp
	Annual maximum	Maximum values are associated with algal blooms. The higher the value the more intense the bloom.	Values >120% saturation are of concern
Turbidity **(NTU)**	Annual median	This represents a mid-range value of turbidity under base-flow conditions. Note that guidelines do not apply to estuaries >40 km in length as these have naturally high turbidity values (Uncles, Stephens & Smith 2002). No guidelines for these long estuaries are available at present.	ECLE 6 NTU ME 8 NTU UE 25 NTU
	Annual maximum	Maximum values are nearly always associated with the introduction of sediment loads during large inflows from the catchment. These maximum values reflect the extent of fine sediment loss from the catchment.	Too variable to set guideline
Oxidised N **(NO_2 + NO_3)** **(mg/L)**	Annual median	This represents a mid-range value of NO_3 nitrogen concentrations under base-flow conditions.	ECLE 0.003 mg/L ME 0.010 mg/L UE 0.015 mg/L
	Annual maximum	Maximum values are nearly always associated with the introduction of dissolved nitrogen loads during large	Values >0.400 mg/L are indicative of a significant

Table 5.1: Indicators and guidelines used for condition assessment			
Indicator	**Statistic**	**Rationale**	**Guideline values for water types**
		inflows from the catchment. These maximum values reflect the extent of nitrogen loss from the catchment.	anthropogenic influence on catchment inputs
Total P **(mg/L)**	Annual median	This represents a mid-range value of phosphorus concentrations under base-flow conditions.	ECLE 0.020 mg/L ME 0.025 mg/L UE 0.040 mg/L
	Annual maximum	Maximum values are nearly always associated with the introduction of dissolved and particulate phosphorus loads during large inflows from the catchment. These maximum values reflect the extent of phosphorus loss from the catchment.	Values >0.2 mg/L are indicative of a significant anthropogenic influence on catchment inputs
Chlorophyll *a* **(µg/L)**	Annual median	This represents a mid-range value of chlorophyll *a* concentrations under base-flow conditions.	ECLE 2 µg/L ME 4 µg/L UE 8 µg/L
	Annual maximum	Maximum values are sometimes associated with a post-flood event phase. The introduction of large catchment nutrient loads to the estuary stimulates phytoplankton growth, but this does not usually occur until the flood-related increase in turbidity (causing reduced light availability) has subsided. This is usually a week or two after the flood. Alternatively, in normally highly turbid estuaries, periods of unusually low turbidity may result in increased chlorophyll *a* levels.	Post-flood values of 15–30 µg/L are common Post-flood values >50 µg/L are a threshold for concern
pH	Annual minimum	pH in estuaries is usually well buffered by saline waters. Minimum values are associated with significant freshwater inflows.	Values <5.5 are of concern unless the catchment has large areas of wallum vegetation Values <4.0 are strongly indicative of acid run-off

5.2 Data presentation

The annual median values of the five key indicators for the most recent five years are presented in Tables 6.1 to 6.10. Data for all sites in all the waters are included in each table. Within the tables, sites have been classified into one of the water types adopted for the guideline values (i.e. ECLE, ME or UE). Thus, sites on the left of the table are the most downstream sites, and those on the right the most upstream sites. Note that not all estuaries have sites in every category, while all sites in coastal waters are ECLE. Guideline values are detailed in Table 5.1, but are also included at the bottom of each table. Sites failing the guideline are shaded pink, with light pink denoting a marginal failure and dark pink a more substantial failure.

Note also that estuaries receiving treated wastewater discharges are identified by brown shading.

The extreme values for each indicator are presented graphically. Figures 5.1 to 5.7 show the three maximum or minimum values for each indicator in each estuary (based on combined data from all sites) over the most recent five-year period, June 2010 to May 2015. Most indicators show maximum values, but for DO and pH, the minimum values are shown as these represent the worst water quality for these indicators.

There are no specific guidelines for minimum or maximum values, but Table 5.1 in this report includes some general guidance on this. Also, the Baffle Creek catchment and estuary are the least impacted in the central Queensland region and so, in assessing values in the maximum/minimum figures, the values for Baffle Creek can be used as a general yardstick of what is ‘normal’ for undisturbed systems. The Baffle Creek values are coloured in green in the figures.

6 Condition results

6.1 Dissolved oxygen

6.1.1 Annual median values

Estuaries (Tables 6.1a & b)

There were relatively few sites failing the DO guidelines, and about half of those were marginal fails (≤3% saturation below the guideline). Even the more substantial fails were not particularly large, with the largest margin being 10% saturation below the guideline. The fails in the Mary are thought to be partly related to the presence of discharges and partly to catchment inflows. Treated sewage effluent discharges to the Fitzroy and Burnett appear to have minimal effect on DO levels.

The estuaries with no point discharges largely comply with the DO guideline, one exception being the Burrum/Isis/Gregory system, which experiences poorer DO values. These occur in most years, so do not seem to be directly related to the wet weather in the first three years. The cause of this is not known, but given there are no discharges to this system, it is most likely to be related to catchment influences. The single non-compliance in Baffle Creek is thought to be related to the very wet conditions in 2010–11.

Table 6.1a: Dissolved oxygen (% sat) in estuaries – annual median vs guideline

Estuary	Year	Water type/ site ID						
		ECLE	ME	ME	ME	ME	UE	UE
Fitzroy			**20.0**	**33.8**	**45.2**	**55.1**	**57.3**	**59.6**
	2010-11		91	89	87	95	84	
	2011-12		87	86	84	94	96	
	2012-13		87	91	89	94	95	97
	2013-14		88	86	88	88	90	88
	2014-15		89	89	89	85	88	84
Calliope		**0**	**3.2**	**6.4**	**12.9**	**16.1**		
	2010-11	97	100	98	91	90		
	2011-12	93	94	95	92	91		
	2012-13	95	98	96	94	91		
	2013-14	95	98	100	97	91		
	2014-15	96	97	98	96	97		
Boyne		**0.0**	**5.1**	**8.6**	**12.0**			
	2010-11	102	91	87	90			
	2011-12	95	93	88	86			
	2012-13	99	94	92	93			
	2013-14	98	93	87	90			
	2014-15	98	89	85	87			
Baffle		**4.1**	**8.5**	**16**	**23.5**			

Table 6.1a: Dissolved oxygen (% sat) in estuaries – annual median vs guideline

Estuary	Year	Water type/ site ID						
		ECLE	ME	ME	ME	ME	UE	UE
	2010-11	99	93	92	76			
	2011-12	99	91	88	86			
	2012-13	96	94	93	89			
	2013-14	98	92	90	85			
	2014-15	98	95	96	87			
Kolan			**5.3**	**8.1**	**12.0**			
	2010-11		84	88	92			
	2011-12		95	94	94			
	2012-13		92	90	95			
	2013-14		92	93	94			
	2014-15		91	93	94			
		DO guideline (%sat)						
		90	**85**	**85**	**85**	**85**	**70**	**70**

🟪	Marginal fail
🟥	Fail
🟧	Estuary receiving wastewater point source discharge

Table 6.1b: Dissolved oxygen (% sat) in estuaries – annual median vs guideline

Estuary	Year	Water type/site ID						
		ECLE	ME	ME	ME	ME	UE	UE
Burnett		**4.8**	**8.5**	**14.7**	**18.7**	**20.3**	**23.5**	
	2010-11	96	93	92	92	95	97	
	2011-12	94	92	87	90	93	97	
	2012-13	93	90	91	91	88	95	
	2013-14	99	100	102	97	98	95	
	2014-15	95	90	88	87	90	96	
Burrum		**0.0**	**5.5**	**12.7**			**19.2**	
	2010-11	95	90	86			66	
	2011-12	90	89	79			83	
	2012-13	92	86	80			83	
	2013-14	95	92	89			77	
	2014-15	95	92	84			75	
Isis			**3.0**	**6.0**			**10.0**	
	2010-11		82	77			84	
	2011-12		82	80			80	
	2012-13		82	80			92	
	2013-14		87	81			77	
	2014-15		84	86			81	

Table 6.1b: Dissolved oxygen (% sat) in estuaries – annual median vs guideline

Estuary	Year	Water type/site ID						
		ECLE	ME	ME	ME	ME	UE	UE
Gregory			**5.8**	**9.5**				
	2010-11		87	75				
	2011-12		85	82				
	2012-13		82	88				
	2013-14		87	80				
	2014-15		84	80				
Mary		**6**	**12.2**	**22.5**	**36.1**	**42.2**	**56.7**	
	2010-11	97	93	81	80	84	90	
	2011-12	96	92	86	76	80	96	
	2012-13	94	89	87	85	87	97	
	2013-14	97	94	90	77	73	104	
	2014-15	96	92	89	78	83	97	
		DO guideline (%sat)						
		90	**85**	**85**	**85**	**85**	**70**	**70**

🟪 Marginal fail
🟥 Fail
🟧 Estuary receiving wastewater point source discharge

Coastal waters (Table 6.2)
All sites easily complied with the guideline.

Table 6.2: Dissolved oxygen in coastal waters (% sat) – annual median vs guideline

Coastal water	Year	Water type/ Site ID					
		ECLE	ECLE	ECLE	ECLE	ECLE	ECLE
Great Sandy Strait		**3**	**924585**	**929721**	**979882**	**979534**	**984979**
	2010-11	97	96	97	98	96	97
	2011-12	105	102	98	100	100	100
	2012-13	101	101	100	100	99	100
	2013-14	99	99	97	99	97	97
	2014-15	98	96	97	99	95	97
Tin Can Inlet		**11269**	**17339**	**21296**	**28353**	**35320**	**43376**
	2010-11	100	100	98	101	99	100
	2011-12	98	96	96	100	96	98
	2012-13	101	96	97	99	98	99
	2013-14	99	97	95	96	96	98
	2014-15	99	94	96	93	94	94
		DO guideline (%sat)					
		90	**90**	**90**	**90**	**90**	**90**

6.1.2 Minimum DO values

Minimum DO concentrations are the three lowest values recorded in each estuary over the period June 2010 to May 2015. Minimum DO concentrations in many estuaries (Figure 6.1) are similar to those in the reference estuary, Baffle Creek (in green), at around 60% saturation. Lower concentrations were recorded in the Burrum/Isis/Gregory system and the Mary. All these low concentrations occurred following significant inflows, indicating that microbial respiration of catchment-sourced organic loads were the likely cause. The unusually low minimum concentrations in the Fitzroy were investigated at the time, and it was concluded that flushing of some large stagnant freshwater lagoons was the main cause.

The generally higher minimum values in coastal waters are a reflection of the fact that these waters are less impacted by flow events.

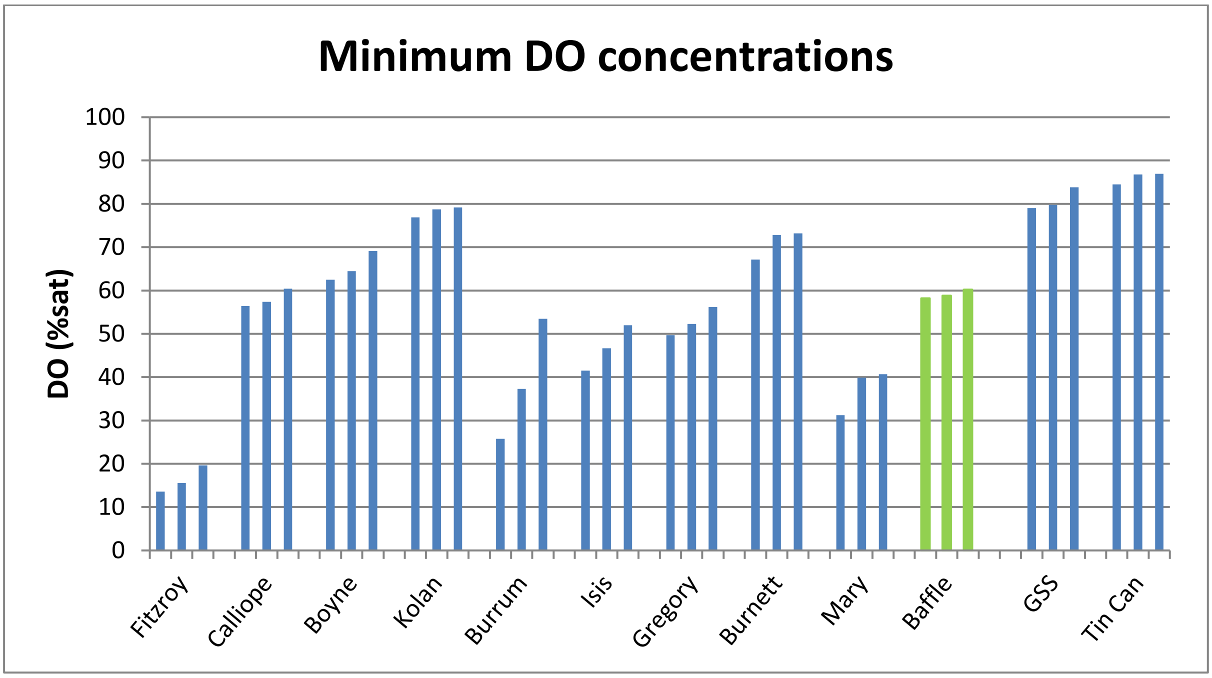

Figure 6.1: Three lowest DO concentrations in the period 2010–15

6.2 Turbidity

6.2.1 Annual median values

Estuaries (Tables 6.3a & b)

Turbidity guidelines were exceeded in most estuaries at times, including the least disturbed system, Baffle Creek. The majority of exceedances were in the wet 2010–11 to 2013–14 period. The wettest year of all was 2010–11, and the greatest number of exceedances occurred in that year. The one exception was the Boyne, and this is because the Awoonga Dam captures most of the freshwater flow in this system, thus greatly reducing the influence of such flows on the estuary. The consistent non-compliance in the Calliope is related to the larger tidal range in this system compared to estuaries further south. The reason for the frequent non-compliance in the Burrum/Gregory/Isis system is not known, but is most likely related to catchment influences.

Turbidity in long estuaries (i.e. >40 km) is naturally high due to sediment trapping and continual resuspension by tidal currents (Uncles, Stephen & Smith 2002). The Fitzroy and Mary both fall into this category. There are no suitable turbidity guidelines for these naturally turbid estuaries, and therefore they have not been assessed for this indicator with regard to condition (data in Table 6.3 is greyed out). However, trend analyses have been undertaken – see section 7.

Table 6.3a : Turbidity (NTU) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID						
		ECLE	ME	ME	ME	ME	UE	UE
Fitzroy			**20.0**	**33.8**	**45.2**	**55.1**	**57.3**	**59.6**
	2010-11		n/a	n/a	n/a	n/a	n/a	n/a
	2011-12		n/a	n/a	n/a	n/a	n/a	n/a
	2012-13		n/a	n/a	n/a	n/a	n/a	n/a
	2013-14		n/a	n/a	n/a	n/a	n/a	n/a
	2014-15		n/a	n/a	n/a	n/a	n/a	n/a
Calliope		**0**	**3.2**	**6.4**	**12.9**	**16.1**		
	2010-11	15	12	11	7	11		
	2011-12	21	14	7	5	8		
	2012-13	13	10	9	6	8		
	2013-14	23	21	17	8	9		
	2014-15	13	12	5	5	12		
Boyne		**0**	**5.1**	**8.6**	**12**			
	2010-11	10	4	6	7			
	2011-12	5	5	6	5			
	2012-13	4	3	4	4			
	2013-14	4	3	3	3			
	2014-15	3	3	3	4			
Baffle		**4.1**	**8.5**	**16**	**23.5**			
	2010-11	7	8	21	17			
	2011-12	8	6	8	11			
	2012-13	4	3	3	7			
	2013-14	3	2	3	4			
	2014-15	2	3	4	7			
Kolan			**5.3**	**8.1**	**12**			
	2010-11		16	17	18			
	2011-12		9	10	9			
	2012-13		8	8	10			
	2013-14		5	7	10			

Table 6.3a : Turbidity (NTU) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID						
		ECLE	ME	ME	ME	ME	UE	UE
	2014-15		4	7	10			
		Turbidity guideline (NTU)						
		6	8	8	8	8	25	25

🟪 Marginal fail
🟥 Fail
🟧 Estuary receiving wastewater point source discharge

Table 6.3b: Turbidity (NTU) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID						
		ECLE	ME	ME	ME	ME	UE	UE
Burnett		**4.8**	**8.5**	**14.7**	**18.7**	**20.3**	**23.5**	
	2010-11	10	9	9	15	20	28	
	2011-12	8	6	6	8	8	14	
	2012-13	5	8	7	7	8	15	
	2013-14	4	7	4	4	5	7	
	2014-15	4	5	4	4	4	7	
Burrum		**0**	**5.5**	**12.7**			**19.2**	
	2010-11	5	6	12			36	
	2011-12	7	22	18			29	
	2012-13	3	7	9			21	
	2013-14	4	7	10			10	
	2014-15	2	3	8			10	
Isis			**3**	**6**			**10**	
	2010-11		12	20			37	
	2011-12		13	14			23	
	2012-13		7	8			17	
	2013-14		8	11			16	
	2014-15		9	12			18	
Gregory			**5.8**	**9.5**				
	2010-11		12	26				
	2011-12		12	24				
	2012-13		11	25				
	2013-14		8	15				
	2014-15		6	12				
Mary		**6**	**12.2**	**22.5**	**36.1**	**42.2**	**56.7**	**56.7**
	2010-11	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2011-12	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2012-13	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2013-14	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2014-15	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 6.3b: Turbidity (NTU) in estuaries – annual median vs guideline								
Estuary	Year	Water type/ Site ID						
		ECLE	ME	ME	ME	ME	UE	UE
		Turbidity Guideline (NTU)						
		6	8	8	8	8	25	25

🟪 Marginal fail
🟥 Fail
🟧 Estuary receiving wastewater point source discharge

Coastal waters (Table 6.4)

For these waters, Secchi depth rather than turbidity was the preferred indicator as it is more sensitive to change in low turbidity waters (see Appendix C). Despite the unusually wet period during 2010 and 2011, there were very few instances of non-compliance with the guideline.

Table 6.4	Secchi depth (m) in coastal waters – annual median vs guideline						
Coastal water	Year	Water type/ Site ID					
		ECLE	ECLE	ECLE	ECLE	ECLE	ECLE
Great Sandy Strait		**3**	**924585**	**929721**	**979882**	**979534**	**984979**
	2010-11	3.2	2.2	2.8	3	2.1	2.5
	2011-12	3.8	2	1.5	2.1	1.2	1.9
	2012-13	4.0	2.0	1.8	2.8	1.7	2.0
	2013-14	3.5	2.2	1.6	2.5	1.9	1.8
	2014-15	3.0	2.3	1.9	2.2	2.2	3.4
Tin Can Inlet		**11269**	**17339**	**21296**	**28353**	**35320**	**43376**
	2010-11	3	2.5	2.1	2.5	2.3	2.4
	2011-12	3.3	2.7	2.6	2.3	2.6	2.6
	2012-13	1.5	3.1	2.6	3.2	2.4	2.9
	2013-14	1.6	2.8	3.0	3.0	3.0	3.0
	2014-15	1.3	2.6	2.2	2.6	2.5	2.4
		Secchi Guideline (m)					
		1.5	1.5	1.5	1.5	1.5	1.5

🟪 Marginal fail
🟥 Fail

6.2.2 Maximum values

Maximum turbidity values in most estuaries (Figure 6.2) are similar to those in the least disturbed catchment, the Baffle Creek (in green). Higher values occur in the Isis and Kolan, indicating higher levels of catchment loading of particulates in these waters. Much higher levels occur in the Fitzroy and Mary. In part this may be due to their large catchments, but it is thought to be mostly due to the greater length of these estuaries and their greater capacity to both retain and remobilise sediments (Uncles, Stephens & Smith 2002). Fitzroy estuary values are higher than those in the Mary, and it is thought this is due in part to the larger tidal range in the Fitzroy producing larger tidal currents.

Peak turbidity values are lower in the coastal waters, which are less impacted by inflows and have better exchange with clean oceanic waters. The influence of outflows from the Mary River on some sites in the Great Sandy Straits results in it having higher maximum turbidity values than Tin Can Inlet, which receives inflows only from small catchments.

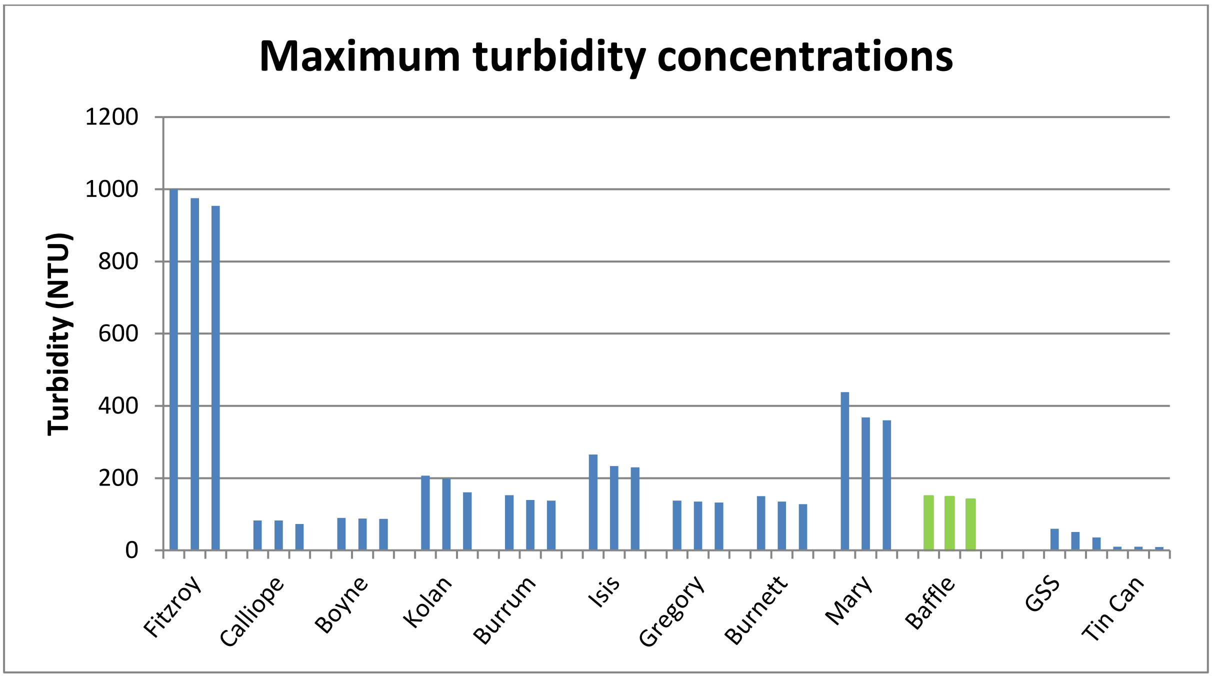

Figure 6.2: Three highest turbidity concentrations in the period 2010–15

6.3 Nutrients: oxidised nitrogen and total phosphorus

6.3.1 Annual median values

Estuaries (Tables 6.5 & 6.6)
The highest median oxidised nitrogen (N) values generally occurred at sites in estuaries receiving wastewater point discharges (Mary, Burnett and Fitzroy).

Oxidised N guidelines were also exceeded in many other estuaries, although to a lesser extent than in those estuaries receiving discharges. In these estuaries, elevated oxidised N mostly occurred in the wetter 2010–11 to 2013–14 period, and are thus associated with catchment inflows. In the least disturbed system, Baffle Creek, only a single marginal exceedance was observed in one of the wetter years.

Total phosphorus (P) guidelines were also consistently exceeded in estuaries receiving point discharges. In other estuaries, total P concentrations mostly complied with, or only marginally exceeded guidelines, mostly in the particularly wet 2010–11 period. One exception was the Kolan, where total P guidelines were exceeded in all years. The cause of this is not known, but it appears that total P values exceed guidelines during dry weather, which suggests that catchment effects are not the main cause.

Table 6.5a: Oxidised N (µg/L) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID					
		ECLE	ME	ME	ME	ME	UE
Fitzroy			**20.0**	**33.8**	**45.2**		**57.3**
	2010-11		230				220
	2011-12		200				67
	2012-13		210				175
	2013-14		230				240
	2014-15		190				295
Calliope		**0**	**3.2**	**6.4**	**12.9**	**16.1**	
	2010-11				13		
	2011-12				6		
	2012-13				11		
	2013-14	6			2		
	2014-15	5			4		
Boyne		**0**	**5.1**	**8.6**	**12**		
	2010-11		5		23		
	2011-12		4		7		
	2012-13		2		5		
	2013-14		4		2		
	2014-15		5		4		
Baffle		**4.1**	**8.5**	**16**	**23.5**		
	2010-11	2	3	5			
	2011-12	4	7	5			
	2012-13	3	4	3	2		
	2013-14	3	3	2	2		
	2014-15	3	3	4	3		
Kolan			**5.3**	**8.1**	**12**		
	2010-11			50			
	2011-12			30			
	2012-13			36			
	2013-14			4			
	2014-15			3			
		Guideline					

Table 6.5a: Oxidised N (µg/L) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID					
		ECLE	ME	ME	ME	ME	UE
		3	10	10	10	10	15

🟪 Marginal fail
🟥 Fail
🟧 Estuary receiving wastewater point source discharge

Table 6.5b: Oxidised N (µg/L) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID					
		ECLE	ME	ME	ME	ME	UE
Burnett		4.8	8.5	14.7	18.7	20.3	23.5
	2010-11		77			89	
	2011-12		39			61	
	2012-13	35	54	90	83	78	64
	2013-14	4	5	22	22	35	39
	2014-15	5	11	34	36	27	37
Burrum		0	5.5	12.7			19.2
	2010-11		11				
	2011-12		14				
	2012-13		54	43			
	2013-14		4	5			
	2014-15		3	13			
Isis			3	6			
	2010-11			17			
	2011-12			20			
	2012-13			36			
	2013-14			5			
	2014-15			9			
Gregory			5.8	9.5			
	2010-11		39				
	2011-12		51				
	2012-13		92				
	2013-14		3				
	2014-15		6				
Mary		6	12.2	22.5	36.1	42.2	56.7
	2010-11		300				150
	2011-12		205				165
	2012-13		230				97

Table 6.5b: Oxidised N (µg/L) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID					
		ECLE	ME	ME	ME	ME	UE
	2013-14		155				19
	2014-15		200				45
		Guideline					
		3	10	10	10	10	15

🟪 Marginal fail
🟥 Fail
🟧 Estuary receiving wastewater point source discharge

Table 6.6a: Total P (µg/L) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID					
		ECLE	ME	ME	ME	ME	UE
Fitzroy			20	33.8	45.2	55.1	57.3
	2010-11		190				220
	2011-12		180				170
	2012-13		145				150
	2013-14		103				140
	2014-15		110				165
Calliope		0	3.2	6.4	12.9	16.1	
	2010-11				26		
	2011-12				21		
	2012-13				23		
	2013-14	17			5		
	2014-15	18			9		
Boyne		0	5.1	8.6	12		
	2010-11		19		30		
	2011-12		8		26		
	2012-13		13		18		
	2013-14		10		12		
	2014-15		10		20		
Baffle		4.1	8.5	16	23.5		
	2010-11	19		47			
	2011-12	16		21			
	2012-13	11	13	17	31		
	2013-14	10	10	12	18		
	2014-15	9	11	20	26		
Kolan			5.3	8.1	12		

Table 6.6a: Total P (µg/L) in estuaries – annual median vs guideline							
Estuary	Year	Water type/ Site ID					
		ECLE	ME	ME	ME	ME	UE
	2010-11			43			
	2011-12			33			
	2012-13			33			
	2013-14			23			
	2014-15			30			
		Guideline					
		20	**25**	**25**	**25**	**25**	**40**

▨ Marginal fail

■ Fail

▧ Estuary receiving wastewater point source discharge

Table 6.6b: Total P (µg/L) – annual median vs guideline							
Estuary	Year	Water type/ Site ID					
		ECLE	ME	ME	ME	ME	UE
Burnett		**4.8**	**8.5**	**14.7**	**18.7**	**20.3**	**23.5**
	2010-11	29	42	85	92	91	
	2011-12	24	31	53	57	57	
	2012-13	27	43	71	80	76	77
	2013-14	16	30	57	61	62	74
	2014-15	15	35	60	70	76	90
Burrum		**0**	**5.5**	**12.7**			**19.2**
	2010-11		11				
	2011-12		21				
	2012-13		17	23			
	2013-14		11	15			
	2014-15		10	22			
Isis			**3**	**6**			**10**
	2010-11			28			
	2011-12			29			
	2012-13			27			
	2013-14			20			
	2014-15			30			
Gregory			**5.8**	**9.5**			
	2010-11		36				
	2011-12		24				
	2012-13		25				
	2013-14		13				

Table 6.6b: Total P (µg/L) – annual median vs guideline							
Estuary	**Year**	**Water type/ Site ID**					
		ECLE	**ME**	**ME**	**ME**	**ME**	**UE**
	2014-15		21				
Mary		**6**	**12.2**	**22.5**	**36.1**	**42.2**	**56.7**
	2010-11			86			60
	2011-12			75			57
	2012-13			58			56
	2013-14			43			40
	2014-15			60			63
		Guideline					
		20	**25**	**25**	**25**	**25**	**40**

▢ Marginal fail

■ Fail

🟧 Estuary receiving wastewater point source discharge

Coastal waters (Tables 6.7 & 6.8)

All sites in the Great Sandy Straits complied with the oxidised N and total P guidelines in all years. Sites in Tin Can Inlet consistently exceeded the oxidised N guideline, although not by large margins. This is thought to be due to freshwater inflows during this wet period, and also the more enclosed nature of these waters compared to the Great Sandy Straits. The total P guidelines were not exceeded at any site.

Table 6.7: Oxidised N (µg/L) in coastal waters – annual median vs guideline					
Coastal waters	**Year**	**Water type/ Site ID**			
		ECLE	**ECLE**	**ECLE**	**ECLE**
Great Sandy Straits		**3**	**924585**	**929721**	**972882**
	2010-11	2	2	2	2
	2011-12	2	2	3	2
	2012-13	2	2	2	3
	2013-14	2	2	3	2
	2014-15	2	2	3	3
Tin Can Inlet		**11269**			**28353**
	2010-11	5			6
	2011-12	4			6
	2012-13	2			7
	2013-14	2			2
	2014-15	3			7
		Guideline			
		3	3	3	3

▢ Marginal fail ■ Fail

Table 6.8: Total P (µg/L) in coastal waters – annual median vs guideline

Coastal waters	Year	Water type/ Site ID			
		ECLE	ECLE	ECLE	ECLE
Great Sandy Straits		**3**	**924585**	**929721**	**972882**
	2010-11	8	12	10	9
	2011-12	12	11	15	13
	2012-13	6	8	8	7
	2013-14	5	9	10	10
	2014-15	7	8	9	10
Tin Can Inlet		**11269**			**28353**
	2010-11	7			8
	2011-12	9			10
	2012-13	5			5
	2013-14	10			4
	2014-15	7			6
		Guideline			
		20	20	20	20

🟪	Marginal fail
🟥	Fail

6.3.2 Maximum values

As with median values, maximum values of oxidised N and total P (Figures 6.3 & 6.4) generally occur in the estuaries receiving wastewater point discharges (Mary, Burnett and Fitzroy). Maximum oxidised N concentrations in many of the non-discharge estuaries exceed those in the un-impacted Baffle Creek (in green), which indicates some degree of catchment influence. In contrast, maximum total P concentrations in the non-discharge estuaries are all fairly consistent.

Maximum oxidised N and total P concentrations in estuaries not receiving point discharges are nearly always associated with catchment inflows. This was illustrated in Figure 4.3, which shows oxidised N and plotted against conductivity for Baffle Creek. Total P behaves similarly.

Maximum oxidised N and total P concentrations in coastal waters were low, a reflection of ocean flushing and the limited impact of catchment run-off in these waters.

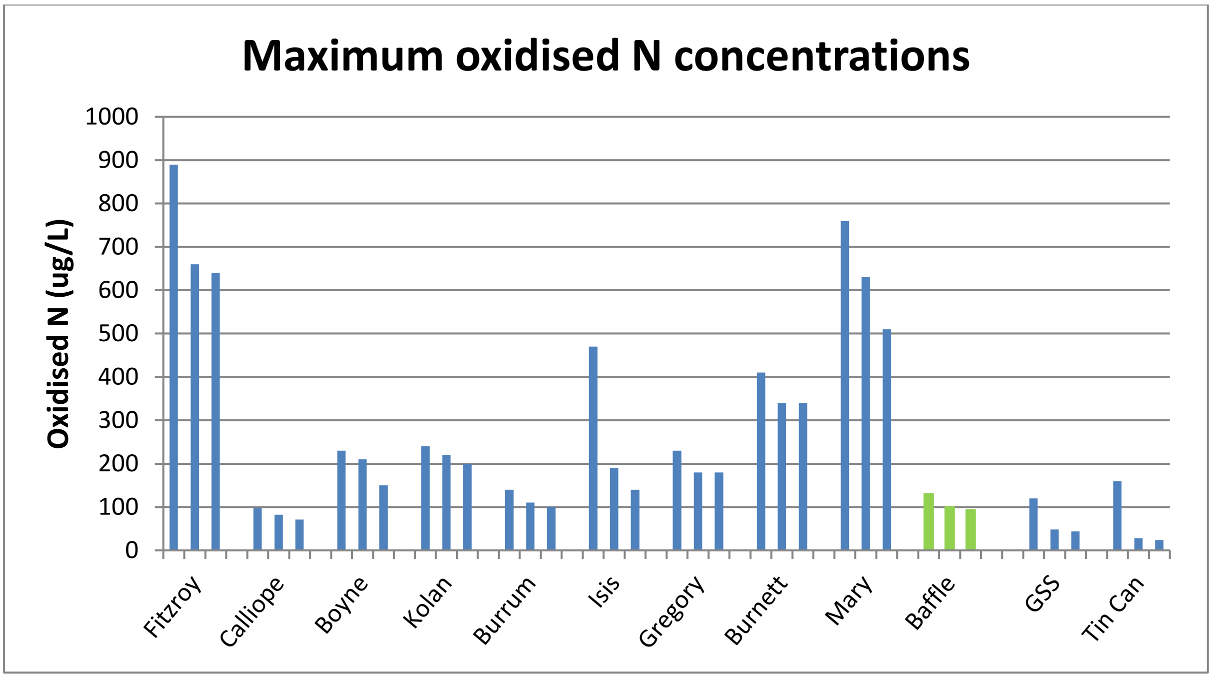

Figure 6.3: Three highest oxidised N concentrations in the period 2010–15

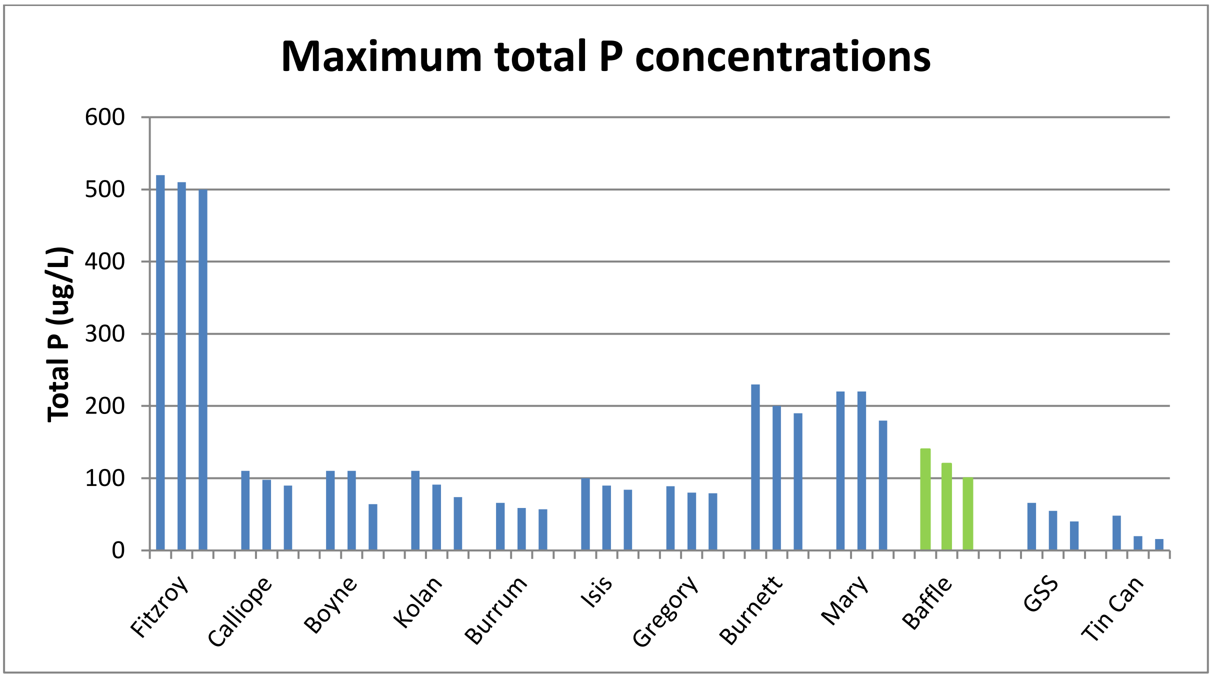

Figure 6.4: Three highest total P concentrations in the period 2010–15

6.4 Chlorophyll *a*

6.4.1 Annual median values

Estuaries (Table 6.9)
There were very few chlorophyll *a* exceedances across all the estuaries, including those receiving wastewater point discharges. Only the Isis and Gregory consistently failed guideline values. The reason for this is not known – nutrient values were elevated, but lower

than in some other estuaries that experienced lower chlorophyll *a* concentrations. However, the finding is consistent with the generally poor water quality in these estuaries, particularly the Isis, across all indicators.

Table 6.9a: Chlorophyll *a* (µg/L) in estuaries – annual median vs guideline

Estuary	Year	Water type/ Site ID						
		ECLE	ME	ME	ME	ME	UE	UE
Fitzroy			**20.0**	**33.8**	**45.2**	**55.1**	**57.3**	**59.6**
🟧	2010-11		1.8	2.6	2	1.6	1.8	1.9
🟧	2011-12		2.5	2.2	1.6	3.1	3.3	4.1
🟧	2012-13		1.2	2.3	1.1	2.1	2.0	2.4
🟧	2013-14		1.5	1.9	2.5	2.2	3.6	2.3
🟧	2014-15		1.1	1.0	1.7	2.2	3.2	1.2
Calliope		**0**	**3.2**	**6.4**	**12.9**	**16.1**		
	2010-11		1.6		2.3	2.9		
	2011-12		1.6	2.9	1.7	3.2		
	2012-13	1.3	1.4	1.4	2.0	3.2		
	2013-14	1.8	2.2	2.6	2.4	2.4		
	2014-15	1.2	2.5	1.5	1.4	2.6		
Boyne		**0**	**5.1**	**8.6**	**12**			
	2010-11			2.8	1.9			
	2011-12			2.4	3.1			
	2012-13			1.7	1.2			
	2013-14	1.0	0.8	1.1	1.7			
	2014-15	0.5	1.2	2.0	0.7			
Baffle		**4.1**	**8.5**	**16**	**23.5**			
	2010-11	1.6	2.1	3.5	2.7			
	2011-12	1.3	1.2	1.5	2.2			
	2012-13	0.9	1.2	0.9	1.9			
	2013-14	0.5	0.7	1.2	2.4			
	2014-15	0.5	0.6	1.1	0.8			
Kolan			**5.3**	**8.1**	**12**			
	2010-11		2.8	3.3	2.8			
	2011-12		2.4	3.6	3.9			
	2012-13		2.6	3.0	3.9			
	2013-14		1.9	2.2	3.8			
	2014-15		1.6	2.2	1.9			
		Guideline						
		2	**4**	**4**	**4**	**4**	**10**	**10**

🟪 Marginal fail

🟥 Fail

🟧 Estuary receiving wastewater point source discharge

Table 6.9b: Chlorophyll *a* (µg/L) in estuaries - annual median vs guideline

Estuary	Year	Water type/ Site ID						
		ECLE	ME	ME	ME	ME	UE	UE
Burnett		**4.8**	**8.5**	**14.7**	**18.7**	**20.3**	**23.5**	
	2010-11	1.9	2.4	2.4	3.7	5.4	4	
	2011-12	0.9	1.3	3	2.4	2	2.9	
	2012-13	1.2	1.5	2.0	2.3	2.0	3.7	
	2013-14	1.4	2.3	3.7	2.6	3.3	3.1	
	2014-15	1.3	1.9	1.7	1.8	2.7	4.9	
Burrum		**0**	**5.5**	**12.7**			**19.2**	
	2010-11	1.1	2.6	2.3			6.2	
	2011-12	1.7	2.2	2.1			1.4	
	2012-13	1.9	1.5	1.5			2.4	
	2013-14	1.6	2.0	2.4			6.1	
	2014-15	1.2	1.4	2.0			4.5	
Isis			**3**	**6**			**10**	
	2010-11			7.7			12.2	
	2011-12			4.7			8.4	
	2012-13			4.4			4.6	
	2013-14			5.3			7.7	
	2014-15			5.1			10.3	
Gregory			**5.8**	**9.5**				
	2010-11		2.5	4				
	2011-12		2.8	5.8				
	2012-13		1.9	3.1				
	2013-14		3.9	7.7				
	2014-15		2.2	5.1				
Mary		**6**	**12.2**	**22.5**	**36.1**	**42.2**	**50.2**	**56.7**
	2010-11	2	2.3	3.6	3.2	2.9	4.8	5.6
	2011-12	1.4	2.8	1.9	2.3	3.1	2.8	3.7
	2012-13	1.6	2.3	1.5	2.7	2.3	3.4	1.1
	2013-14	0.9	3.0	2.2	4.2	4.2	6.1	7.2
	2014-15	1.8	1.4	1.6	0.9	1.8	2.9	5.3
		Guideline						
		2	**4**	**4**	**4**	**4**	**10**	**10**

🟪 Marginal fail

🟥 Fail

🟧 Estuary receiving wastewater point source discharge

Coastal waters (Table 6.10)

All sites complied with the chlorophyll *a* guideline.

Table 6.10: Chlorophyll *a* (µg/l) in coastal waters – annual median vs guideline

Coastal water	Year	Water type/ Site ID					
		ECLE	ECLE	ECLE	ECLE	ECLE	ECLE
Great Sandy Straits		**3**	**924585**	**929721**	**979882**	**979534**	**984979**
	2010-11	0.5	0.6	0.9	0.7	0.8	0.6
	2011-12	0.4	1	1.4	1	1.5	0.7
	2012-13	0.5	0.6	1.0	0.9	0.9	0.6
	2013-14	0.5	0.7	0.7	0.5	0.8	0.8
	2014-15	0.5	0.5	0.6	0.6	1.0	0.7
Tin Can Inlet		**11269**	**17339**	**21296**	**28353**	**35320**	**43376**
	2010-11	0.6			0.9		
	2011-12	0.7			1.1		
	2012-13	1.1			0.7		
	2013-14	0.5			0.7		
	2014-15	0.5			0.6		
		Chla guideline (ug/L)					
		2	**2**	**2**	**2**	**2**	**2**

6.4.2 Maximum values

High (i.e. >40 µg/L) maximum chlorophyll *a* concentrations (Figure 6.5) occur in two of the estuaries that receive wastewater point discharges (Fitzroy, Mary), although not in the Burnett. However, equally high maximum concentrations occurred in the Burrum/Isis/Gregory system, which receives no such discharges.

Maximum chlorophyll *a* values in estuaries with no point discharge are usually associated with catchment inflows, and are a response to diffuse source nutrient enrichment. This was illustrated in Figure 4.4 (section 4) with data from the largely un-impacted Baffle Creek (in green). Peak chlorophyll *a* values are all associated with low conductivity levels. In estuaries receiving nutrient rich discharges, the situation is more complex, but peak values are still sometimes associated with catchment inflows. This suggests that micro-nutrients in inflows are equally important in stimulating phytoplankton growth as the major nutrients N and P.

The high maximum chlorophyll *a* values in the Burrum/Gregory/Isis system suggest that these estuaries are receiving larger nutrient inputs from their catchments than the other non-discharge estuaries. However, there is no direct evidence for this.

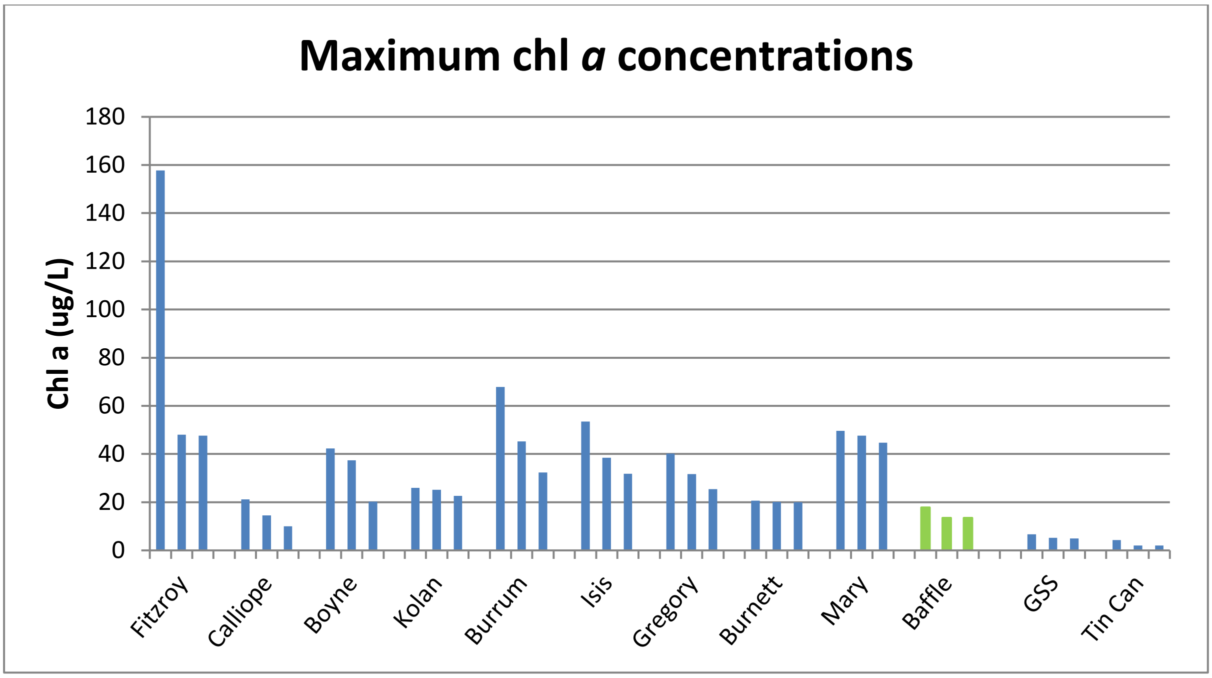

Figure 6.5: Three highest chlorophyll *a* concentrations in the period 2010–15

6.5 pH

A detailed assessment of pH condition has not been undertaken because pH in estuaries varies quite normally over a range of ~6 to ~8.2, depending on salinity and algal activity. Even lower values can occur naturally if inflowing freshwater is sourced from acidic wallum vegetation areas, although natural values rarely fall below 5.0.

The main pH issue that can arise in estuaries is related to the influx of freshwater from catchments where acid sulphate soils have been exposed to the air. This can sometimes reduce pH in the estuary to the point where fish kills occur (i.e. less than about 4.0). To assess if in any of the estuaries in this report are affected by acid run-off, the minimum values that occurred during 2010 to 2013 were assessed – see Figure 6.6.

Minimum values were mostly above 6, with a few values in the Baffle and Burrum between 5 and 6. None of these values are low enough to be indicative of significant anthropogenic acid run-off. The lower pH values in the Burrum and Baffle are most likely to be related to natural run-off from wetlands and streams with high levels of humic acids.

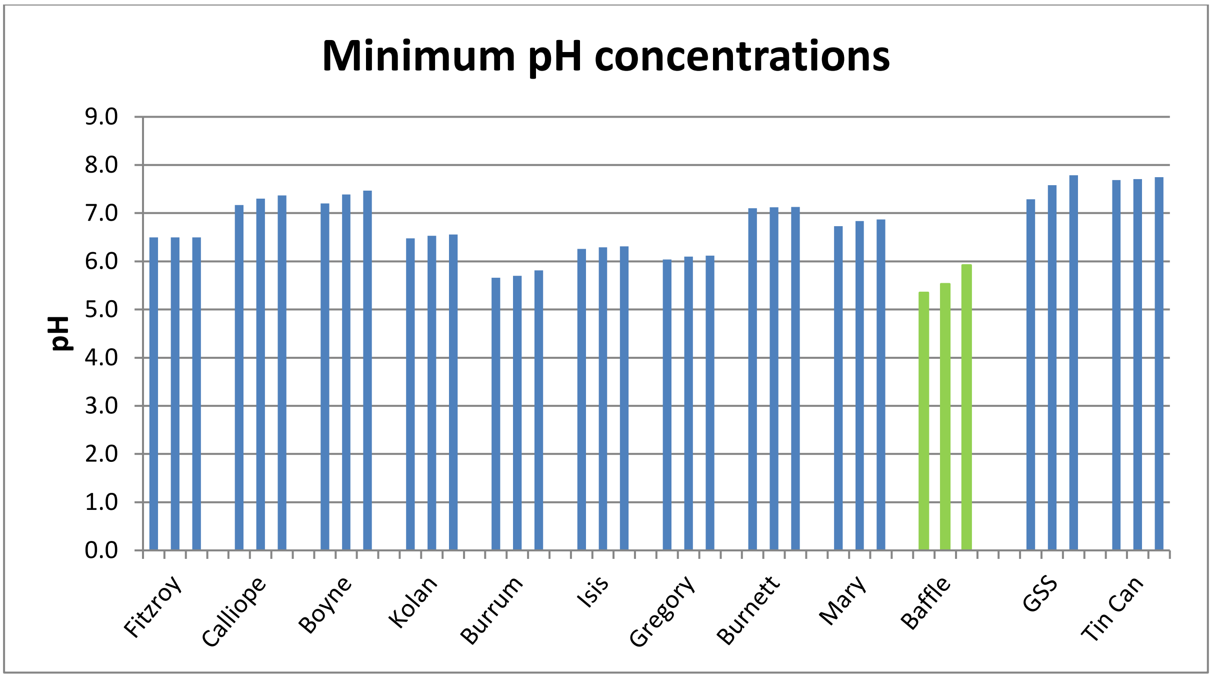

Figure 6.6: Three lowest pH values in the period 2010–15

7 Trend assessment methodology

7.1 Indicators

A subset of the indicators monitored has been selected for trend analysis. They include:

- Dissolved oxygen
- Turbidity (in estuaries)
- Secchi depth (in coastal waters Great Sandy Straits and Tin Can)
- Oxidised N
- Total P
- Chlorophyll *a*.

These indicators are more fully described in Appendix D.

The rationale for using Secchi depth rather than turbidity in coastal waters is that, in these low turbidity waters, Secchi depth is a much more sensitive indicator of change than turbidity (see explanation in Appendix C).

7.2 Scope of trend assessment dataset

Monitoring in some water bodies commenced in mid-1993, while in others it did not commence until mid-1994. Thus, the total period available for trend analysis is from June 1993 or June 1994 until May 2015 (i.e. 21 or 22 years).

The previous report on the CQAMP data Queensland Department of Environment and Heritage (2012) identified a number of methodological issues in measurement of some indicators. These included field method issues and changes in laboratory methods. These issues added a dimension of variance to the data that confounded the calculation of trends in some of these indicators, principally DO and total P. It was not until 1999 that all of these issues had been fully understood and addressed. Therefore, for the purposes of this report, a decision was made to exclude from the primary trend analysis all data prior to mid-1999.

However, for indicators which were largely unaffected by QA issues (turbidity, Secchi depth, chlorophyll *a* and oxidised N), the trends from the start of the dataset (i.e. 1993) have also been considered. Specifically, where there is a significant disagreement between trends detected in the 1999–2015 dataset and those in the full 1993–2015 dataset, this is identified and conclusions are drawn based on the results of both analyses. The main finding that arose from this comparison of the two data periods is that, occasionally, the longer term dataset (i.e. ~22 years) identified very long-term cycles in water quality that were not apparent in the shorter (16 years) dataset. The obvious implication of this is that the results of trend assessment on even moderately long datasets need to be treated with great circumspection unless there is a known driver for the detected trend.

The number of sites monitored in each water body varied from three, in small estuaries such as the Isis, up to 12 in large estuaries like the Mary. For the purposes of trend analysis, a total of six representative sites were selected from all water bodies in which six or more sites were available. In water bodies with less than six sites, all available sites were assessed.

It should be noted that, while DO, Secchi depth and turbidity were monitored at all sites, nutrients (oxidised N & total P) and chlorophyll *a* were only monitored at a restricted set of sites, due to resource limitations – see details in Appendix A. Thus, in each estuary, there were usually only 1–2 sites with nutrient data and 1–4 sites with chlorophyll *a* data.

7.3 Statistical approach

7.3.1 Methods

In the report on data up to 2006 (Queensland Department of Environment and Heritage 2012) trend assessment was undertaken using a relatively simple approach. This involved assessing linear time trends on selected annual statistics, principally the annual median and the annual 80th percentile. The median in particular is a statistic that is robust against variation in extreme values and seasonal variation. However, this approach does not make full use of the available information nor does it account for variation relating to flow (i.e. the natural differences in water quality between wet and dry years). For these reasons, it was decided to adopt a more sophisticated statistical approach for this report.

There are a number of statistical methods that could be applied to the data to assess trends. However, for this report, it was decided that the seasonal Kendall test (Hirsch, Slack & Smith 1982) would be the primary method employed. To set the context, the seasonal Kendall test is described below.

The first section, in italics, is the complete abstract from the Hirsch, Slack and Smith (1982) paper, which provides a succinct summary of the features and merits of the seasonal Kendall test. This is followed by a brief justification for its use to assess the AMP data.

> ***Seasonal Kendall test***
> *Some of the characteristics that complicate the analysis of water quality time series are non-normal distributions, seasonality, flow relatedness, missing values, values below the limit of detection and serial correlation. Presented here are techniques suitable in the face of complications listed above for the exploratory analysis of monthly water quality data for monotonic trends. The first procedure described is a non-parametric test for trend applicable to data sets with seasonality, missing values or values reported as 'less than': the seasonal Kendall test. Under realistic stochastic processes (exhibiting seasonality, skewness and serial correlation), it is robust in comparison to parametric alternatives, although neither the seasonal Kendall test nor the alternatives can be considered an exact test in the presence of serial correlation. The second procedure, the seasonal Kendall slope estimator, is an estimator of trend magnitude. It is an unbiased estimator of the slope of a linear trend and has considerably higher precision than a regression estimator where the data are highly skewed but a somewhat lower precision where the data are normal. The third procedure provides a means for testing change over time in the relationship between constituent concentration and flow, thus avoiding the problem of*

> *identifying trends in water quality that are artefacts of the particular sequence of discharges observed (e.g. drought effect). In the method a flow-adjusted concentration is defined as the residual (actual minus conditional expectation) based on a regression of concentration on some function of discharge. These flow-adjusted concentrations, which may also be seasonal and non-normal, can then be tested from trend using the seasonal Kendall test.*

The characteristics of water quality data collected in the CQAMP closely resemble those described by Hirsch, Slack and Smith (1982). As routine monthly data, it is similar to that collected by the US Geological Survey, which was the principal dataset for which the seasonal Kendall test was originally developed. The use of the seasonal Kendall test as a primary approach for assessing trends in the CQAMP data is therefore seen as appropriate. The test provides an estimate of the significance, direction and magnitude of trends, which is the key outcome required by the CQAMP. It also allows data to be flow adjusted, which is critical for the CQAMP data.

There are other approaches to assessing trend assessment. Some are relatively simple but very easy to apply, for example, undertaking a basic regression on annual medians or other annual statistics, as was employed in the first report on this program (Queensland Department of Environment and Heritage 2012). Others are more complex, for example, the use of constructed General Additive Models. However, it is considered that, for this type of data, the seasonal Kendall test strikes a good balance between power, handling some key issues with water quality data (seasonality, impacts of flow and missing data) and ease of application. In a review of seven methods of linear trend assessment, Hess, Hari and Malm (2001) concluded that the seasonal Kendall test generally performed as well as or better than other methods, except under one or two very specific circumstances.

7.3.2 Application of the seasonal Kendall test to the CQAMP data

In this report, the seasonal Kendall test is applied to the CQAMP dataset using the Time Trends software developed through the New Zealand National Institute of Water and Atmospheric Research by Ian Jowett (Jowett 2015). This robust and easy to apply software allows rapid assessment of large datasets for trends, and also allows the application of covariates to reduce climatic-related variance in the data.

The seasonal Kendall test is based on comparing data from defined seasons within a year with the same season in subsequent years, thus addressing the seasonal variation component in the data. The number of seasons assessed is normally between four and 12. Trends are calculated for each season, and these are then combined to give overall trends across the years. Where monthly data is available, the test is applied to 12 seasons (i.e. months) in a year. The year can start at any month and, for the CQAMP dataset, the year was started in June (i.e. mid-winter), when water quality is least variable. This allows the much more variable summer season to be captured in its entirety within each annual dataset (for northern hemisphere data, the year is usually started in January for similar reasons).

Preliminary assessment of the CQAMP datasets showed that, for some indicators, a significant proportion of the variance could be explained by use of flow correction. For the CQAMP data, the surrogate covariate indicator employed for correcting for flow variation was conductivity @ 25 ^{0}C. Conductivity in estuaries is a good measure of recent freshwater inflows, and therefore likely to be strongly related to catchment inputs of pollutants.

The Time Trends software has a number of choices for estimating the relationship between the selected covariate and the indicator of interest. The procedure used was to plot the variable in question against the covariate, and decide the best fitting relationship (Linear, log-log or GAM). In the great majority of cases, the GAM method gave the greatest reduction in variance in most indicators, but for some indicators at some sites, a log-log or occasionally a linear relationship was superior. The covariate correction method used in each case is specified in the results tables. Where a conductivity-based flow adjustment is applied, the indicator trend is based on the residual values.

In order to reduce the chance of spurious adjustments to variance by the conductivity based flow covariate, it was decided to generally limit application of this correction to instances where the application of the covariate explained ≥10% of the variance in the data. This is a subjective value based on the author's examination of the effects of different levels of application. Where less than 10% of the variance was explained by the conductivity-based flow adjustment, trend assessment was based on the uncorrected dataset.

The outputs from Time Trends software used in this report are:

- the statistical significance (p) of the trend in each indicator at each site (the method will always calculate a trend value, but it may not be significant)
- where significant trends are detected, the slope of the trend and the annual percentage change
- some graphical outputs to illustrate various outcomes from, or issues with, the statistically based results of trend assessment.

7.4 Further evaluation of seasonal Kendall trend outputs

While the seasonal Kendall test provides a robust method for detecting a statistically significant trend within a dataset, the test results should not be applied simplistically and without careful consideration of other factors. These include:

- time period over which the test is applied – some datasets exhibit long-term cycles, presumably related in most cases to climatic factors. Even with covariate correction, applying the trend test over different portions of such a dataset will frequently give different trend results. Thus, a negative trend could turn into a positive trend if, for example, the analysis was delayed while a further two years of data was collected. Some examples of this are highlighted in the results for some estuaries
- the significance value determined by the seasonal Kendall test – this appears to be sensitive to small changes in the data or to very small changes in covariate corrections. For example, the removal of only two data values from a 20-year monthly dataset can change a trend result from statistically significant to statistically non-significant

- where indicators are mostly at very low values – a very few slightly higher values can have a large impact on trend, either positive or negative, depending on where in the data set they occur. Covariate adjustment may not adjust adequately for this
- climatic conditions over the study period – as discussed in section 3.3, freshwater flows varied considerably during the study period and significantly impacted on variation in water quality. While covariate adjustment can allow for some of this variation, because the relationships are mathematical approximations, it is simply not possible to adjust all the data values adequately. Also, the existence of a trend in the covariate itself can to some extent confound the statistical output.

These issues mean that the statistical output from the trend test should never be taken at face value and reported as such. Where a statistically significant trend is detected by the seasonal Kendall test, particularly one where the p value is close to 0.05, the data should be carefully reviewed.

In this report the following review steps were undertaken when a significant trend was calculated by the seasonal Kendall test:

- an assessment of the possible impact of variation in climatic conditions (particularly freshwater flows) during the study period on the trend result
- a graphical assessment of the dataset that involved:
    - an assessment of long-term cycles and how these may be affecting trend calculated at a particular point in time
    - an assessment of unusual patterns in the data
    - a review of residual data plots to assess the effectiveness of the covariate correction
- an assessment of any possible causes of a negative or positive trend
- where data values are very low and close to detection limits, an assessment of the real significance of the calculated trend.

Once the data has been reviewed, a final assessment of each trend is reported. While the post-seasonal Kendall test assessment is to some extent subjective, it is considered by the author to be essential in order to avoid reporting of misleading or spurious trends, and also to further interpret the causes of trends. In this report, all the statistically significant trends are still reported so that readers are able to make their own judgments on the post-statistical assessments.

7.5 Presentation of data

Trend data is presented in separate sections for each estuary. The results shown in the tables are based on assessment of the datasets from June 1999 to May 2015. The prior data (1993–98) was omitted because of QA issues with some indicators (see section 2.6). However, for indicators where QA issues were not considered to affect trend results, the 1993 to 2015 trends were also calculated, although they are not shown in the tables. Where these were not in agreement with the 1999 to 2015 trend outcome, this is stated in the discussion, and the final assessment of trend is based on consideration of both trend results.

In each section there is a table showing the results for all sites/indicators for which a statistically significant trend was detected. The table includes the temporal extent of the dataset, the number of samples, the median value, the covariate (if applied) and covariate adjustment method, the p (probability value), the median slope and the % annual change (+ve or –ve.). Deteriorating trends are highlighted in bold red text.

Following the main table, there are further evaluations of the trends detected, including graphical presentations. The graphs derived from the Time Trends software include both the uncorrected trend line and the covariate corrected trend line (where a covariate is applied).

8 Trend results

8.1 Fitzroy

Figure 8.1: Fitzroy estuary monitoring sites

Table 8.1: Fitzroy estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Turbidity *(NTU)*	33.8	179	115	6/99 - 5/15	Cond/Log	0.04	3.43	**2.98**
	55.1	181	29	6/99 - 5/15	Cond/Log	<0.01	-1.29	-4.45
	57.3	180	25	6/99 - 5/15	Cond/Log	<0.01	-1.34	-5.48
	59.6	176	20	6/99 - 5/15	Cond/Log	<0.01	-1.05	-5.21
NOx *(µg/L)*	57.3	174	260	6/99 - 5/15	Cond/GAM	<0.01	-10.48	-3.92
TP *(µg/L)*	20	175	110	6/99 - 5/15	Cond/GAM	0.05	1.66	**1.51**
	57.3	174	232	6/99 - 5/15	None	<0.01	-10	-4.31
Chl a *(µg/L)*	20	140	2.1	3/00 - 3/15	None	<0.01	-0.13	-4.3
	45.2	155	2.4	6/99 - 3/15	None	0.05	-0.07	-2.9

Turbidity

An increasing trend was detected at a mid-estuary site (33.8). The full 1993–2015 data showed a similar increasing trend at this site, and also at site 20.0 further towards the mouth. There are no clear drivers for increased turbidity in the lower reaches of the Fitzroy, but these trends appear to have real environmental significance. The upper estuary in contrast showed decreasing turbidity trends at three sites. Again, there are no obvious drivers of these trends. The raw data at the upstream sites is very variable. Figure 8.2 shows the turbidity time series at site 57.3 as an example, so that the statistical results need to be treated with caution.

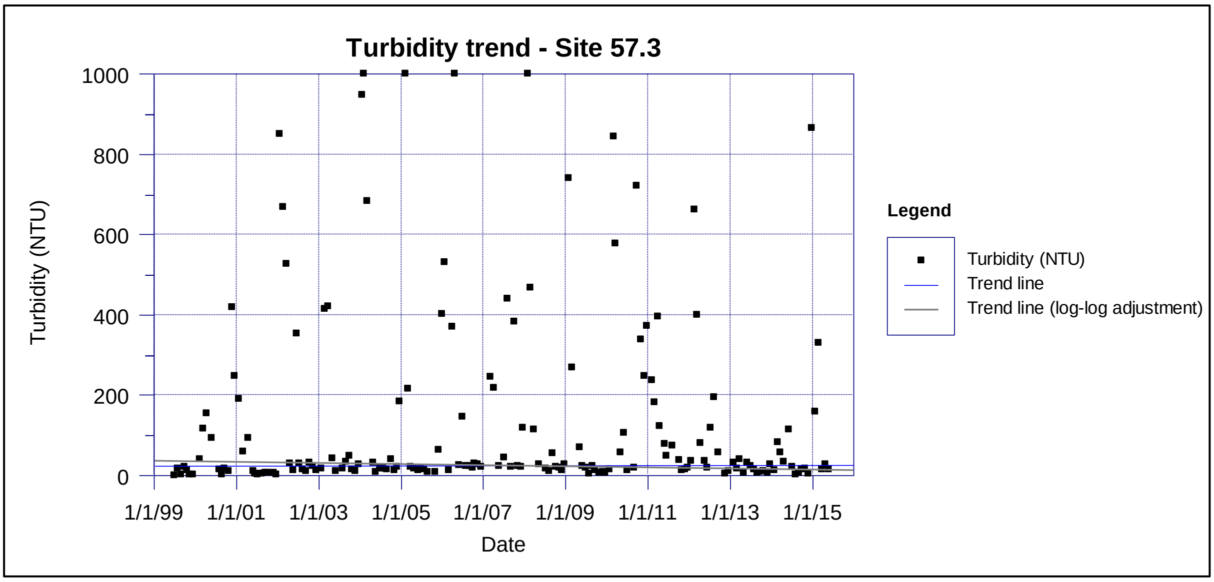

Figure 8.2: Turbidity decreasing trend in the upper Fitzroy estuary

Nutrients

A small increasing trend in total P was detected at site 33.8. This is most likely to be related to the increase in suspended particulates (as measured by turbidity) at this site. Significant decreases in both oxidised N (NOx) (Figure 8.3) and total P were detected in the upper estuary at site 57.3. These are related to upgrades to the wastewater treatment plant discharges entering the upper reaches of the Fitzroy estuary.

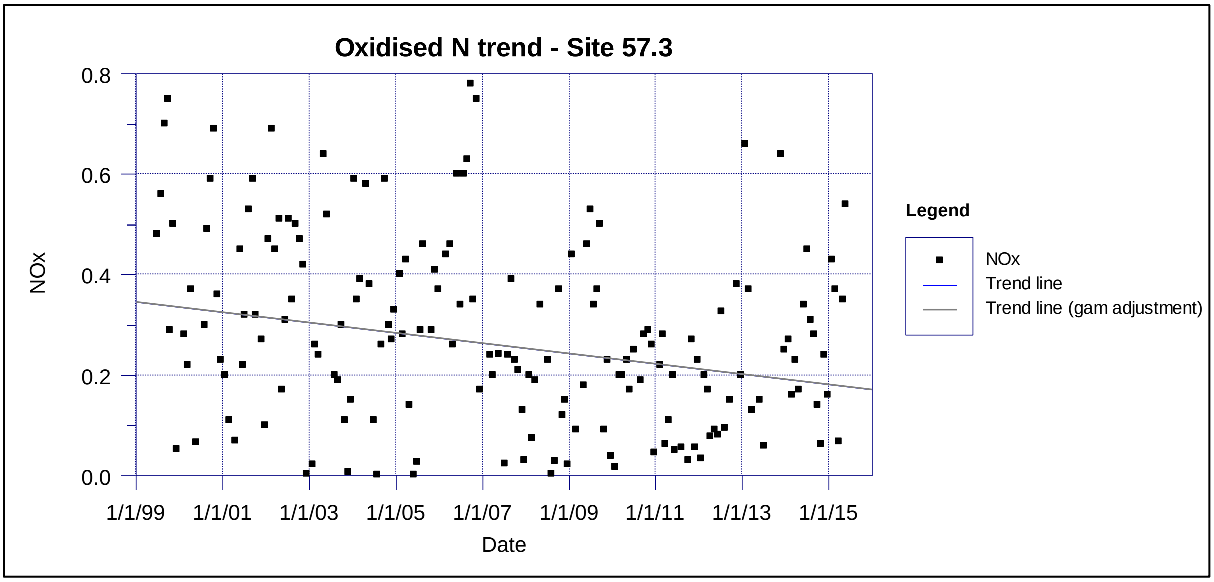

Figure 8.3: Oxidised N (NOx) decreasing trend in the upper Fitzroy estuary

Chlorophyll *a*

Significant decreasing trends were detected at two sites in the mid to lower estuary (these trends were also present in the full 1993–2015 dataset). These may be related to the decrease in the point source nutrient load entering the upper estuary, or could be due to the general increase in turbidity (and therefore light limitation) in these reaches.

8.2 Calliope

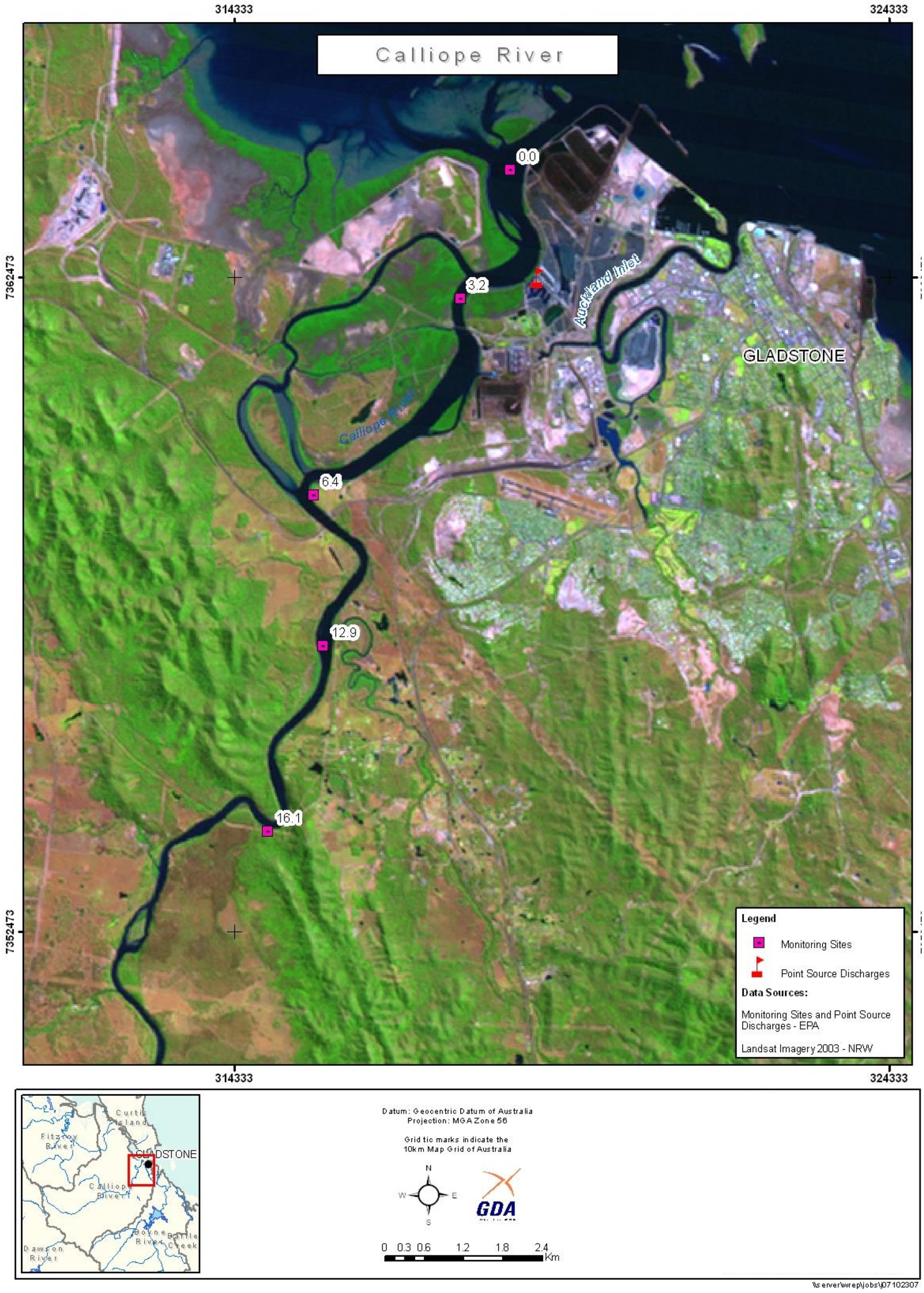

Figure 8.4: Calliope estuary monitoring sites

Table 8.2: Calliope estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Turbidity *(NTU)*	0.0	171	14	8/99 - 5/15	None	<0.01	0.56	**3.96**
DO *(%sat)*	16.1	173	93.8	8/99 - 5/15	Cond/GAM	0.05	0.28	0.3
Chl a *(µg/L)*	12.9	150	2.5	6/99 - 3/15	None	0.02	-.24	-2.72

Turbidity

There was a small but significant increasing trend in turbidity at site 0.0, the estuary mouth (Figure 8.5). Application of flow correction accounted for only 5% of the variance, and so flow effects were apparently not a large factor contributing to this increase. The full 1993–2015 dataset exhibited a similar increase, and additionally an increase at the next site upstream (Site 3.2).

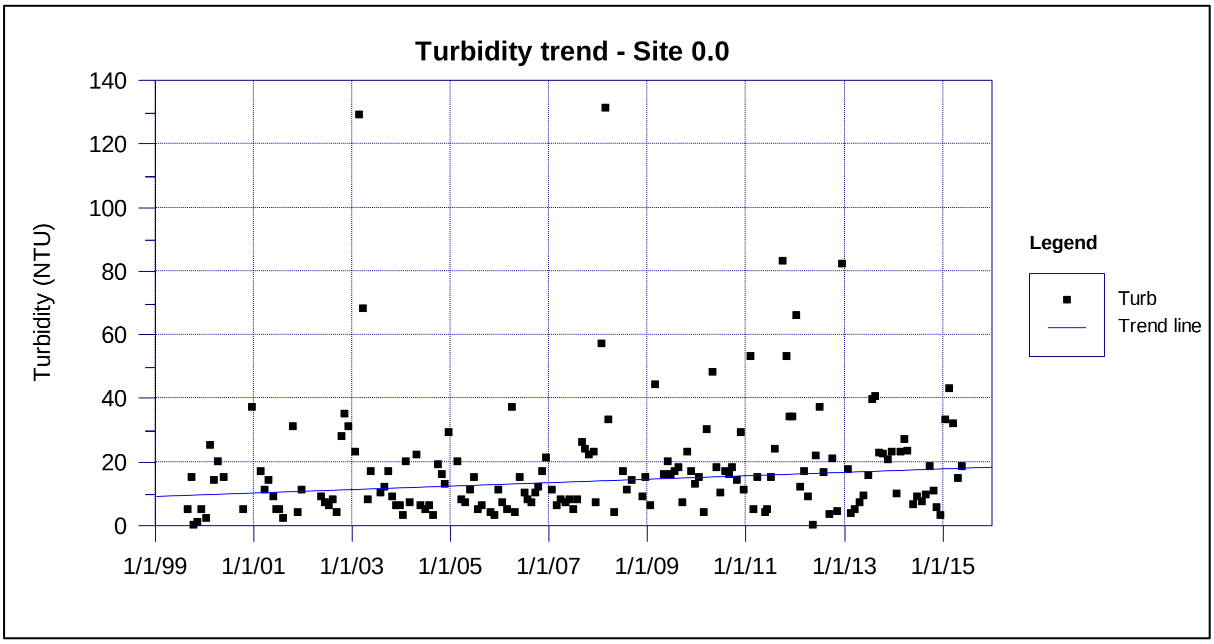

Figure 8.5: Increasing turbidity trend in the lower Calliope estuary

Dissolved oxygen

A significant increase in DO was detected at site 16.1 in the Calliope. The trend was very small and is unlikely to have any real environmental significance.

Chlorophyll *a*

A small negative trend in chlorophyll *a* occurred at site 12.9, representing an improvement in water quality. The cause of this trend is not known, and it is unlikely to be of any real environmental significance.

8.3 Boyne

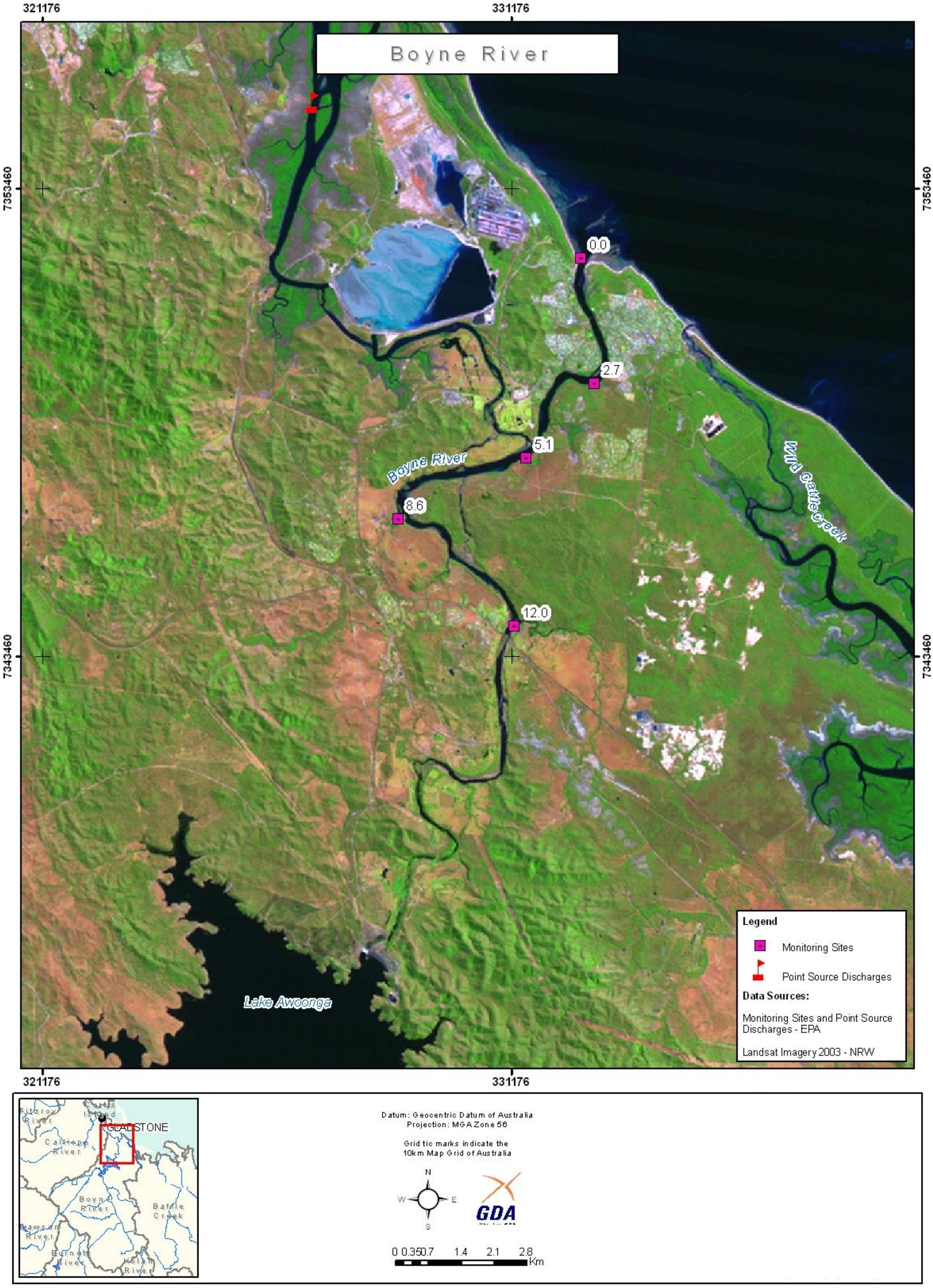

Figure 8.6: Boyne estuary monitoring sites

Table 8.3: Boyne estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Turbidity *(NTU)*	2.7	168	4	8/99 - 5/15	Cond/GAM	0.02	0.11	**2.65**
	12.0	168	6	8/99 - 5/15	Cond/GAM	0.01	-0.19	-3.11
DO *(% sat)*	5.1	176	94.1	6/99 - 5/15	None	0.05	-0.22	**-0.24**
NOx *(µg/L)*	12.0	166	4	6/99 - 5/15	Cond/GAM	<0.01	-0.22	-5.58
TP *(µg/L)*	12.0	166	16	6/99 - 5/15	Cond/GAM	0.02	-0.2	-1.28
Chl a *(µg/L)*	8.6	152	1.1	6/99 - 5/15	Cond/Linear	<0.01	-0.07	-6.05
	12.0	152	1.9	6/99 - 5/15	Cond/Linear	<0.01	-0.11	-5.61

Flow conditions in the Boyne estuary were different from other estuaries. This was due to the upstream presence of the Awoonga Dam. This captured most freshwater flows in the Boyne catchment from 1999 until late 2010, although some high flow releases were made in 2004, 2009 and 2010. The first major overtopping occurred in late 2010, the first time in around 15 years. Water quality trends need to be assessed in the light of this unusual flow regime.

Turbidity

A decreasing trend was detected at the upstream site 12.0. However, inspection of the data (Figure 8.7) shows that the decrease only occurred after the dam overtopped in late 2010. The most likely explanation is that the large freshwater inflow scoured fine sediments from the upper estuary, resulting in lower turbidity values. The increase in turbidity at the lower estuary site 2.7 was small, with no obvious cause. Neither trend was present in the full 1993–2015 dataset.

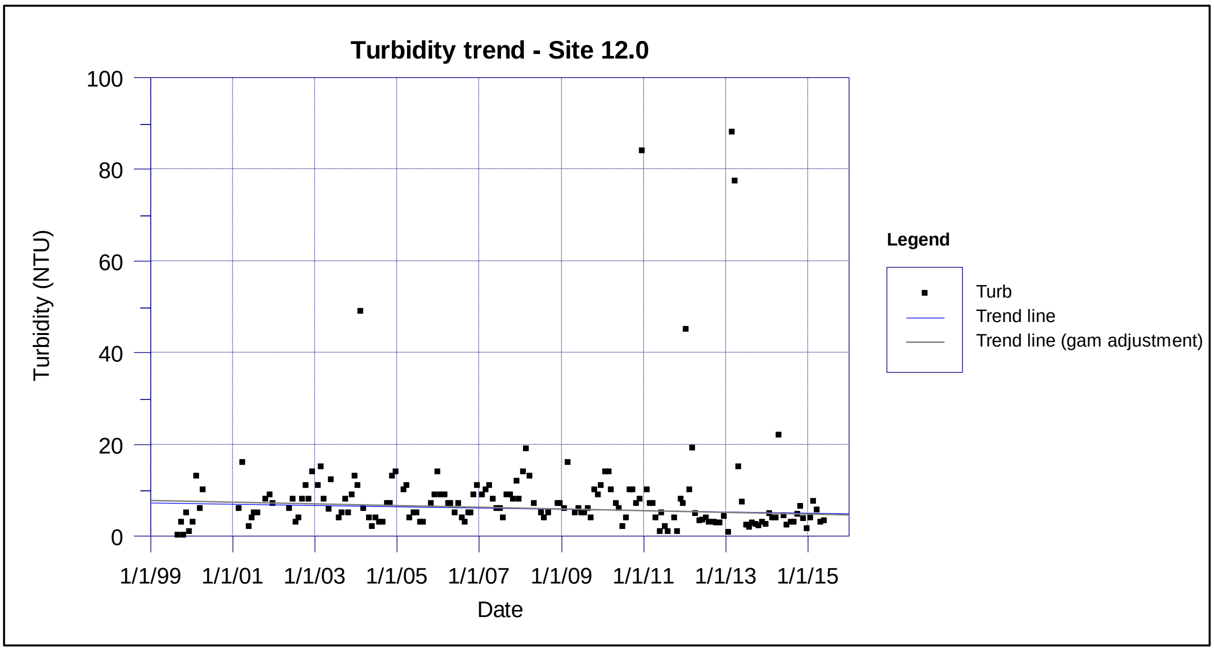

Figure 8.7: Decreasing turbidity trend at upper Boyne River estuary site

Dissolved oxygen

The decreasing trend at site 5.1 was largely related to a reduction in the incidence of supersaturation from 2011 onwards. As with turbidity at site 12.0, this change coincided with the large inflow in late 2010. This may have scoured out benthic algal populations, and hence reduced the incidence of supersaturation, but this is speculative.

Oxidised N

Levels of this indicator were very low, often below detection limits. The statistical decrease is therefore doubtful and, given the very low concentrations, unlikely to be of any real significance to the overall estuary condition.

Total P

As with oxidised N, this small statistical decrease is of doubtful significance and has no real significance to overall estuary condition.

Chlorophyll *a*

Statistically significant negative trends were recorded at two upstream sites. These trends are related to a reduction in residual values (following application of the conductivity covariate correction) after the late 2010 dam overtopping. It is therefore most likely that the decreasing trend is a statistical artefact (due to the broad approximations involved in covariate correction) rather than a real change.

8.4 Baffle Creek

Figure 8.8: Baffle Creek estuary monitoring sites

Table 8.4: Baffle estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Turbidity *(NTU)*	4.1	170	3	6/99 - 5/15	Cond/Log	0.01	0.11	**3.63**
	23.5	170	8	6/99 - 5/15	Cond/Log	<0.01	-0.26	-3.25
TP *(µg/L)*	8.5	178	13	6/99 - 5/15	Cond/GAM	<0.01	-0.2	-1.54
	16.0	176	17	6/99 - 5/15	Cond/GAM	0.02	-0.3	-1.78
Chl a *(µg/L)*	16.0	161	1.7	6/99 - 5/15	Cond/GAM	0.05	-0.04	-2.31
	23.5	161	2.6	6/99 - 5/15	Cond/GAM	<0.01	-0.14	-5.25

All indicator summary

Detected trends in Baffle Creek are mostly negative and also small, indicating either improving water quality or more probably no real change to quality. A small increase in turbidity was detected at site 4.1, but this appears to be mainly caused by high turbidity levels during the wet 2010–13 period that are not adequately corrected for by the conductivity covariate. This trend was not present in the full 1993–2015 dataset.

8.5 Kolan

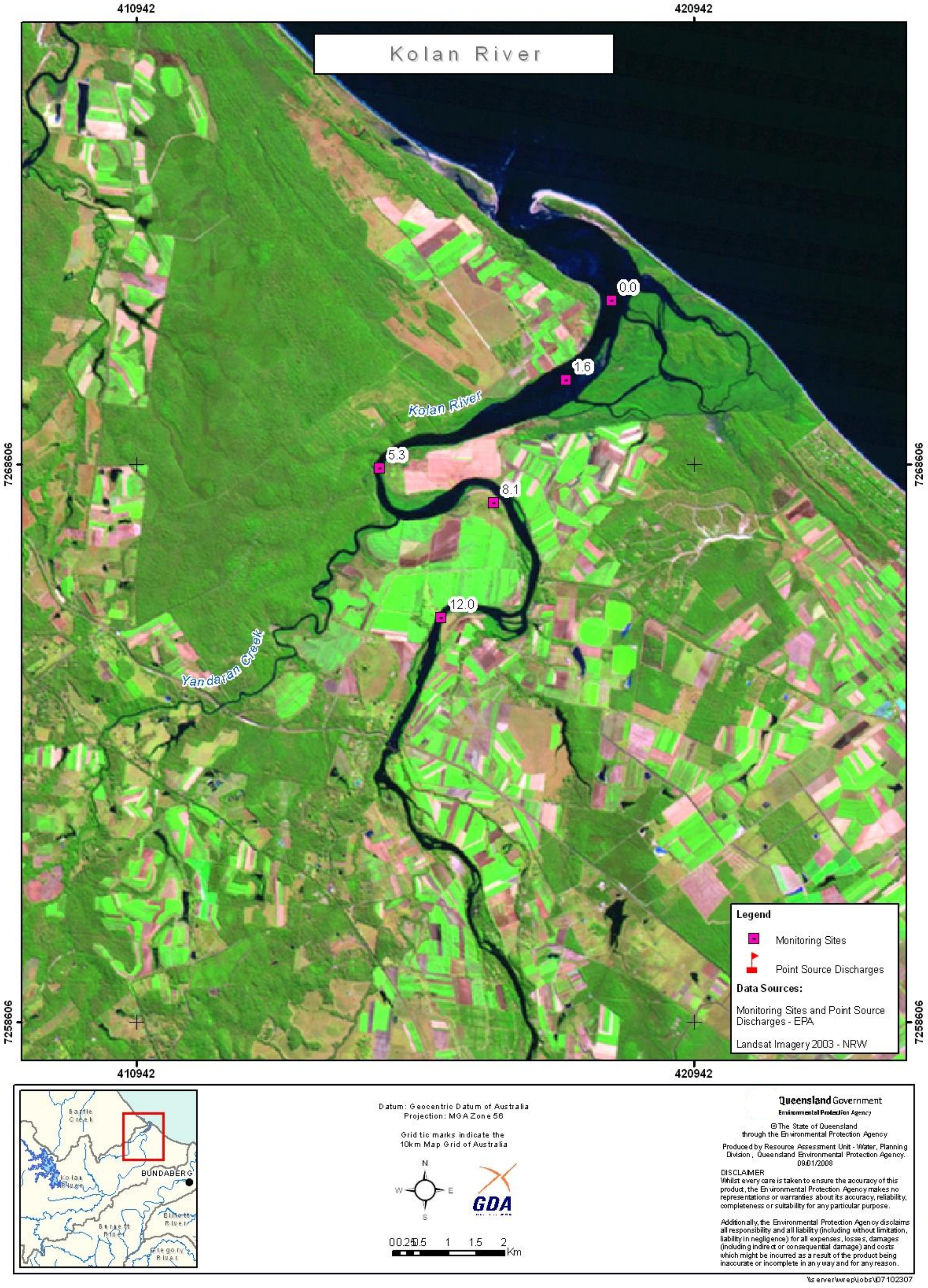

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Figure 8.9: Kolan River estuary monitoring sites

Table 8.5: Kolan estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
DO *(%sat)*	12.0	157	92.3	6/99 - 4/15	None	0.05	0.36	0.39
Chl a *(µg/L)*	8.1	147	2.9	6/99 - 4/15	Cond/GAM	0.01	-0.08	-2.69

All indicator summary

There were small improving trends in quality for single indicators at two sites. Neither of these is likely to be of any real environmental significance.

8.6 Burnett

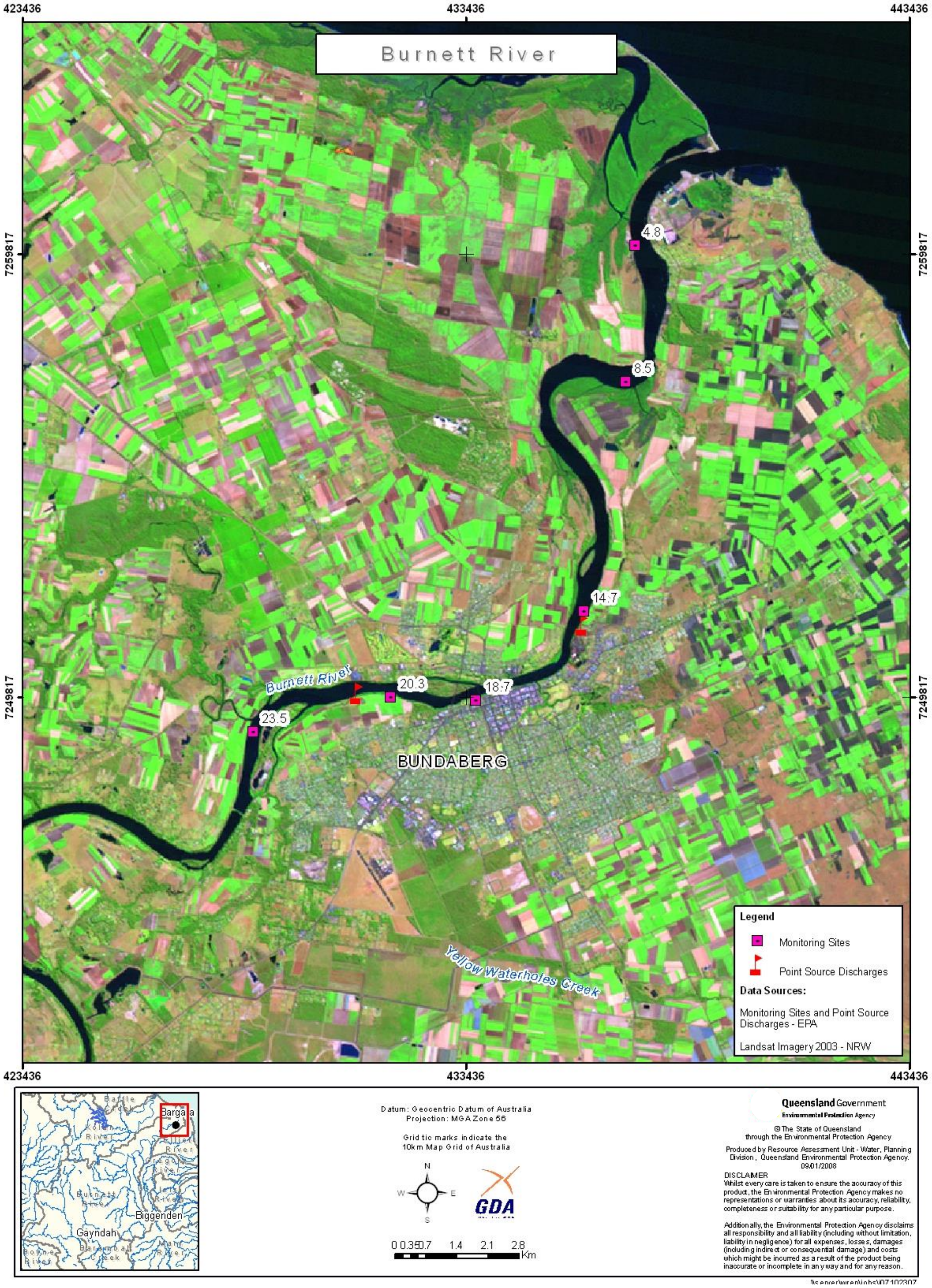

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Figure 8.10: Burnett River estuary monitoring sites

Table 8.6: Burnett estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Turbidity *(NTU)*	4.8	171	5.7	6/99 - 5/15	Cond/GAM	0.05	-0.14	-2.49
	14.7	168	5.3	6/99 - 5/15	Cond/GAM	<0.01	-0.19	-3.55
	18.7	168	9	6/99 – 5/15	Cond/Log	<0.01	-0.41	-4.52
	20.3	166	9	6/99 - 5/15	Cond/Log	<0.01	-0.41	-4.52
	23.5	160	13.1	6/99 - 5/15	Cond/Log	0.01	-0.56	-4.29
TP *(µg/L)*	8.5	170	38	6/99 - 5/15	Cond/GAM	<0.01	-1.11	-2.93
	18.7	171	120	6/99 - 5/15	None	<0.01	-4.85	-4.04
Chl a (µg/L)	14.7	159	4.0	6/99 - 5/15	None	0.04	-0.11	-2.6
	18.7	157	4.3	6/99 - 5/15	None	0.04	-0.09	-2.02

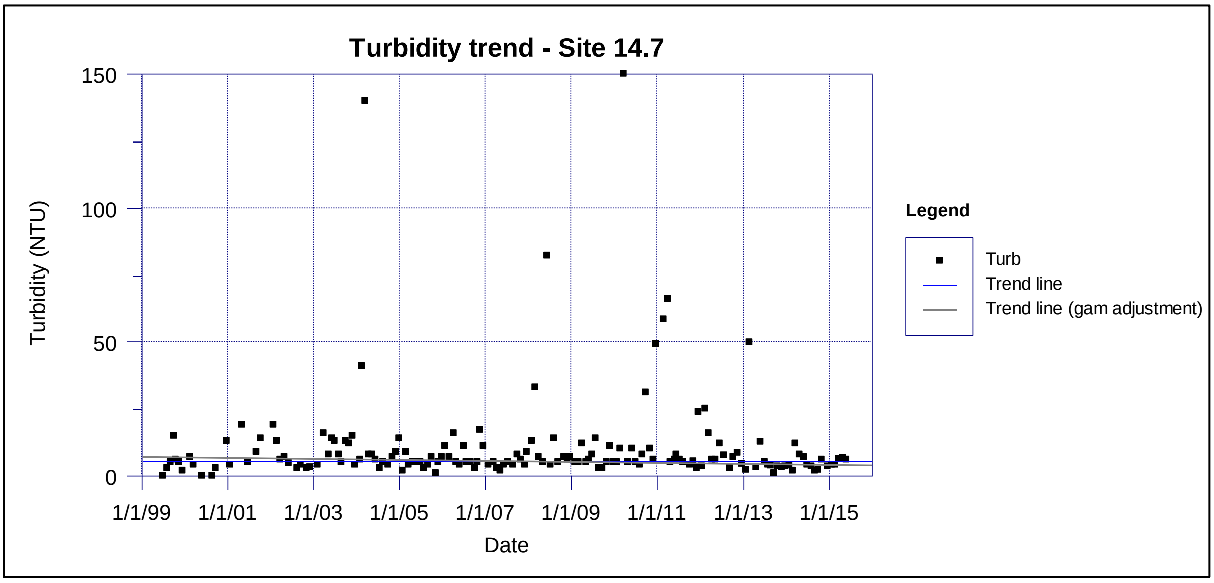


Figure 8.11: Decreasing turbidity trend at mid-Burnett River estuary site

Turbidity

Decreasing turbidity trends were detected at a many sites. Figure 8.11 shows an example at site 14.7. Visually these trends do not appear very significant, and there is no obvious driver for them. Nevertheless, the occurrence of this trend at a number of sites suggests it is a genuine trend.

Nutrients and chlorophyll *a*

There were some significant decreasing trends in total P concentrations at sites 8.5 and 18.7. These resulted from improved treatment at the two main wastewater treatment plants that discharge treated effluent to the Burnett estuary. Figure 8.12 illustrates the abrupt change in concentrations at site 18.7 with the implementation of the upgrades.

A corresponding decrease in chlorophyll *a* occurred at two sites, clearly related to the upgraded discharge quality. Figure 8.13 shows this related decrease at site 18.7

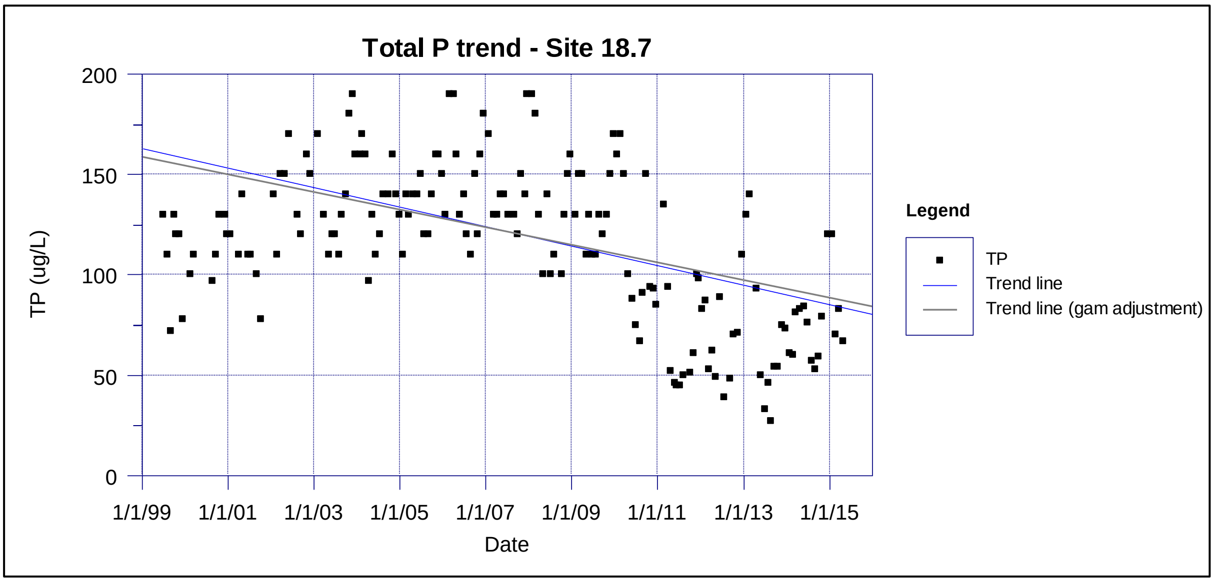


Figure 8.12: Decreasing trend in total P at Burnett estuary site 18.7

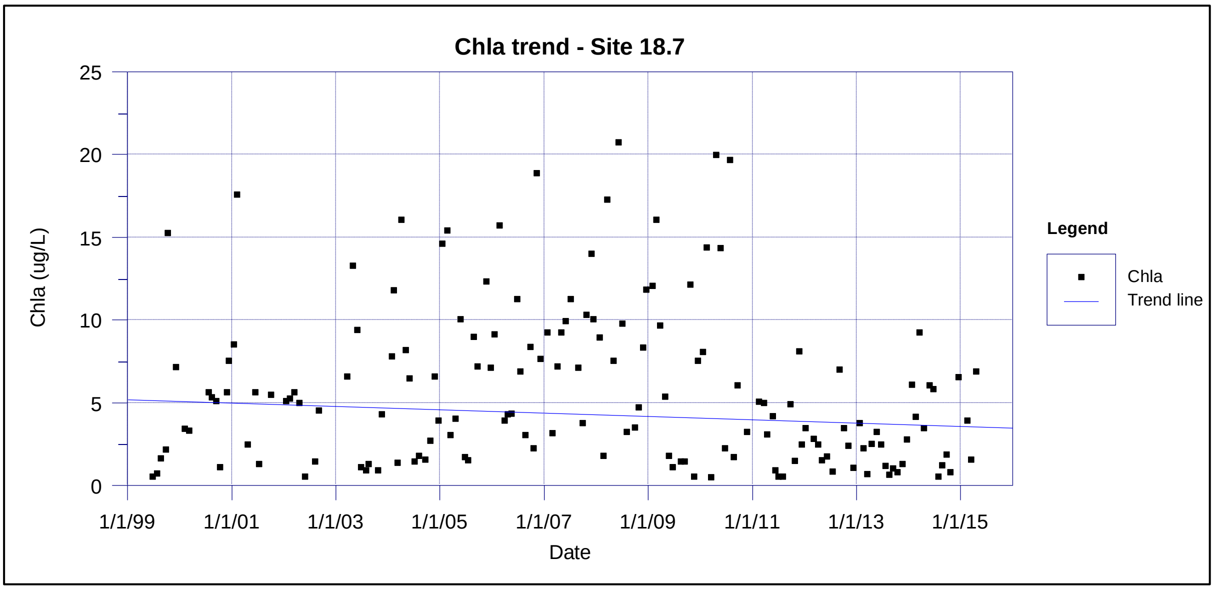


Figure 8.13: Decreasing trend in chlorophyll *a* at Burnett estuary site 18.7

8.7 Burrum/Gregory/Isis

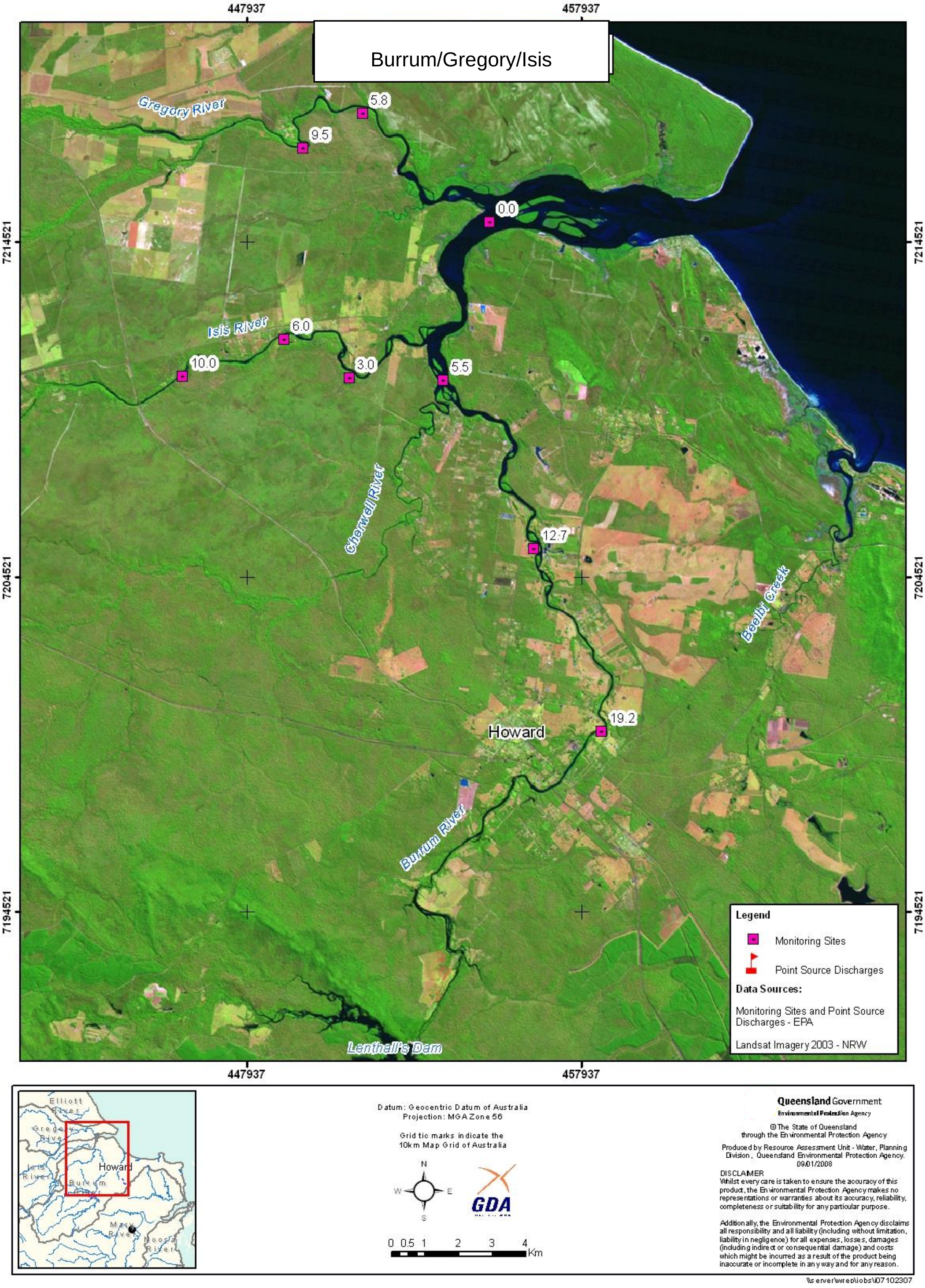


Figure 8.14: Burrum/Gregory/Isis River estuary sites

Burrum

Table 8.7: Burrum estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Secchi	0.0	168	2	6/00 - 5/15	Cond/GAM	0.01	-0.04	**-1.26**
	5.5	166	1.7	6/00 - 5/15	Cond/GAM	0.01	-0.03	**-1.74**
	12.7	169	1	6/00 - 5/15	Cond/GAM	0.03	-0.01	**-1.39**
Turbidity *(NTU)*	0.0	166	3	6/00 - 5/15	Cond/GAM	0.05	0.07	**2.46**
	19.2	166	16.1	6/00 - 5/15	Cond/GAM	0.01	-0.42	-2.59
TP (µg/L)	12.7	124	10	6/00 - 5/15	Cond/GAM	0.04	0.24	1.97
Chl a (µg/L)	12.7	159	2.4	6/00 - 5/15	Cond/GAM	0.01	-0.09	-3.57

Secchi/turbidity

There are significant deteriorating trends in both Secchi and turbidity in the lower reaches of the Burrum, both indicating an increase in suspended particulates. Figure 8.15 shows an example (residual Secchi after conductivity covariate correction at site 5.5). These trends appear to have real environmental significance, but the cause is not known.

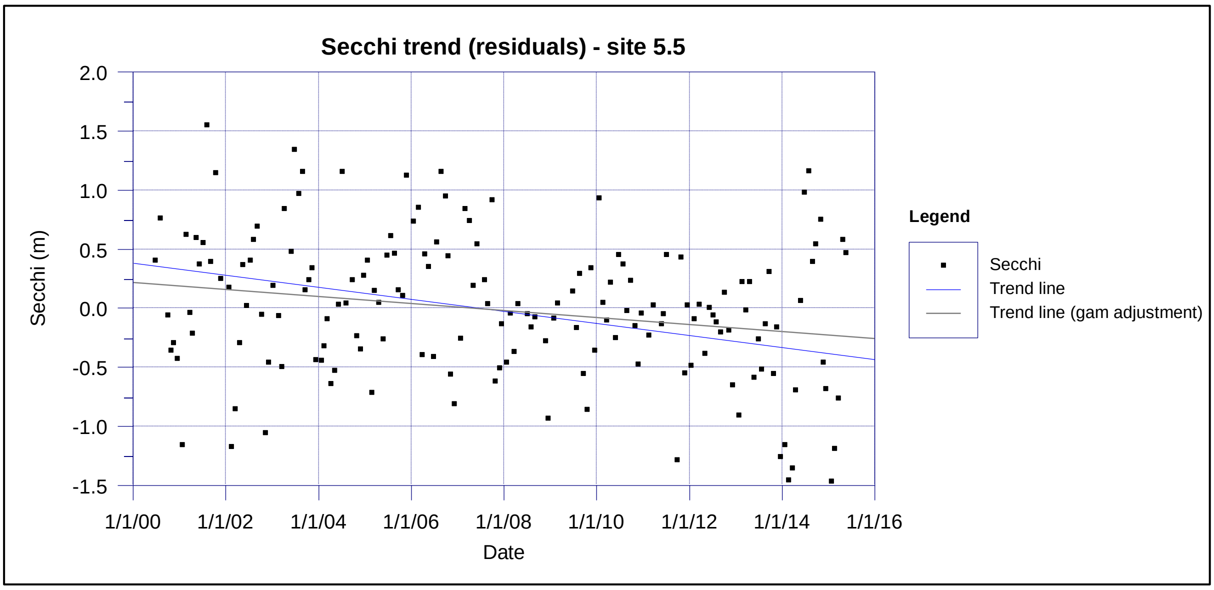


Figure 8.15: Decreasing Secchi depth trend at a lower Burrum estuary site

Nutrients/Chlorophyll *a*

There is a significant increasing trend in total P at site 12.7. This is consistent with the increase in suspended particulates noted above, but again, the cause is not known. The decreasing trend in chlorophyll *a* at site 12.7 is a small but improving trend, but with no known cause.

Gregory

Table 8.8: Gregory estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Turbidity *(NTU)*	9.5	177	18	6/99 - 5/15	Cond/Log	0.04	0.04	-1.11

Gregory all indicator summary

The only detected trend in the Gregory was a decrease in turbidity in its upper reaches – site 9.5. This appears to be mainly due to inadequate covariate correction during the wet 2010–13 period and probably has little true environmental significance.

Isis

Table 8.9: Isis estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Secchi	3.0	176	1	6/99 - 5/15	Cond/GAM	<0.01	-0.02	**-3.35**
Turbidity *(NTU)*	3.0	177	8.4	6/99 - 5/15	Cond/GAM	0.03	0.03	**3.71**
	10.0	176	22	6/99 - 5/15	Cond/Log	0.01	-0.48	-2.2
DO *(% sat)*	10.0	176	89.3	6/99 - 5/15	Cond/Linear	<0.01	-1.05	**-1.18**
Chl a (µg/L)	6.0	168	6.1	6/99 - 5/15	Cond/GAM	0.05	-0.12	-1.95
	10.0	167	14.1	6/99 - 5/15	Cond/GAM	<0.01	-0.59	-4.15

Secchi/turbidity

Consistent with the lower reaches of the Burrum, there are decreasing Secchi and increasing turbidity trends in the lower Isis, suggesting an increase in suspended particulates in the whole lower estuary region of this system. A small improvement in turbidity was noted in the upper estuary.

Dissolved oxygen

The decreasing trend in DO is illustrated in Figure 8.16 below. The figure shows that the decrease is due to the reduction in the incidence of supersaturation rather than any increase in organic loading. This is entirely consistent with the detected decrease in chlorophyll *a*.

Nutrients/chlorophyll *a*

Significant decreases in chlorophyll *a* were detected at mid and upper estuary sites (see Figure 8.17). These decreases are almost certainly the cause of the reduction in supersaturation at these site, but the cause is not known. There were no corresponding decreases in nutrient levels.

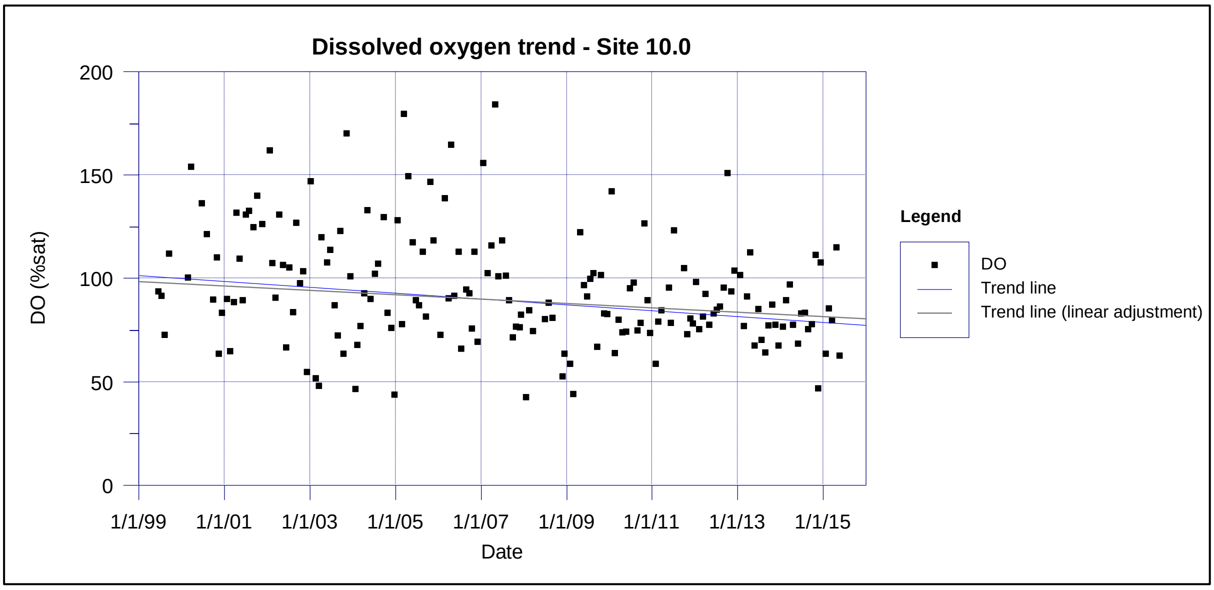


Figure 8.16: Decreasing DO trend at an upper Isis estuary site

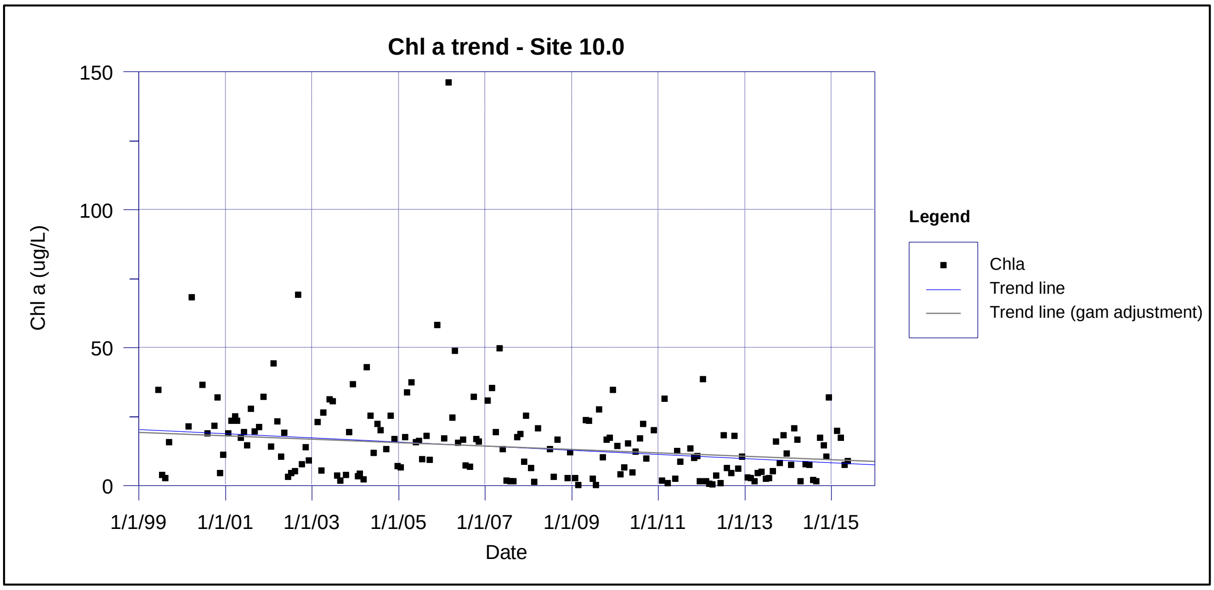


Figure 8.17: Decreasing chlorophyll *a* trend at an upper Isis estuary site

8.8 Mary

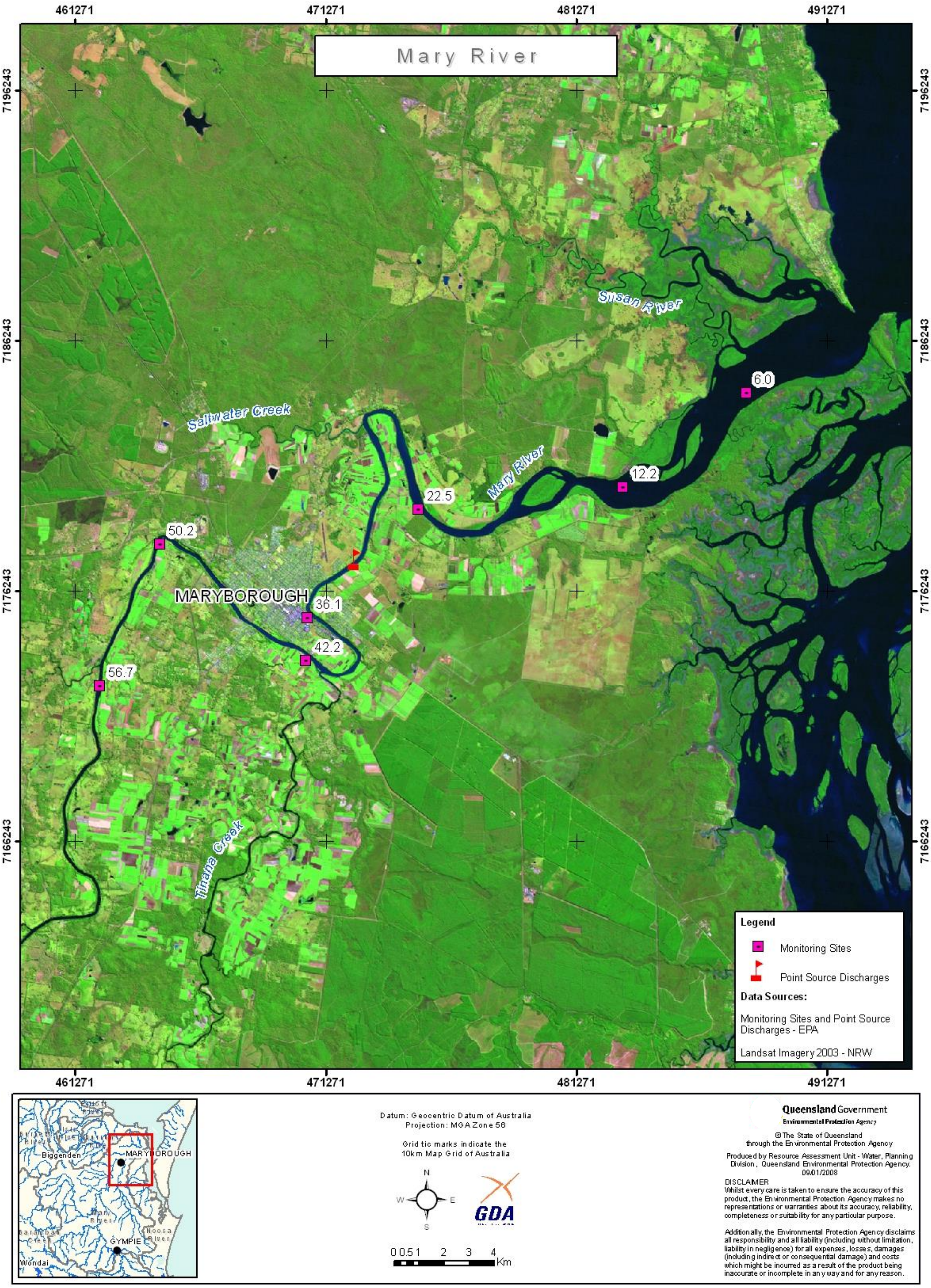


Figure 8.18: Mary River estuary monitoring sites

Table 8.10: Mary estuary – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Turbidity *(NTU)*	36.1	178	74	6/99 - 5/15	None	0.01	-1.95	-2.63
DO *(% sat)*	6.0	178	95.3	6/99 - 5/15	Cond/Linear	0.02	0.13	0.14
	56.7	176	92.0	6/99 - 5/15	Cond/Linear	<0.01	0.72	0.79
NOx *(µg/L)*	22.5	178	250	6/99 - 5/15	Cond/GAM	<0.01	-6.62	-2.65
TP *(µg/L)*	22.5	178	61.5	6/99 - 5/15	Cond/Log	0.01	-0.81	-1.31
Chl a *(µg/L)*	6.0	164	1.4	6/99 - 5/15	None	0.04	0.03	**2.21**

Turbidity

Trends in turbidity in the Mary are highly dependant on the time period assessed. If data back to1993 are included, then a positive trend is present while the years 1999 to 2015 indicate a negative trend detected. Figure 8.19 shows the data with a best fit polynomial line, indicative of a long-term cycle with no dominant upward or downward trend.

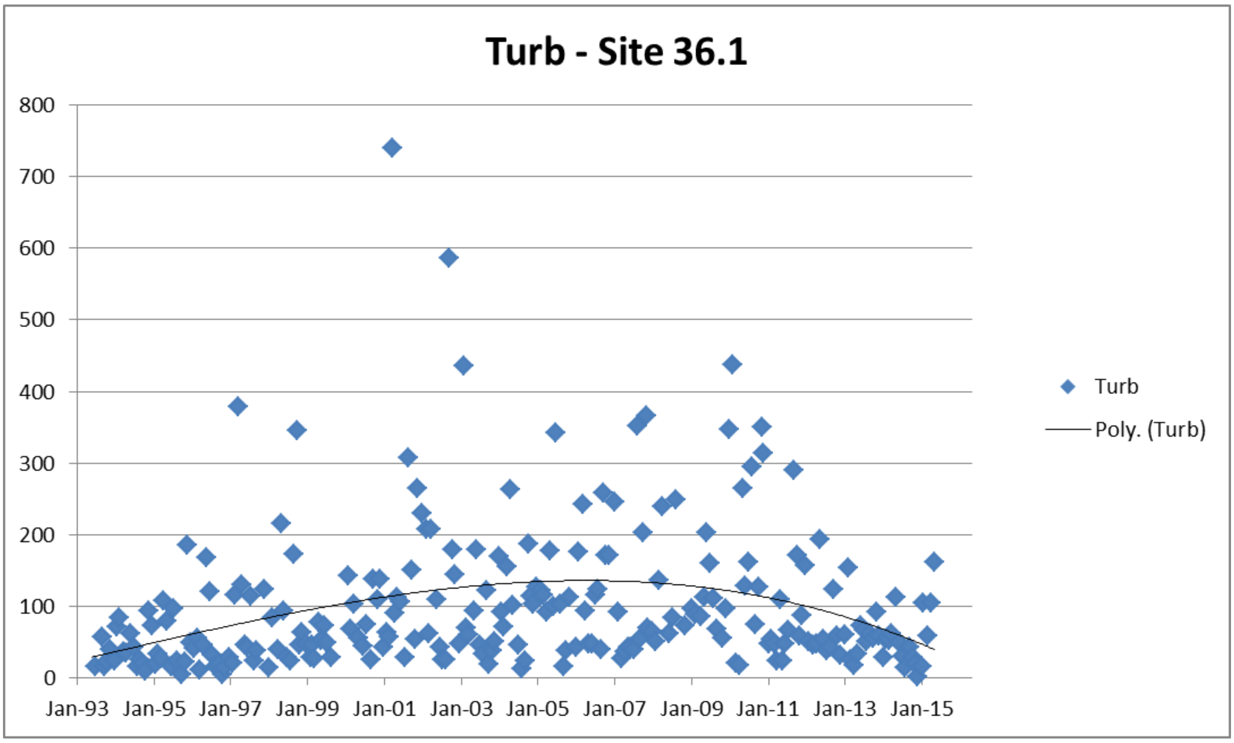


Figure 8.19: Long-term turbidity cycle in the mid-Mary River estuary

Dissolved oxygen

Visual assessment of DO at site 6.0 suggests that the small statistical trend is not representative of real environmental change (see Figure 8.20). However, the increase at site 56.7 appears to be a sustained upward trend due to increasing frequency of supersaturation (see Figure 8.21). This may be due to increased algal production, although no increase in chlorophyll *a* was detected at this site.

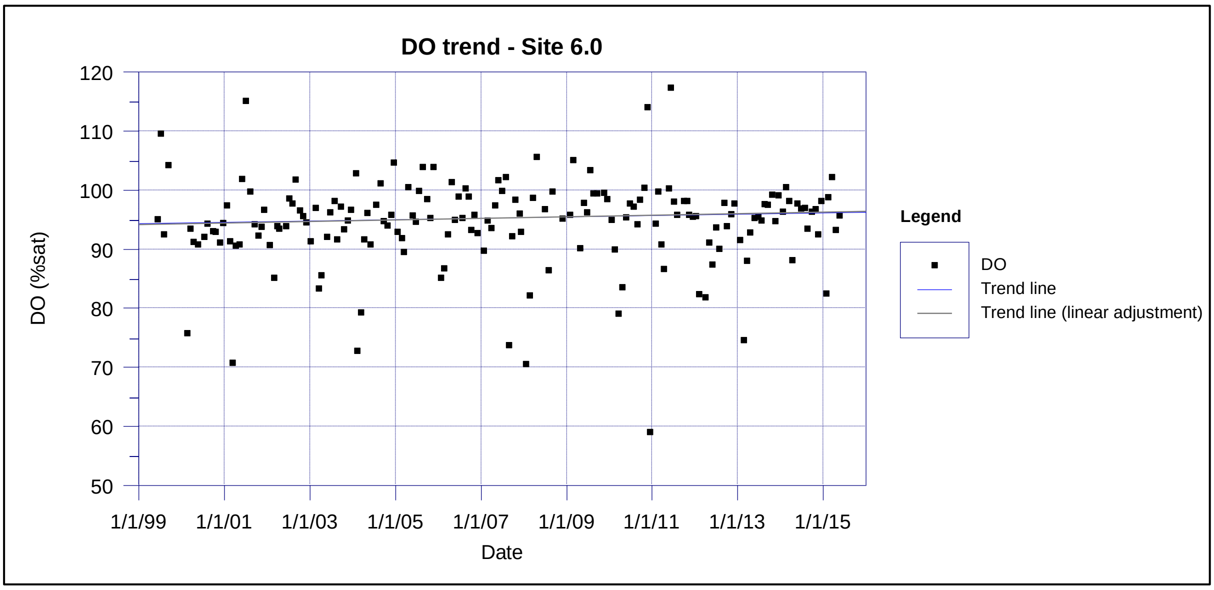


Figure 8.20: Increasing DO trend at lower Mary River estuary site

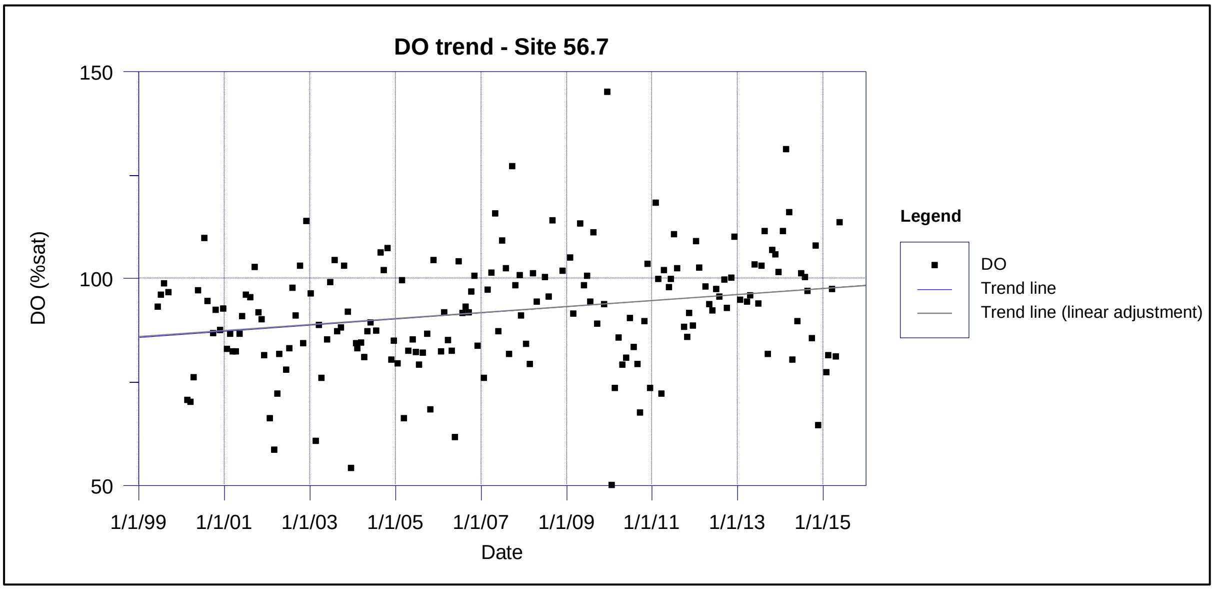


Figure 8.21: Increasing DO trend at the most upstream Mary River estuary site

Nutrients and chlorophyll *a*

There is a statistically significant and visually very apparent reducing trend in oxidised N at the mid-estuary site 22.5 (see Figure 8.22). This site is close to the Maryborough Waste Water Treatment Plant discharge. The most obvious explanation of the downward trend would be an improved treatment train at the plant. However, consultation with Wide Bay Water, which is responsible for the treatment plant, has established that the plant has not undergone any significant modifications in the past 20 years. Thus the cause of the decrease remains unclear.

Site 22.5 also experienced a parallel decrease in total P, which is similarly suggestive of an improvement in the wastewater treatment.

The increase in chlorophyll *a* at site 6.0 is too small to support any reliable conclusions, and is unlikely to represent a real environmental change.

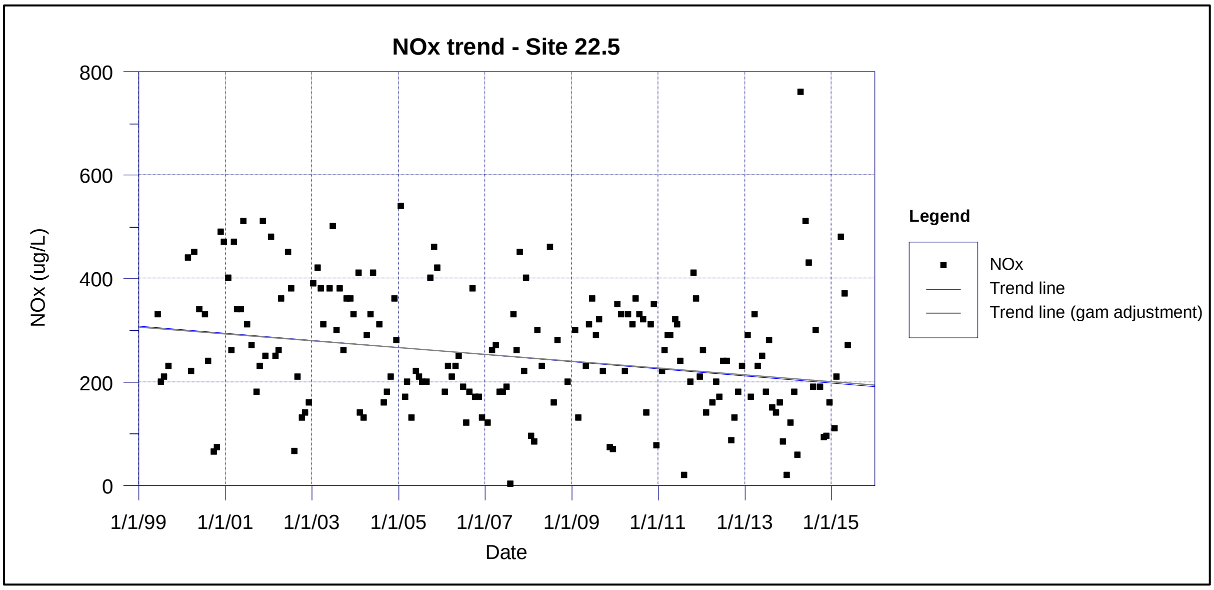
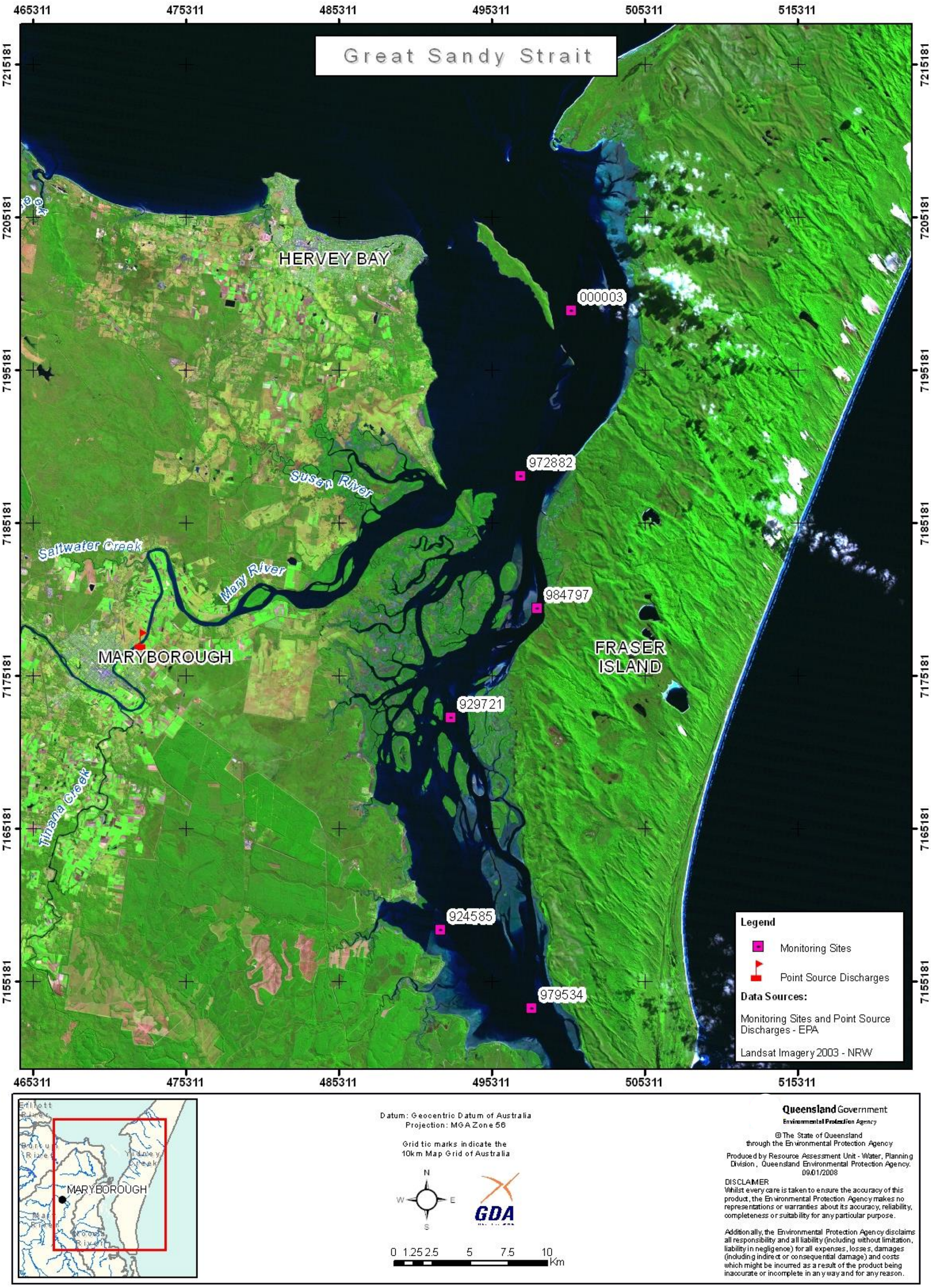


Figure 8.22: Decreasing oxidised N trend at a Mary River mid-estuary site

8.9 Great Sandy Straits



Datum: Geocentric Datum of Australia
Projection: MGA Zone 56

Grid tic marks indicate the 10km Map Grid of Australia

Produced by Resource Assessment Unit - Water, Planning Division, Queensland Environmental Protection Agency.
09/01/2008

Figure 8.23: Great Sandy Straits monitoring sites

Table 8.11: Great Sandy Straits – summary of statistically significant trends

Indicator	Site	No samples	Median	Date range	Covariate/ adjustment	p	Median slope *(annual)*	% annual change
Secchi *(m)*	000003	159	4.9	6/99 - 5/15	None	<0.01	-0.14	**-2.86**[1]
	972882	163	3.6	6/99 - 5/15	Cond/GAM	<0.01	-0.12	**-3.37**[1]
	984797	159	3.4	6/99 - 5/15	Cond/GAM	<0.01	-0.08	**-2.47**[1]
	929721	159	2.4	6/99 - 5/15	Cond/GAM	<0.01	-0.06	**-2.65**[1]
	924585	156	2.6	6/99 - 5/15	Cond/GAM	0.02	-0.04	**-1.55**[1]
	979534	154	2.2	6/99 - 5/15	None	0.03	-0.04	**-1.85**[1]
DO *(% sat)*	000003	157	98.9	6/99 - 5/15	None	<0.01	0.17	0.17
	972882	163	99.3	7/99 - 5/15	None	0.01	0.16	0.16
Chl a *(µg/L)*	000003	143	0.6	7/99 - 5/15	Cond/GAM	0.01	<0.01	-0.48

1 Note comments in Secchi section below

Dissolved oxygen

There were significant increases in DO at the two most northern sites. Figure 8.24 shows the data for one of these sites. This appears to be a consistent and fairly steady increase, indicating it is a real change. The change may be due to increased primary productivity, but there is no evidence of any increase in phytoplankton chlorophyll *a* at either of these sites. An alternative explanation is an increase in benthic algal productivity, but there is no data available to assess this possibility. No significant DO trends were recorded at sites further south.

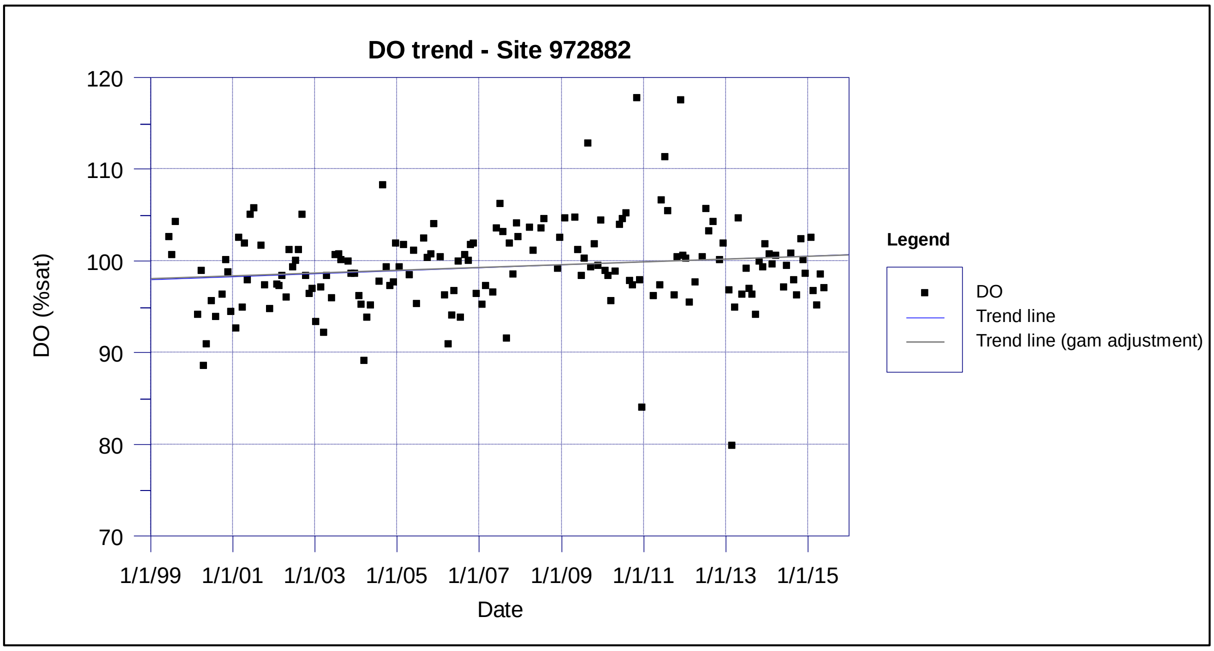


Figure 8.24: Increasing DO trend at a Great Sandy Straits site

Secchi depth

The seasonal Kendall analysis indicated significant and very substantial decreasing trends in Secchi depth at all sites over the period 1999 to 2015. However, this is a good example of how looking at trends over a given period can be misleading. If the data from 1993 is included, there are no significant trends at any site. Figure 8.25, which shows data from site 972882, demonstrates why this is the case. A best fit polynomial line exhibits a convex curve. Values increase between 1993 and around 2000, and then decrease again. Clearly there was a significant decrease between mid-1999 and 2015, but this appears to have been part of an even longer term cycle. Having said that, the decrease in Secchi values, and hence light availability, over the 16-year period 1999 to 2015 may well have had some impact on seagrass and other light dependant biota over that time.

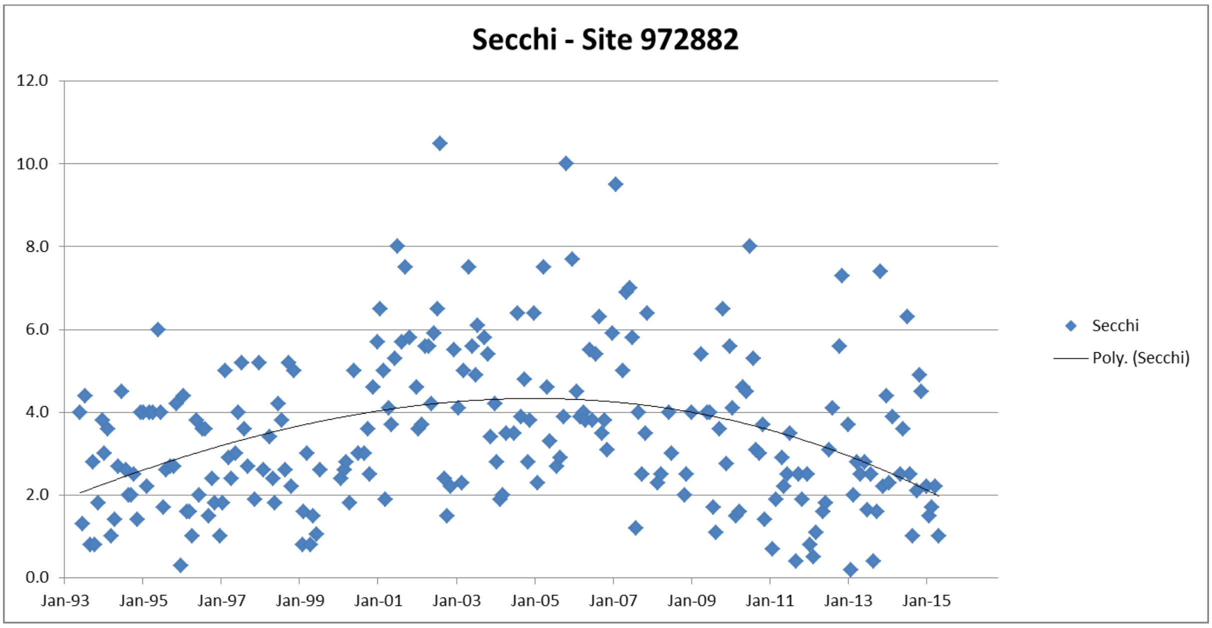


Figure 8.25: Secchi depth at a Great Sandy Strait site showing a very long-term cycle

Nutrients and chlorophyll *a*

A small decreasing trend in chlorophyll *a* was detected at site 000003 – see Figure 8.26. This appears to be due to a period of consistently low values from 2013 onwards. At these low chlorophyll *a* values, no great weight should be attached to this apparent trend.

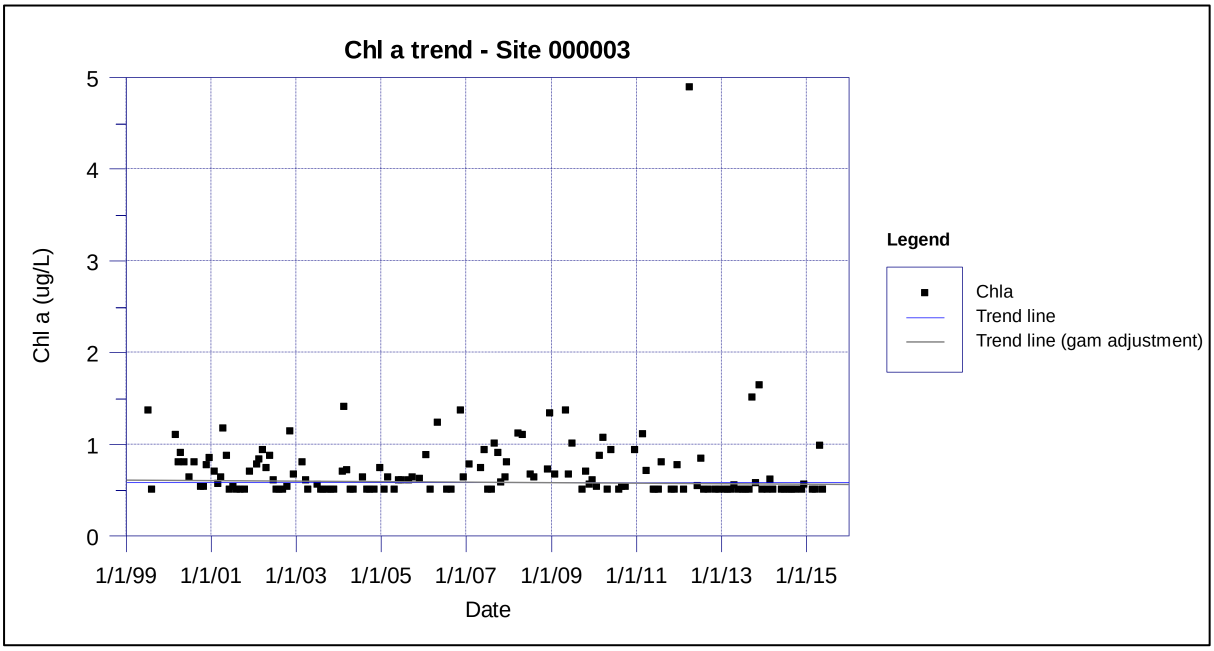
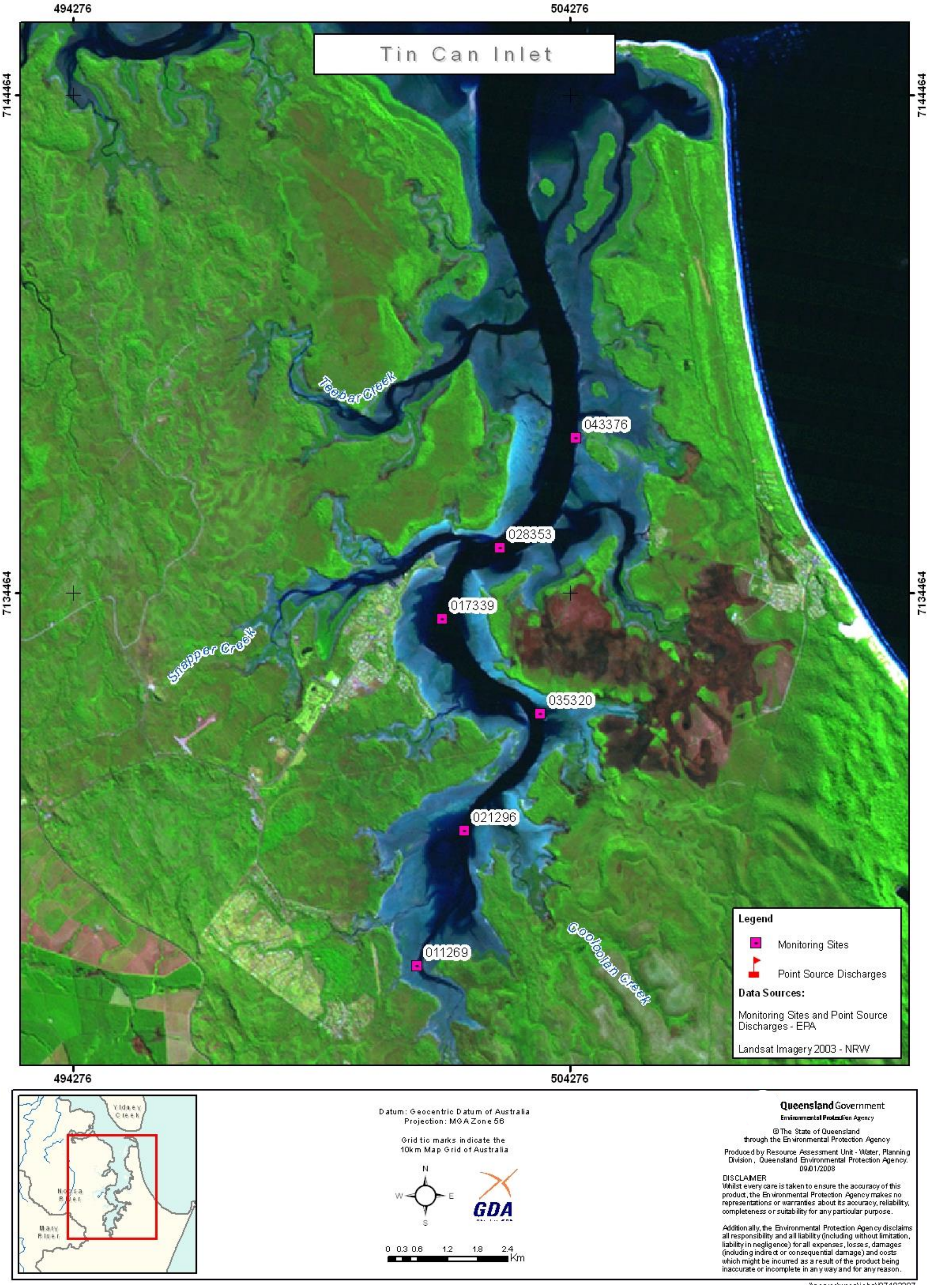


Figure 8.26: Decreasing chlorophyll *a* trend at a northern Great Sandy Strait site

8.10 Tin Can Inlet



Produced by Resource Assessment Unit - Water, Planning Division, Queensland Environmental Protection Agency.
09/01/2008

Figure 8.27: Tin Can Inlet monitoring sites

Table 8.12: Tin Can Inlet – summary of statistically significant trends								
Indicator	**Site**	**No samples**	**Median**	**Date range**	**Covariate/ adjustment**	**p**	**Median slope *(annual)***	**% annual change**
Secchi *(m)*	11269	169	1.3	6/99 - 5/15	None	0.01	0.02	1.91
	21296	169	2.4	6/99 - 5/15	Cond/GAM	0.04	0.02	1.0
	43376	170	3.0	6/99 - 5/15	Cond/GAM	0.05	-0.04	-1.38
Chl a *(µg/L)*	11269	153	0.8	6/99 - 5/15	None	0.04	<0.01	-0.14

Secchi depth

There are small positive trends at sites 11269 and 21296. The trend at 11296 is also present in the full 1993–2015 dataset (see Figure 8.28), but the trend at 21296 is not. Thus the trend at site 11296 may have real environmental significance, while that at 21296 is more questionable. The small negative trend at site 43376 is completely absent from the longer dataset, so is also unlikely to have any real significance.

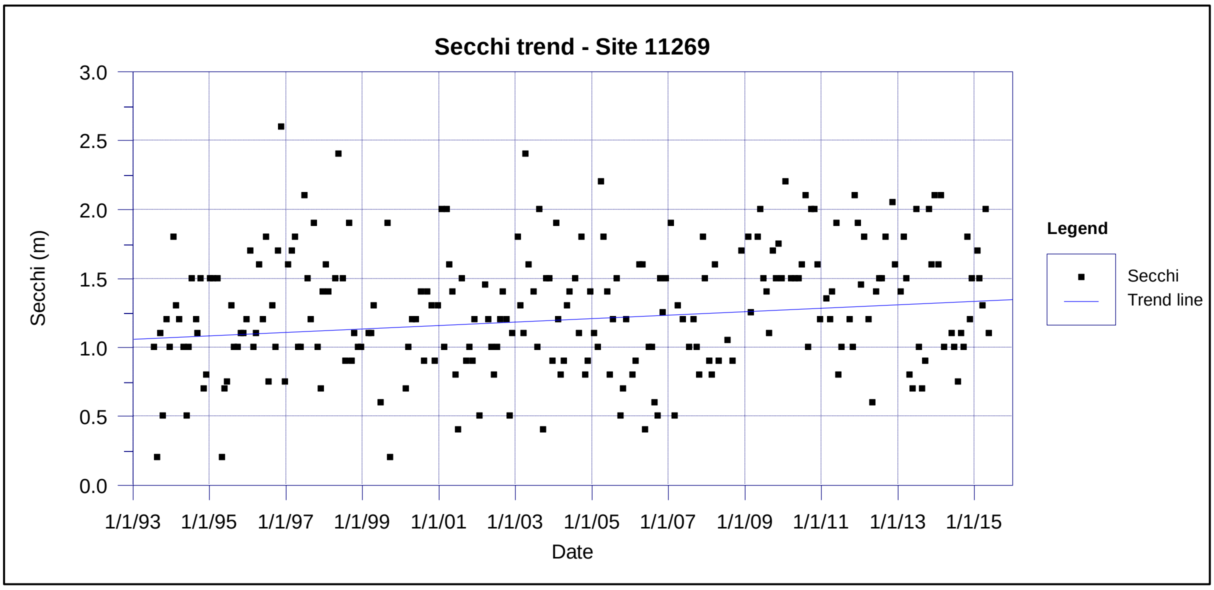


Figure 8.28: Increasing Secchi depth trend at a Tin Can Inlet site

Nutrients and chlorophyll *a*

At the low levels of chlorophyll *a* present, the negative chlorophyll *a* trend is too small to allow any releable conclusions. Negative trends in NOx were detected in the full 1993–2015 dataset, but are also considered too small to allow reliable conclusions.

9 Conclusions

Water quality condition

1. Water quality in the three estuaries that receive significant wastewater point source discharges does not comply with the guidelines for some indicators. However, the extent of non-compliance in most cases is not large.
2. There were also a number of instances of non-compliance in estuaries not receiving point source discharges. In some cases, this can be explained by the fact that the period of compliance assessment covered some of the wettest years in the history of the program. The increased degree of compliance in the drier years of the five-year compliance period is apparent in the condition tables.
3. However, in some of these estuaries, and in particular the Burrum/Isis/Gregory system, non-compliance appears to occur more generally across a number of indicators, and is not explained by the wet period. It would appear that these estuaries are impacted by diffuse sources of pollution, although the origin of these is not known.
4. Baffle Creek, which has the least disturbed estuary and catchment, generally exhibited the highest level of compliance, although wet weather related non-compliance did occur for some indicators.
5. Assessment of extreme water quality values (either maxima or minima, depending on the indicator) recorded over the past five years (2010 to 2015) showed that water quality very rarely declines to a point where it might cause serious short-term ecological impacts. The one exception to this was a low DO event in the Fitzroy River estuary that was caused by inflows from large and organically enriched lagoons, and which resulted in fish deaths. (A caveat on this conclusion is that it is based on monthly data. It is likely that there were short periods of water quality poorer than the recorded extreme values).
6. Virtually all the extreme water quality values in these estuaries are associated with periods following significant freshwater inflows.
7. Water quality in the two coastal waters was generally very good, apart from wet weather related non-compliance with the Secchi disc clarity guideline.

Water quality trends

8. The three estuaries receiving wastewater point source discharges (predominantly treated sewage effluent) all showed improving trends in quality. In the Fitzroy and Burnett, these improvements were related to upgraded effluent treatment. In the Mary, while similar improvements were detected, the cause is unclear, as there were apparently no significant upgrades to effluent treatment.
9. Perhaps one of the main findings of the program is that, in most of the estuaries not receiving point discharges, water quality has remained remarkably consistent over the assessment period. The general absence of large long-term trends indicates that changes in water quality due to catchment and diffuse pollutant impacts may only occur over considerably longer periods than the current span of this program.
10. Of the trends that were detected, the majority were minor improving trends, with a much smaller number of minor deteriorating trends.

11. The most significant improving trends occurred in the Burrum/Isis/Gregory system, where the Burrum and Isis estuaries recorded significant reductions in chlorophyll *a* levels in their upper reaches.
12. The deteriorating trends of most concern were:

    - Increasing turbidity in the lower Calliope which were not explained by freshwater inflows
    - A general increase in turbidity in the lower reaches of the Burrum/Isis/Gregory system for which there is no obvious explanation
    - Decreasing clarity (Secchi depth) in the Great Sandy Straits. Although it is demonstrated that this may be part of a very long-term cycle, it is nevertheless a 15-year decline, and may have affected seagrass viability. Results from future years will be of considerable interest.

10 Recommendations

- The ambient water monitoring program in central Queensland has been ongoing for over 20 years. It continues to address the main aim, to assess change over time, but the data has also been used for a wide range of other purposes. Having collected, and now analysed, over 20 continuous years of data, we are in a good position to make informed judgments about the design of the program and the nature and true value of the data. As with all long-term programs, it is important that this program be reviewed and, with the completion of this extensive data analysis, it is appropriate that such a review be undertaken at this time. Such a review should make recommendations about the future design of the program, but it is important to note that there are a number of factors that will constrain the extent to which the program can be modified. The main ones are described below:

    - Data from this and allied monitoring programs in north Queensland are increasingly being used as key inputs to the estuary component of regional reef report cards. This includes data from Fitzroy estuary sites used in the Fitzroy report card, and data from the Calliope and Boyne estuaries which both adjoin Port Curtis, currently a high priority report card area.

    - Monitoring in many locations will need to be continued anyway due to priorities associated with individual estuaries. These include:
        - Fitzroy – monitoring is associated with ongoing assessment of sewage treatment plants and other discharges, and receives some Receiving Environment Monitoring Program funding
        - Baffle Creek – this is a key reference estuary and, as such, maintaining a long-term dataset has high strategic significance
        - Burnett – DES receives funding from Bundaberg Regional Council to undertake monitoring, and so we need to continue the program here
        - Mary – a significant estuary with discharges from Maryborough and large catchment impacts
        - Great Sandy Strait – an iconic area which is also an important marine park.

    - Long-term water quality datasets are difficult to achieve and become increasingly valuable as time goes on. They are often used for purposes which may not be envisioned at the start of the program, for example, tracking climate change effects. Interrupting or altering a long-term program, and thus creating disturbances to the dataset, should therefore never be implemented without very careful consideration.

- While there are important constraints, it is still timely that the program be reviewed and recommendations made about its design, even if this only confirms that the program should continue largely unchanged.

- While the current program is very much focused on monitoring of waterway condition, it has become apparent that it is equally important to undertake parallel monitoring of the various pressures that impact on condition (e.g. land use and other anthropogenic catchment activities). This information can be used to address different types of questions:

  - Firstly, if a change in condition is recorded, then the immediate question is why? If there is information on parallel changes in pressures then this question can be addressed and this also provides direction in terms of management needs.
  - Alternatively, if a change in condition is recorded but there are no changes in pressures, then this raises questions about indicators and methods and the possible need to revise them.

    Thirdly, if no change in condition is recorded but pressures have changed, then this might similarly indicate a problem with indicators or, alternatively, that the particular changes in pressures are of no consequence for the water body.
  - Whatever the scenario, the possession of relevant pressure data allows a much more informed assessment of the condition data to be made.

- A further important reason for assessing pressures is that it allows informed judgments about monitoring priorities. Thus, where no changes in pressures have occurred, the risk would be assessed as low and monitoring resources could be directed to higher risk waters. Conversely, where major increases in pressures have occurred, this would indicate a higher priority for monitoring.

- The current program design is best suited to assessing estuary condition under base-flow conditions. However, over the 20 years of the program, a proportion of samples were collected in post-event periods, and it was clear that the poorest water quality mostly occurs in these periods. Monthly monitoring rarely captures these short-lived post-event periods, and does not in any case cover them adequately. However, technical advances in remote instrumentation are starting to allow us to acquire much more comprehensive data during these highly variable periods. It is therefore recommended that more effort be put into this type of monitoring, which allows us to acquire good data during post-event periods. This will provide a better understanding of the magnitude of short-term variation under base-flow conditions.

- With the large water quality data set now available and allying this type of data with freshwater flow data, there are opportunities to develop models that can simulate both and increase our understanding of the impacts of diffuse source pollutants as well as ambient water quality.

- The current program is very much focused on water quality issues. From other studies, it has become apparent that water quality is only one of a range of issues affecting Queensland estuaries and coastal waters. Issues such as habitat modification, reduction of inflows due to impoundments and the reduction in connectivity with freshwater reaches can all significantly impact on estuaries. To address these issues, monitoring programs need to have a broader ambit than just water quality. A framework for undertaking more broad-based assessments has been recently developed by the Coastal Cooperative Research Centre (Moss et al. 2006).

It is recommended that consideration be given to applying this assessment framework to the monitoring of all estuaries in Queensland

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APPENDICES

Appendix A – Monitoring sites and indicators

Table A1: Monitoring sites – locations, indicators and monitoring period

Estuary or coastal area	Location AMTD or AMG[1]	Water type [2]	Monitoring period	Indicators monitored		
				Nutrients	*Chlorophyll a*	*In-situ*[3]
Fitzroy	20.0	ME	June 93-May 15	✓	✓	✓
	33.8	ME	June 93-May 15		✓	✓
	39.6	ME	June 93-May 15			✓
	45.2	ME	June 93-May 15		✓	✓
	50.2	ME	June 93-May 15		✓	✓

Table A1: Monitoring sites – locations, indicators and monitoring period

Estuary or coastal area	Location AMTD or AMG[1]	Water type [2]	Monitoring period	Indicators monitored		
				Nutrients	*Chlorophyll a*	*In-situ*[3]
	52.6	ME	June 93-May 15			✓
	55.1	ME	June 93-May 15		✓	✓
	57.3	UE	June 93-May 15	✓	✓	✓
	59.6	UE	June 93-May 15		✓	✓
Calliope	0	ECLE	June 93-May 15		✓	✓
	1.6	ECLE	June 93-May 15			✓
	3.2	ME	June 93-May 15		✓	✓
	4.8	ME	June 93-May 15			✓
	6.4	ME	June 93-May 15			✓
	11.3	ME	June 93-May 15			✓
	12.9	ME	June 93-May 15	✓	✓	✓
	14.5	ME	June 93-May 15			✓
	16.1	ME	June 93-May 15		✓	✓
			June 93-May 15			
Boyne	0	ECLE	June 93-May 15			✓
	2.7	ECLE	June 93-May 15		✓	✓
	5.1	ME	June 93-May 15	✓		✓

Table A1: Monitoring sites – locations, indicators and monitoring period

Estuary or coastal area	Location AMTD or AMG[1]	Water type [2]	Monitoring period	Indicators monitored		
				Nutrients	*Chlorophyll a*	*In-situ*[3]
	8.6	ME	June 93-May 15		✓	✓
	12.0	ME	June 93-May 15	✓	✓	✓
Baffle	4.1	ECLE	June 93-May 15		✓	✓
	11.0	ME	June 93-May 15			✓
	16.0	ME	June 93-May 15	✓	✓	✓
	23.5	ME	June 93-May 15		✓	✓
	35.8	UE	June 93-May 15	✓	✓	✓
Kolan	0	ECLE	June 93-May 15			✓
	1.6	ECLE	June 93-May 15			✓
	5.3	ME	June 93-May 15			✓
	8.1	ME	June 93-May 15	✓	✓	✓
	12.0	ME	June 93-May 15		✓	✓
Burnett	0	ECLE	June 93-May 15			✓
	4.8	ECLE	June 93-May 15		✓	✓
	6.0	ME	June 93-May 15			✓
	8.5	ME	June 93-May 15	✓	✓	✓
	11.4	ME	June 93-May 15			✓

Table A1: Monitoring sites – locations, indicators and monitoring period

Estuary or coastal area	**Location AMTD or AMG[1]**	**Water type [2]**	**Monitoring period**	**Indicators monitored**		
				Nutrients	***Chlorophyll a***	***In-situ*[3]**
	14.7	ME	June 93-May 15		✓	✓
	17.4	ME	June 93-May 15			✓
	18.7	ME	June 93-May 15	✓	✓	✓
	20.3	ME	June 93-May 15		✓	✓
	23.5	UE	June 93-May 15		✓	✓
Burrum	0	ECLE	June 93-May 15			✓
	5.5	ME	June 93-May 15		✓	✓
	12.7	ME	June 93-May 15	✓	✓	✓
	19.2	UE	June 93-May 15		✓	✓
Isis	3.0	ME	June 93-May 15			✓
	6.0	ME	June 93-May 15	✓	✓	✓
	10.0	UE	June 93-May 15		√	✓
Gregory	5.8	ME	June 93-May 15	✓	✓	✓
	9.5	ME	June 93-May 15		✓	✓
Mary	6.0	ECLE	June 93-May 15		✓	✓

Table A1: Monitoring sites – locations, indicators and monitoring period

Estuary or coastal area	Location AMTD or AMG[1]	Water type [2]	Monitoring period	Indicators monitored		
				Nutrients	*Chlorophyll a*	*In-situ*[3]
	12.2	ME	June 93-May 15		✓	✓
	17.7	ME	June 93-May 15			✓
	22.5	ME	June 93-May 15	✓	✓	✓
	27.5	ME	June 93-May 15			✓
	32.8	ME	June 93-May 15			✓
	36.1	ME	June 93-May 15		✓	✓
	39.1	ME	June 93-May 15			✓
	42.2	ME	June 93-May 15		✓	✓
	45.4	ME	June 93-May 15			✓
	50.2	UE	June 93-May 15		✓	✓
	56.7	UE	June 93-May 15	✓	✓	✓
Great Sandy Straits	000003	ECLE	June 93-May 15	✓	✓	✓
	924585	ECLE	June 93-May 15	✓	✓	✓
	929721	ECLE	June 93-May 15	✓	✓	✓
	951657	ECLE	June 93-May 15		✓	✓
	972882	ECLE	June 93-May 15	✓	✓	✓
	979534	ECLE	June 93-May 15		✓	✓

Table A1: Monitoring sites – locations, indicators and monitoring period

Estuary or coastal area	Location AMTD or AMG[1]	Water type [2]	Monitoring period	Indicators monitored		
				Nutrients	*Chlorophyll a*	*In-situ*[3]
	984797	ECLE	June 93-May 15		✓	✓
Tin Can Inlet	011269	ECLE	June 93-May 15	✓	✓	✓
	017339	ECLE	June 93-May 15			✓
	021296	ECLE	June 93-May 15			✓
	028353	ECLE	June 93-May 15	✓	✓	✓
	035320	ECLE	June 93-May 15			✓
	043376	ECLE	June 93-May 15			✓

1: AMTD (Adopted Middle Thread Distance) is the distance (kilometres) upstream from the mouth of a river system and is used to locate estuary sites. AMG (Australian Mapping Grid) coordinates (6 digit numbers) are used to locate coastal sites.

2: Water types are defined in Appendix B.

3: In-situ readings include temperature, conductivity, pH, turbidity, DO.

Appendix B – Water types

Water type		Description
Upper estuary	UE	The most upstream reaches of estuaries – areas subject to very little tidal movement and poor flushing/dispersion during dry weather
Mid estuary	ME	All estuarine waters upstream of the immediate influence of strong daily tidal exchange, but excluding upper estuarine waters
Enclosed coastal/ lower estuary	ECLE	Coastal waters with reduced influence or exchange with ocean waters. It includes shallower coastal waters enclosed by offshore islands or in embayments. It also includes the most downstream reaches of estuaries – the zone which exchanges with coastal waters on every tide

Appendix C - Turbidity & Secchi depth relationship

The relationship between these indicators is such that, at low turbidity levels, the Secchi depth measure is more sensitive to change, while at higher turbidity levels, the turbidity measure becomes more sensitive to change. The reason for this is the power relationship between the two measures. A graphical example is shown below based on data from the Great Sandy Straits (Figure C1).

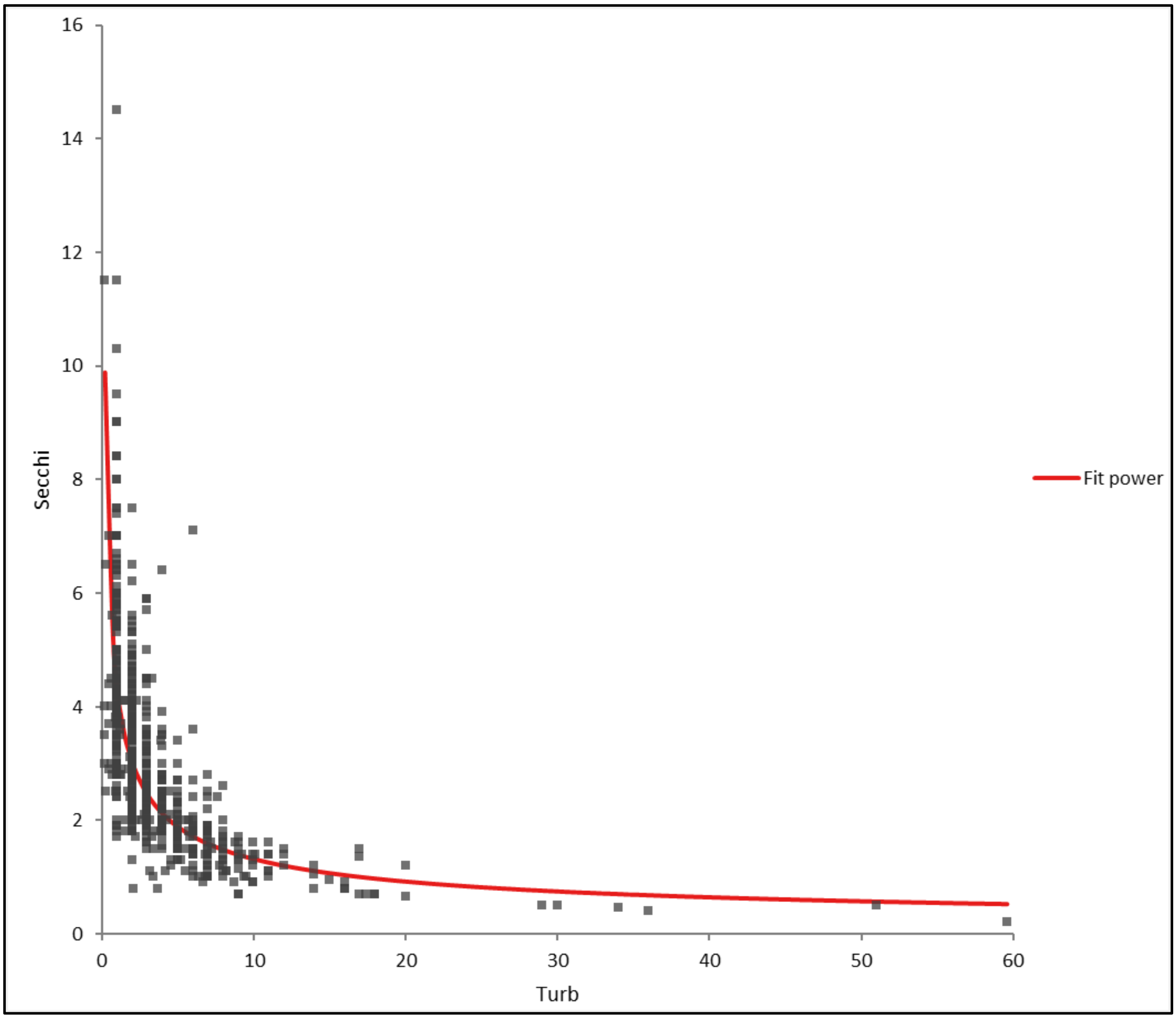

Figure C1: Turbidity (NTU) vs Secchi depth (m) relationship

The power relationship calculated for this dataset is:

Secchi = 4.316 * Turbidity $^{-0.5149}$ *(R^2 = 0.63)*

Using this relationship, Secchi depth values calculated over a range of turbidity values are shown below in Table C1.

Table C1: Relationship between turbidity and Secchi depth in the Great Sandy Straits

Turbidity (NTU)	Secchi (m)
0.5	6.2
1	4.3
2	3.0
5	1.9
10	1.3
15	1.1
50	0.6
100	0.4

The table shows that at low turbidity levels, a small change gives rise to large changes in Secchi depth. Thus, an increase in turbidity from 0.5 to 2 NTU is equivalent to a reduction in Secchi depth of >3 m. The accuracy of field turbidity meters at such low levels is ±1 NTU at best, whereas a change of Secchi from 6 m to 3 m is readily detectable, accuracy being ±0.2 to 0.3 m. Within the 20th–80th percentile range of turbidity in the Great Sandy Straits (1–5 NTU), Secchi depth is clearly a more sensitive indicator.

Conversely, as turbidity levels increase above 8–10 NTU, the sensitivity of Secchi depth to change in turbidity starts to decrease exponentially, and turbidity would become the preferred measure. At values in between, use of either measure could be justified.

Appendix D – Description of indicators

Table D1: Description of water quality indicators used in the report

Category	Indicator	How measured	Why is it measured?	Causal factors
Nutrients	Nitrogen >Total N > Organic > NO2+NO3 > NH3 Phosphorus > Total P > Filterable reactive P	Total nutrients are made up of a dissolved component (e.g. nitrate plus nitrite, ammonia and filterable reactive phosphorus) and an organic component, which is bound to carbon (e.g. organic nitrogen). Nutrients in the dissolved state can be readily used by plants.	High nutrient concentrations in a water body (eutrophication) may lead to excessive weed and algal growth.	Excess nutrients enter a water body through several means, including discharge of treated sewage, stormwater, and in run-off from land, for example as fertiliser, animal waste, or decaying plant matter.
Chlorophyll *a*	Chlorophyll *a*	Chlorophyll *a* is a pigment found in green plants, including aquatic plants. Measuring the amount of chlorophyll *a* in the water therefore indicates the amount of green algae present in the water.	High concentrations of algae (algal blooms) may harm other aquatic organisms, either through the production of toxins, reduction of available light through covering the water surface, or by using all available oxygen during respiration at night.	Algal growth is stimulated by high concentrations of nutrients. Low levels of light (e.g. in a stream shaded by riparian vegetation, or a turbid estuary) may limit algal growth even if nutrient concentrations are high.
Water clarity	Turbidity	Turbidity is a measure of how cloudy or murky the water is, and is measured by determining the scattering of light by suspended particles in the water column.	Water clarity (the degree of light penetration) is important, as aquatic plants depend on light to photosynthesise and produce oxygen. Large amounts of sediment in a water body can also smother benthic organisms.	Sediment enters the water through erosion and run-off from the surrounding land; clearing of land, particularly the riparian zone, may result in increased sediment loads to a waterway.
	Secchi depth	A direct indicator of water clarity, Secchi depth is the depth to which the black and white markings on a Secchi disc can be clearly seen from the surface.		

Table D1: Description of water quality indicators used in the report

Category	Indicator	How measured	Why is it measured?	Causal factors
Oxygen	Dissolved oxygen	Oxygen is measured as the amount of oxygen dissolved in the water at that temperature.	Oxygen is essential for life processes of most aquatic organisms. Many aquatic organisms will suffocate if there is insufficient oxygen in the water.	Typically, oxygen levels may decrease as a result of excess algal and bacterial respiration. If a large amount of algae is present in a water body, oxygen production (photosynthesis) during the day may result in supersaturated oxygen levels (above 100%), while respiration during the night when there is no photosynthesis will deplete the oxygen concentrations. Large amounts of organic matter in a waterway result in increases in populations of bacteria that break down the matter, and an increase in the rate of break down. Oxygen is consumed during the decomposition process, and results in little oxygen being available for other organisms.
pH	pH	A measure of the acidity or alkalinity of the water.	Extremes of pH (less than 6.5 or greater than 9) can be toxic to aquatic organisms.	Changes to pH can be caused by a range of potential water quality problems (e.g. low values due to acid sulphate run-off). pH values are also related to soil geology, and may be naturally low (e.g. in melaleuca swamps) or high (e.g. in limestone areas). High pH values can also be caused temporarily when high rates of photosynthesis by aquatic plants (including algae) lead to a decrease in carbon dioxide, and therefore a decrease in carbonic acid in the water.
Salinity	Conductivity	A measure of the amount of dissolved salts in the water, and therefore an indicator of salinity.	In freshwater, low conductivity indicates suitability for agricultural use. In salt waters, low conductivity indicates freshwater inflows such as stormwater run-off.	Excess salinity in freshwater streams occurs as a result of excess soil salinity, which may be caused by excess land clearing and changes to the groundwater table.