Water quality of the Elizabeth River estuary, Darwin Harbour, before and during the 2006-2007 wet season

2010

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1 SUMMARY

The Elizabeth River estuary is a major tributary of Darwin Harbour, and the area surrounding the estuary is subject to increasing urban and industrial development. The catchments of several proposed suburbs drain into Mitchell Creek and Brooking Creek, both tributaries of the Elizabeth River estuary. River flows reflect the region’s wet and dry seasonal rainfall, with flows typically commencing during December and January, and reaching maximum levels during between January and March. By June most rivers have ceased to flow.

This study investigates water quality indicators and processes associated with freshwater inflow influence on marine waters, such as reduced mixing of the water column. The study also compares results with local water quality objectives developed to help protect water quality in the Darwin Harbour region.

Four sites were monitored from December 2006 to April 2007. All sites had low variation in physical indicators such as salinity, turbidity and conductivity, and nutrient measurements prior to wet season freshwater inflows. Less variation in physical measurements was observed in the April 2007 samplings, after much of the freshwater inflows had occurred, than during the wet season. In general, oxidised nitrogen (NO\textsubscript{x}) had the greatest variation at all sites in the March 2007 samplings. In contrast, total nitrogen (TN) and turbidity, for example, were likely to have also been associated with surface runoff transport during the much greater February 2007 rainfall and freshwater inflow events. In general, the surface one metre of depth had the greatest variation in nutrient values. Statistical analyses indicated significant differences between the surface depth and the middle or bottom depths sampled for TN, NO\textsubscript{x}, total phosphorus (TP), salinity and conductivity.

Water quality objective values have been developed to help protect water quality in the Darwin Harbour region. In the Elizabeth River estuary, upper estuary water quality objective values were complied with for median values of pH, NO\textsubscript{x}, ammonia, TP and filterable reactive phosphorus (FRP). Median chlorophyll-a and TN values over all samplings did not comply with upper estuary water quality objectives. TN also did not comply with upper estuary water quality objectives prior to the wet season. TN is mostly organic N, as NO\textsubscript{x} is only a small proportion of TN in this region. Inflow of NO\textsubscript{x} is unlikely to contribute to non compliance of the TN water quality objective. The study increased our understanding of several water quality processes associated with wet season freshwater inflows in the region.

During the wet season 116 phytoplankton (algae) taxa were identified in 29 samples from four sites. The phytoplankton taxa of all sites was dominated by two taxa, the diatom \textit{Odontella} and dinoflagellate 103. Samples collected after the peak of the wet season as flows reduced had a greater number of taxa recorded.
2 BACKGROUND

2.1 Darwin Harbour and catchment

The Darwin Harbour and surrounding catchments are located in the wet-dry tropics of northern Australia. The catchment of Darwin Harbour covers an area of approximately 3,230 km² comprising a land area of 2,010 km² and an estuary area of 1,220 km² at the high water mark.

The climate is tropical with distinct wet and dry seasons. Rainfall averages 1,714 mm per year with 64% of average rainfall falling between January and March (McKinnon et al. 2006). Savannah woodlands and forest dominate the catchment, with approximately 80% of the catchment uncleared. Land use and features in the Darwin Harbour catchment are shown in Figure 1. The catchment’s geology is ancient and highly weathered, consequently many soils in the region have poor fertility (McKinnon et al. 2006). The topography of the catchment is relatively low-lying with most land being less than 30 m above sea level. Inland plains are flooded with freshwater to a depth of up to two meters each wet season.

Darwin city supports the largest concentration of the Northern Territory population. The City of Palmerston, south of Darwin, is also subject to increasing urban development. The population of the Darwin region is approximately 117,000 (ABS 2008), with a large number (>700,000 annually) of overnight visitors to the region (Tourism NT 2008). By 2026, around 165,000 people are predicted to live in the Darwin region (ABS 2008).

Darwin Harbour is a large macro-tidal estuary that experiences tidal variations up to 8 m. The mean spring tidal ranges are approximately 6 m, while mean neap tidal ranges are around 3 m. These macrotides produce strong currents that can peak at speeds of up to 2-2.5 m/s. Tidal flows between East Point and Mandorah have been measured in the order of 120,000 cubic m/s (Williams and Wolanski, 2003).

Continued growth of urban and rural activities around Darwin Harbour will place increasing pressure on the Harbour’s waterways.
2.2 Water quality objectives to protect water quality

A Water Quality Protection Plan is being developed for Darwin Harbour for protection of water quality in the region. Locally-derived guidelines called water quality objectives (WQOs) have been established in phase one of the ongoing Water Quality Protection Plan. The aim is to ensure that water quality objectives are maintained and that community’s values for waterways are protected.

Water quality objectives have been established under a process developed by the National Water Quality Management Strategy. Further details are available in ANZECC guidelines and related publications. Further details of Darwin Harbour
WQOs are available in Fortune (2010). The definitions of the classification of water types including upper, mid and outer estuaries are presented in Fortune (2010). The upper estuary is the ‘most upstream of all estuarine waters with a residence time as estimated by a hydrodynamic model of greater than 32 days’ (Fortune 2010). Darwin Harbour WQOs have been developed for ‘slightly disturbed waters’ (Fortune 2010). WQOs for upper estuary waters such as the Elizabeth River estuary of Darwin Harbour are summarised in Table 1. Water quality values from monitoring activities can be compared with water quality objectives to help evaluate water quality condition.

Field data from the current study are compared with WQOs in section 4.9 of this report.

Table 1 Water quality objectives for upper estuaries in Darwin Harbour.

<table>
<thead>
<tr>
<th>Indicator and units</th>
<th>Water quality objective for upper estuary in Darwin Harbour</th>
<th>Water quality objective for upper estuary in Darwin Harbour (as units commonly presented in this report)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6-8.5</td>
<td>6-8.5</td>
</tr>
<tr>
<td>Dissolved oxygen (%)</td>
<td>80-100</td>
<td>80-100</td>
</tr>
<tr>
<td>Chlorophyll a (µg/L)</td>
<td>&lt;4</td>
<td>&lt;4</td>
</tr>
<tr>
<td>NO₃</td>
<td>&lt;20 (µg N/L)</td>
<td>&lt;0.02 (mg N/L)</td>
</tr>
<tr>
<td>Ammonia</td>
<td>&lt;20 (µg N/L)</td>
<td>&lt;0.02 (mg N/L)</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>&lt;300 (µg N/L)</td>
<td>&lt;0.3 (mg N/L)</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>&lt;30 (µg P/L)</td>
<td>&lt;0.03 (mg P/L)</td>
</tr>
<tr>
<td>FRP</td>
<td>&lt;10 (µg P/L)</td>
<td>&lt;0.01 (mg P/L)</td>
</tr>
</tbody>
</table>

Note: 1 mg/L contains 1000 µg/L.

2.3 Stressors to water quality in the Elizabeth River estuary

Given the predicted increases in population, it is inevitable that the pressure on the Harbour’s waters will intensify. Development around the Elizabeth River estuary is increasing.

In Palmerston four new suburbs are planned. The new suburbs of Bellamack, Johnston, Mitchell and Zuccoli will provide 3,700 new residential lots for housing and will increase Palmerston’s population by around 15,000 people (DPI 2009). Zuccoli will produce up to 1,750 lots of new residential housing, commencing for sale in 2010 and will become one of the biggest suburbs in Palmerston. The suburb of Bellamack is undergoing development, and construction of the new suburb of Johnstone has commenced. The proposed suburb of Zuccoli will also drain to the estuary. The proposed city of Weddell south of Palmerston will drain into the upper reaches of the Elizabeth River estuary.

Growing urbanisation, industry and clearing in the catchment contribute to increasing diffuse and point source loads to the harbour (Skinner et al. 2008). Impacts of increased loads appear to be confined to localised areas of the harbour and upstream areas of the estuary where tidal mixing is limited. This is even more pronounced during the wet season when extensive turbid plumes from tidal creeks and upper reaches extend into the estuary. Water quality drivers, stressors and responses for the Elizabeth River estuary are summarised in Table 2.
Table 2 Selected water quality drivers, stressors and responses identified for the Elizabeth River estuary.

<table>
<thead>
<tr>
<th>Driver</th>
<th>Water Quality Stressor</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated sewage wastewater and point discharge</td>
<td>Increased nutrient, toxicant and pollutant loads</td>
<td>Increased algal growth, accumulation of pollutants in sediments.</td>
</tr>
<tr>
<td>Development, and erosion</td>
<td>Increased suspended sediment and turbidity and reduced light penetration</td>
<td>Reduced photosynthesis, loss of macro-invertebrate diversity.</td>
</tr>
<tr>
<td>Groundwater extraction</td>
<td>Reduced flows</td>
<td>Reduced biomass and flow. Loss of diversity.</td>
</tr>
<tr>
<td>Diffuse (stormwater) discharge</td>
<td>Increased suspended sediment, nutrients and other pollutants</td>
<td>Increased algal growth. Loss of diversity.</td>
</tr>
<tr>
<td>Fire in the catchment and riparian zones</td>
<td>Reduced canopy and increased light penetration</td>
<td>Increased growth of aquatic macrophytes. Changes to macro-invertebrate community.</td>
</tr>
</tbody>
</table>

2.4 The Elizabeth River estuary and water quality

The Elizabeth River estuary is a major tributary of Darwin Harbour and is located at the south-eastern end of the East Arm. The Elizabeth River catchment extends across the Stuart Highway to the east through Noonamah and extends further south.

River flows reflect the region’s rainfall, with flows typically commencing during December and January, and reaching maximum levels during periods of heavy rainfall between January and March. By June most rivers have ceased to flow with the exception of Darwin and Howard Rivers, and the spring-fed Berry Creek. Correspondingly, diffuse discharge is negligible in the dry season as flows to many of the seasonal creeks which enter the estuary cease to flow by June most years. Diffuse discharge is associated with wet season flows and is typically accompanied by a series of intense pulses of freshwater together with the contaminants it carries.

Water quality in the outer and mid estuary regions of the Darwin Harbour is in excellent condition and is similar to Shoal Bay, both large bodies of open water (Fortune et al. 2009). In contrast, water quality of some tidal creeks and upper estuaries can be affected by tidal movement (Figure 2) and effects of urbanisation. Tidal creeks can have lower oxygen levels due to the decomposition of organic material present from nearby mangroves which consumes oxygen (Water Monitoring Branch 2005).

The Elizabeth River and estuary water quality at upper estuary monitoring sites is in good condition, although some indicators did not comply with water quality objectives (Fortune et al. 2009). More recent monitoring indicated all water quality objectives used in the ‘Darwin Harbour Region Report Cards 2010’ were complied with (Drewry et al. 2010).
2.5 Estuaries and water quality

Water quality can change with depth and season in freshwater and estuarine water bodies. Oxygen dissolving into surface waters, for example, is normally mixed down to bottom waters. When water is poorly mixed, or when the rate of consumption exceeds supply, concentrations then decline. Water column stratification is where bottom water exchange is isolated from surface waters. Stratification can include, for example, reduced oxygen in bottom waters where exchange is isolated from oxygen rich surface waters (Diaz 2001). Increased urbanisation and subsequent eutrophication has been associated with reduced levels of oxygen in coastal waters.

Freshwater inflow during high rainfall periods into estuaries can result in stratification where a surface layer of freshwater overlays marine water. A halocline (salinity gradient) can form between low salinity in the upper layer and marine water in lower layers (Dong et al. 2004). Salt water may be flushed completely under very high flow conditions in parts of Australian tropical estuaries (Eyre 1998), although such flushing is commonly dependent on rainfall and catchment size. Due to the large tidal ranges in some tropical Australian estuaries, recovery is rapid, commonly by a stratified salt wedge intruding along the channel bottom followed by partial and full mixing (Eyre 1998). In contrast, in the dry season, runoff is minimal or nil so estuarine water is generally well mixed, although high evaporation rates may lead to high salinity in upper estuaries.

Recent research in Darwin Harbour indicates that a large source of nitrogen to the harbour system was from the ocean due to higher N concentrations in incoming tides than outgoing tides (Burford et al. 2008). Nitrogen recycling within the water column and mangrove areas was also considered to be an important process. Water quality data for the Blackmore River estuary and mid harbour sites for the 2003 wet and dry season were evaluated by McKinnon et al. (2006). The study indicated that some nutrient concentrations recorded in the Blackmore River estuary in the wet season
were less than recorded during the dry season. It was suggested that lower nutrient concentrations may be a factor in later wet season inflows.

Other research in Darwin Harbour included quarterly interval monitoring at selected sites 2002-2004, including one site in the Elizabeth River estuary (Duggan 2006). However, further research is required to help quantify nutrient concentrations and physical indicators across a range of wet season inflows over an entire wet season. There is no such research that we are aware of in the Elizabeth River estuary.

2.6 Rationale and objectives

Development around the Elizabeth River estuary is increasing with the suburbs of Bellamack and Johnstone under construction. Drainage and overland flow from these suburbs enters Mitchell Creek and Brooking Creek. Darwin Harbour is divided into four priority zones (A, B, C, and D) for monitoring by the Aquatic Health Unit. Zone A, the highest priority, is the East Arm – Elizabeth River area waterways which are subject to increasing pressure from development.

The objectives of this report were to:

- investigate water quality processes of the Elizabeth River estuarine water and influences of freshwater inflow;
- investigate water quality in two upper estuarine tributaries that will be subject to future urban development;
- build knowledge of the state of aquatic health in the estuary; and
- use this knowledge to compare water quality with local water quality objectives and develop conceptual diagrams to aid communication of key water quality processes.
3 METHODS

This section presents methods used in this study.

3.1 Site location

The four estuarine monitoring sites with Hydstra database G-codes and site characteristics are shown in Table 3 and Figure 3. Mitchell Creek flows from the north around the Stuart Highway and east of the residential development associated with Palmerston. The Brooking Creek catchment begins to the north near Howard Springs township. Both these creeks meet before reaching the confluence of the Elizabeth River. Site B is located on the Elizabeth River estuary, approximately 1 km down stream from the Channel Island road bridge. Site EDW is located approximately 2 km upstream of the Mitchell Creek – Elizabeth River confluence. The surrounding catchments and the freshwater stream gauge at Elizabeth River are also shown in Figure 3.

Table 3 Estuarine monitoring sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>G-code</th>
<th>Easting</th>
<th>Northing</th>
<th>Approx depth (m) of water column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site B</td>
<td>G8155542</td>
<td>713751</td>
<td>8613566</td>
<td>6</td>
</tr>
<tr>
<td>Brooking Creek</td>
<td>G8155661</td>
<td>716878</td>
<td>8613069</td>
<td>3.5</td>
</tr>
<tr>
<td>Mitchell Creek</td>
<td>G8155662</td>
<td>716271</td>
<td>8613338</td>
<td>4.5</td>
</tr>
<tr>
<td>Site EDW</td>
<td>G8155663</td>
<td>717036</td>
<td>8610372</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 3 Monitoring sites and catchments.
3.2 Field methods and sampling

Water quality data were collected at the four sites prior to and during the wet season at approximately fortnightly intervals from 13 December 2006 to 26 April 2007.

3.3 Measurements

3.3.1 Water quality indicators

Water quality indicators used in this study are shown in Table 4.

Table 4 Water quality indicators in this study and why they are used as indicators.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>What it represents</th>
<th>Why it is used as an indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conductivity</td>
<td>A measure of electrical conductivity (dissolved solids, usually salts).</td>
<td>Inhibits plant and animal growth if too high. Provides an indication of freshwater or marine water.</td>
</tr>
<tr>
<td>pH</td>
<td>A measure of the acidity or alkalinity of a solution</td>
<td>Important for many chemical and biological processes.</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Cloudiness in water</td>
<td>A measure of the light scattering as a result of material suspended in water. This affects the amount of light available for photosynthesis.</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>A measure of the amount of oxygen in the water. Varies with physical and chemical conditions.</td>
<td>Critical for aquatic organisms to survive. Low dissolved oxygen is the major cause of freshwater fish kills.</td>
</tr>
<tr>
<td>Chlorophyll-a</td>
<td>The green component of plants used in photosynthesis.</td>
<td>Is used as an index of the amount (biomass) of algae.</td>
</tr>
<tr>
<td>NO₃</td>
<td>Nitrate + nitrite (dissolved) forms of nitrogen</td>
<td>Nitrate stimulates plant growth. Travels with water in solution.</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Total ammonia is the sum of un-ionised ammonia and the ammonium forms of nitrogen</td>
<td>Readily used by aquatic plants. Decomposition and excretion product. Ammonia can be toxic to biota.</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>Nitrogen.</td>
<td>Nitrogen is essential for living organisms. Includes all forms of nitrogen.</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>Phosphorus.</td>
<td>Phosphorus is essential for living organisms. Travels mainly with sediment in water.</td>
</tr>
<tr>
<td>Filterable reactive phosphorus</td>
<td>Fraction of phosphorus that passes through a fine filter.</td>
<td>Stimulates aquatic plant growth. Travels with water in solution.</td>
</tr>
<tr>
<td>Pheophytin</td>
<td>A pigment produced by digestion or degradation of chlorophyll-a.</td>
<td>Used as an index of the amount (biomass) of algae.</td>
</tr>
<tr>
<td>Euphotic depth</td>
<td>A measure of how deep light penetrates through the water.</td>
<td>Euphotic depth extends from the atmosphere-water interface downwards at a depth where light intensity, used for photosynthesis, falls to 1% of that measured at the surface.</td>
</tr>
<tr>
<td>Photosynthetically active radiation (PAR)</td>
<td>Waveband of light used by photosynthetic organisms.</td>
<td>Waveband of light (400-700 nm) used by photosynthetic organisms. PAR measurements are used to calculate euphotic depth.</td>
</tr>
</tbody>
</table>

Euphotic depth is greater in clearer water than in water with high turbidity. The clearer the water, the deeper light penetration is.
3.3.2 Physical measurements

Physical parameters of dissolved oxygen, electrical conductivity (EC) and salinity were measured with a Hydrolab multi-parameter probe at approximately 0.25 m, 0.5 m and other depths through the profile to near the bottom of the water column. The Hydrolab was calibrated prior to use for all samplings. Turbidity was measured at the surface (approx 0.25 m) using a Hach 2100P turbidity meter. Sampling dates are shown in Table 5. A range of tide conditions prevailed during samplings, with conditions for selected samplings including main flow event samplings shown in Table 6.

Table 5 Sampling dates during the 2006-2007 wet season on the Elizabeth River estuary.

<table>
<thead>
<tr>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>13/12/2006</td>
</tr>
<tr>
<td>28/12/2006</td>
</tr>
<tr>
<td>29/01/2007</td>
</tr>
<tr>
<td>8-9/02/2007</td>
</tr>
<tr>
<td>27/02/2007</td>
</tr>
<tr>
<td>14/03/2007</td>
</tr>
<tr>
<td>28/03/2007</td>
</tr>
<tr>
<td>11/04/2007</td>
</tr>
<tr>
<td>26/04/2007</td>
</tr>
</tbody>
</table>

Table 6 Tide conditions at selected samplings for each site.

<table>
<thead>
<tr>
<th>Date and site</th>
<th>28/12/2006</th>
<th>25/01/2007</th>
<th>27/02/2007</th>
<th>14/03/2007</th>
<th>28/03/2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDW</td>
<td>Incoming</td>
<td>Incoming</td>
<td>Incoming</td>
<td>Incoming</td>
<td>Incoming</td>
</tr>
<tr>
<td>Mitchell</td>
<td>Incoming, near high</td>
<td>High</td>
<td>Incoming</td>
<td>Incoming</td>
<td>Incoming</td>
</tr>
<tr>
<td>Brooking</td>
<td>Outgoing, near high</td>
<td>Outgoing</td>
<td>High</td>
<td>Incoming, near high</td>
<td>Incoming</td>
</tr>
<tr>
<td>Site B</td>
<td>Outgoing, near high</td>
<td>Incoming</td>
<td>High</td>
<td>Incoming, near high</td>
<td></td>
</tr>
</tbody>
</table>

3.3.3 Nutrient measurements and laboratory methods

Nutrient samples were taken at three points within the profile: the water surface (s; approx 0.25 m), middle (m) of the profile and near the bottom (b) of the water column (Table 7). During the study period, several initial samplings only had surface samples taken for nutrient analysis. Separate sample bottles were collected for total and filterable nutrients and ammonia.

Table 7 Depths for surface, middle and bottom samplings for each site.

<table>
<thead>
<tr>
<th>Site</th>
<th>Approximate depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>s</td>
</tr>
<tr>
<td>Site B</td>
<td>0.25</td>
</tr>
<tr>
<td>Brooking Creek</td>
<td>0.25</td>
</tr>
<tr>
<td>Mitchell Creek</td>
<td>0.25</td>
</tr>
<tr>
<td>Site EDW</td>
<td>0.25</td>
</tr>
</tbody>
</table>
All samples were analysed for total kjeldahl nitrogen (TKN), nitrite (NO$_2$), nitrate (NO$_3$), ammonia-N, total phosphorus (TP), and filterable reactive phosphorus (FRP). Nutrient samples for nitrite, nitrate and FRP were filtered with 0.45 µm filters in the field. The chemical and nutrient analyses were carried out by Northern Territory Environmental Laboratories (NTEL), Berrimah. Ammonia is a measure of the ammonium ion NH$_4^+$, and is measured by the automated phenate method by NTEL (NTEL staff pers. comm.). All samples were collected, transported and stored using recommended sampling protocols, preservation protocols and chain of custody documentation. All nutrient samples were determined using APHA standard methods (Table 8). NO$_x$ and total N (TN) were calculated as follows:

$$TN = TKN + \text{nitrite} + \text{nitrate}$$
$$NO_x = \text{nitrite} + \text{nitrate}$$

**Table 8** Laboratory methods for water quality.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Method</th>
<th>APHA (1998) number</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3$</td>
<td>Automated cadmium reduction method</td>
<td>4500-NO$_3$-F</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>Automated cadmium reduction method</td>
<td>4500-NO$_3$ F</td>
</tr>
<tr>
<td>NH$_3$</td>
<td>Automated phenate method</td>
<td>4500-NH$_3$ F</td>
</tr>
<tr>
<td>TKN</td>
<td>Sulphuric acid digestion followed by the automated phenate method</td>
<td>4500 TKN D</td>
</tr>
<tr>
<td>Filterable reactive P</td>
<td>Flow injection analysis for orthophosphate</td>
<td>4500-P F (B1)</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>Persulphate digestion followed by automated ascorbic acid method</td>
<td>4500-P H</td>
</tr>
<tr>
<td>Chlorophyll-a</td>
<td>Fluorometry (3) or spectrophotometry (H2)</td>
<td>10200 H (APHA 2005)</td>
</tr>
<tr>
<td>Pheophytin</td>
<td>Fluorometry (3) or spectrophotometry (H2)</td>
<td>10200 H (APHA 2005)</td>
</tr>
</tbody>
</table>

APHA (1998) unless otherwise stated
APHA (2005) for chlorophyll-a and pheophytin; method depends on concentration.

### 3.3.4 Measurements associated with aquatic health

Chlorophyll-a is one of the most important indicators of aquatic health in water bodies. Chlorophyll-a was filtered by vacuum and Whatman 45 µm filters in the laboratory, and kept in dark conditions in a freezer prior to dispatch to the laboratory. Chlorophyll-a (chl-a) and pheophytin concentrations were measured and were analysed (Table 8) by the Department of Primary Industries and Fisheries Management Laboratory, Berrimah. All samples were collected, transported and stored using recommended sampling protocols, preservation protocols and chain of custody documentation.
Phytoplankton

Twenty-nine phytoplankton samples were collected from four sites (Site B, Site EDW, Brooking Creek and Mitchell Creek) in December 2006, February, March and April 2007. In February and March 2007 samples were collected from surface, middle and bottom parts of the water column. All other samples were collected from surface waters. No samples were collected from Site B in February. Cell density (cells/litre) is calculated from a sub-sample of counted cells. Samples were concentrated and preserved in Lugol's solution. A sample of 1000 ml was suspended in a measuring cylinder and allowed to settle for seven days before being reduced to 100 ml concentrated volume. Phytoplankton species and class were identified, and the cell density was measured by Dalcon Environmental, Perth. All samples were collected, transported and stored using recommended sampling protocols, preservation protocols and chain of custody documentation.

Photosynthetically active radiation

Photosynthetically active radiation (PAR) was recorded at the sites in clear conditions using a Li-COR spherical quantum sensor light meter (model LI-193SA). A light recording was taken at the surface, then lowered through the water column at 0.5 metre intervals. The euphotic depth (99% light extinction coefficient) was calculated as described in section 3.4.

3.4 Data and statistical analyses

Where concentrations of nutrients and other measurements were below limit of detection, half the limit of detection was used in calculations.

Data are presented as summary statistics, box and whisker plots, and scatter plots. Box plots present the median, 25th and 75th percentiles, minimum and maximum values.

Data were also analysed by analysis of variance (ANOVA) to evaluate effects between sites, between sampling dates or between depths using the statistical package Statistica. Significance was assessed at the P<0.05 level. Where appropriate, vertical bars denote 0.95 confidence intervals. There were a range of tidal inflow and outflow conditions, with some inconsistencies in sampling regime, particularly depth of physical measurements, and missing data for physical measurements, so for some of the data it would be difficult to draw strong conclusions. For the physical measurements, to analyse depth, the depth data was classified as surface, middle or bottom depths to enable the statistical analysis to be undertaken and be consistent with the nutrient data methodology. For box plots, this classification was not required.

The euphotic depth (99% light extinction coefficient) was calculated using the light meter data and the Beer-Lambert equation (Masson and Pena 2009). Attenuation of PAR through the water column was estimated from a regression of natural log-transformed PAR with depth (Townsend and Padovan 2005; Masson and Pena 2009).
4 RESULTS

4.1 Rainfall

Both Mitchell Creek and Brooking Creek are ephemeral streams and stop flowing through the dry season. The Bureau of Meteorology monthly rainfall data (September 2006 to August 2007), indicates no rainfall was registered in the months of June – August. The wettest month was March with 642 mm (Table 9).

Table 9 Total monthly rainfall (mm) for the 2006-2007 wet season at Elizabeth Valley, BOM site number 14222.

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep</td>
<td>17.8</td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>5.8</td>
<td>642</td>
</tr>
<tr>
<td>Nov</td>
<td>144</td>
<td>15.6</td>
</tr>
<tr>
<td>Dec</td>
<td>149</td>
<td>12.4</td>
</tr>
<tr>
<td>Jan</td>
<td>334</td>
<td>0</td>
</tr>
<tr>
<td>Feb</td>
<td>341</td>
<td>0</td>
</tr>
<tr>
<td>Mar</td>
<td>642</td>
<td>0</td>
</tr>
<tr>
<td>Apr</td>
<td>15.6</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>12.4</td>
<td>0</td>
</tr>
<tr>
<td>Jun</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jul</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aug</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Total rainfall for this period 1661 mm. Data from www.bom.gov.au.

4.2 Catchment hydrology

4.2.1 Catchment hydrology 2006-2007 wet season

During the 2006-2007 wet season the Elizabeth River estuary did not begin registering freshwater flows until the 13 January 2007. Data were obtained from the Elizabeth River hydrographic gauge station (G8150018) located on the Stuart Highway in the freshwater section of the river and upstream of site EDW. There is no stream gauge station in the Mitchell and Brooking Creek catchments. The Elizabeth River hydrograph (Figure 4) shows mean daily flow with sampling date. Peak flow periods were experienced during the months of March and April 2007. Flows for other years are shown in Figure 5 for comparison.

Figure 4 Elizabeth River gauge station mean daily flow (ML/d) and sampling date.
The mean daily flows one day before and at the date of sampling are shown in Table 10. This can be used to help evaluate preceding flow conditions.

Table 10 Elizabeth River gauge station mean daily flow (ML/d) one day before sampling and at the sampling date.

<table>
<thead>
<tr>
<th>Sampling</th>
<th>Date</th>
<th>Mean flow (ML/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 day before sampling</td>
<td>12/12/2006</td>
<td></td>
</tr>
<tr>
<td>Sampling</td>
<td>13/12/2006</td>
<td></td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>27/12/2006</td>
<td></td>
</tr>
<tr>
<td>Sampling</td>
<td>28/12/2006</td>
<td></td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>24/1/2007</td>
<td>26</td>
</tr>
<tr>
<td>Sampling</td>
<td>25/1/2007</td>
<td>11</td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>7/2/2007</td>
<td>109</td>
</tr>
<tr>
<td>Sampling</td>
<td>8/2/2007</td>
<td>123</td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>26/2/2007</td>
<td>558</td>
</tr>
<tr>
<td>Sampling</td>
<td>27/2/2007</td>
<td>860</td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>13/3/2007</td>
<td>2584</td>
</tr>
<tr>
<td>Sampling</td>
<td>14/3/2007</td>
<td>800</td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>27/3/2007</td>
<td>862</td>
</tr>
<tr>
<td>Sampling</td>
<td>28/3/2007</td>
<td>550</td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>10/4/2007</td>
<td>175</td>
</tr>
<tr>
<td>1 day before sampling</td>
<td>25/4/2007</td>
<td>59</td>
</tr>
<tr>
<td>Sampling</td>
<td>26/4/2007</td>
<td>56</td>
</tr>
</tbody>
</table>

4.2.2 Catchment hydrology long term

The Elizabeth River gauge station (G8150018) hydrograph for mean daily flows from 1990 to 2009 are shown in Figure 5 for comparison to the current study flows (marker indicates the 2006/07 wet season in this study). Wet season flows can commence in December, with the greatest median monthly flow occurring in February, followed by March and January (Figure 6). Typically, minimal or nil flows occur from June to November.

Figure 5 Elizabeth River gauge station (G8150018) mean daily flow (ML/d) 1990-2009.
4.3 Gauge station pollutant concentrations and loads

This section presents Elizabeth River gauge station 2007 wet season pollutant concentrations and load data, for comparison to data from the estuary. Data was obtained from a composite sampling technique at the gauge station, with methods and results reported in Skinner et al. (2009). This section of the report presents previously unpublished data, which is discussed later in the report.

Pollutant concentrations and load data from the Elizabeth River gauge station are presented in Table 11. Note that the Elizabeth River gauge station has an area of approximately 10,100 km², while an estimate of the catchment surrounding the Elizabeth River estuary is approximately 22,900 km² (Fortune et al. 2009). This figure does not include the area for the catchment draining the Mitchell and Brooking Creeks. The flow-weighted event mean concentrations at the gauge station over the wet season were 0.74 mg N/L for TN and 0.012 mg P/L for TP.
Table 11 Elizabeth River gauge station freshwater pollutant concentrations and loads from January to May 2007.

<table>
<thead>
<tr>
<th>Gauge station sample</th>
<th>Collection from</th>
<th>Collection to</th>
<th>Cumulative discharge (ML)</th>
<th>TN (mg/L)</th>
<th>Conc’n (mg/L)</th>
<th>TP (mg/L)</th>
<th>TSS (mg/L)</th>
<th>TN (kg)</th>
<th>Load (kg)</th>
<th>TSS (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>23/01/07</td>
<td>6/02/07</td>
<td>1150</td>
<td>0.85</td>
<td>0.025</td>
<td>14</td>
<td>980</td>
<td>29</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6/02/07</td>
<td>16/02/07</td>
<td>890</td>
<td>0.77</td>
<td>0.025</td>
<td>11</td>
<td>680</td>
<td>22</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>16/02/07</td>
<td>25/02/07</td>
<td>1140</td>
<td>0.76</td>
<td>0.025</td>
<td>17</td>
<td>860</td>
<td>28</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>25/02/07</td>
<td>27/02/07</td>
<td>980</td>
<td>0.64</td>
<td>0.02</td>
<td>30</td>
<td>630</td>
<td>20</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Estimated</td>
<td>27/02/07</td>
<td>6/03/07</td>
<td>32700</td>
<td>0.58</td>
<td>0.015</td>
<td>19</td>
<td>19000</td>
<td>490</td>
<td>606</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>6/03/07</td>
<td>12/03/07</td>
<td>7330</td>
<td>0.52</td>
<td>0.01</td>
<td>7</td>
<td>3810</td>
<td>73</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>12/03/07</td>
<td>14/03/07</td>
<td>4720</td>
<td>0.28</td>
<td>0.01</td>
<td>14</td>
<td>1320</td>
<td>47</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>14/03/07</td>
<td>23/03/07</td>
<td>7290</td>
<td>0.27</td>
<td>0.01</td>
<td>8</td>
<td>1970</td>
<td>73</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>23/03/07</td>
<td>3/04/07</td>
<td>9290</td>
<td>0.26</td>
<td>0.005</td>
<td>3</td>
<td>2420</td>
<td>46</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>3/04/07</td>
<td>16/04/07</td>
<td>2960</td>
<td>0.25</td>
<td>0.005</td>
<td>2</td>
<td>740</td>
<td>15</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>16/04/07</td>
<td>10/05/07</td>
<td>1360</td>
<td>0.46</td>
<td>0.025</td>
<td>9</td>
<td>630</td>
<td>34</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

TSS is total suspended solids

4.4 Physical measurements

4.4.1 Summary of all data

Summary statistics across all sites and samplings are presented in Table 12. Further details are presented in the following sections.

Table 12 Summary statistics of physical measurement data.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std.Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>225</td>
<td>4.6</td>
<td>4.5</td>
<td>2.6</td>
<td>7.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Conductivity (uS/cm)</td>
<td>301</td>
<td>45900</td>
<td>47300</td>
<td>9750</td>
<td>57900</td>
<td>5840</td>
</tr>
<tr>
<td>Salinity (ppthou)</td>
<td>301</td>
<td>29.8</td>
<td>30.8</td>
<td>5.4</td>
<td>34.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>31</td>
<td>7.8</td>
<td>5.1</td>
<td>0.1</td>
<td>45.8</td>
<td>8.9</td>
</tr>
</tbody>
</table>

N is number of samples

4.4.2 Site and samplings

Salinity values for each site and sampling date are shown in Figure 7. The samplings of the 27 February, 14 and 28 March 2007 had large salinity ranges at the EDW site, with the greatest salinity range on the 14 March 2007. These samplings occurred after flow events. The Brooking site also had a large range in salinity on 14 March 2007.

Median values for several sites were low at the 8 February 2007 sampling after a small flow event (Figure 7 and Table 13). Median salinity values were the lowest at the 8 February sampling at the EDW site (21.9 ppt; sampled to 5 m depth). These results indicate inflow of freshwater. Variation with depth is presented in section 4.4.3.
Figure 7 Box plots for salinity for each site and sampling date.
### Table 13 Statistics for salinity (ppt) for each site and sampling.

<table>
<thead>
<tr>
<th>Sampling number</th>
<th>Location</th>
<th>N</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (28 Dec 06)</td>
<td>EDW</td>
<td>10</td>
<td>34.3</td>
<td>0.02</td>
<td>34.3</td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Mitchell</td>
<td>9</td>
<td>34.6</td>
<td>0.04</td>
<td>34.6</td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Brooking</td>
<td>8</td>
<td>34.6</td>
<td>0.05</td>
<td>34.7</td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Site B</td>
<td>10</td>
<td>34.7</td>
<td>0.02</td>
<td>34.7</td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>EDW</td>
<td>7</td>
<td>30.5</td>
<td>1.5</td>
<td>31.4</td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>Mitchell</td>
<td>7</td>
<td>32.5</td>
<td>0.1</td>
<td>32.4</td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>Brooking</td>
<td>7</td>
<td>32.2</td>
<td>0.1</td>
<td>32.2</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>EDW</td>
<td>11</td>
<td>22.4</td>
<td>1.4</td>
<td>21.9</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Mitchell</td>
<td>10</td>
<td>26.1</td>
<td>1.6</td>
<td>26.5</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Brooking</td>
<td>7</td>
<td>23.7</td>
<td>1.1</td>
<td>23.9</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Site B</td>
<td>11</td>
<td>30.5</td>
<td>0.3</td>
<td>30.3</td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>EDW</td>
<td>20</td>
<td>30.1</td>
<td>3.0</td>
<td>31.5</td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>Mitchell</td>
<td>19</td>
<td>31.6</td>
<td>1.8</td>
<td>32.3</td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>Brooking</td>
<td>18</td>
<td>31.5</td>
<td>1.7</td>
<td>32.5</td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>Site B</td>
<td>18</td>
<td>31.8</td>
<td>2.3</td>
<td>32.6</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>EDW</td>
<td>8</td>
<td>23.6</td>
<td>7.4</td>
<td>26.5</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Mitchell</td>
<td>7</td>
<td>26.0</td>
<td>2.2</td>
<td>26.9</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Brooking</td>
<td>7</td>
<td>23.5</td>
<td>7.8</td>
<td>26.5</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Site B</td>
<td>10</td>
<td>27.1</td>
<td>1.6</td>
<td>27.0</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>EDW</td>
<td>8</td>
<td>25.0</td>
<td>5.9</td>
<td>27.6</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Mitchell</td>
<td>7</td>
<td>26.9</td>
<td>2.9</td>
<td>28.0</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Brooking</td>
<td>6</td>
<td>27.6</td>
<td>1.9</td>
<td>28.5</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Site B</td>
<td>10</td>
<td>28.2</td>
<td>3.6</td>
<td>29.6</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>EDW</td>
<td>10</td>
<td>29.5</td>
<td>1.3</td>
<td>30.1</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Mitchell</td>
<td>9</td>
<td>30.1</td>
<td>1.0</td>
<td>30.5</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Brooking</td>
<td>7</td>
<td>29.6</td>
<td>1.5</td>
<td>30.4</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Site B</td>
<td>10</td>
<td>30.8</td>
<td>1.1</td>
<td>31.4</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>EDW</td>
<td>8</td>
<td>32.0</td>
<td>1.0</td>
<td>32.4</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Mitchell</td>
<td>6</td>
<td>31.7</td>
<td>1.7</td>
<td>32.7</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Brooking</td>
<td>6</td>
<td>32.0</td>
<td>1.3</td>
<td>32.7</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Site B</td>
<td>10</td>
<td>32.7</td>
<td>0.6</td>
<td>33.1</td>
</tr>
</tbody>
</table>

Dissolved oxygen concentrations by site and sampling date are shown in Figure 8 and dissolved oxygen concentrations for each site and depth are shown in Figure 13 and Table 14. The greatest variation occurred during the 14 and 28 March 2007 samplings. The 14 March and 28 March 2007 samplings occurred after freshwater flow events.
Figure 8 Box plots for dissolved oxygen for each site and sampling date.

Table 14 Statistics for dissolved oxygen (mg/L) for each site and sampling.

<table>
<thead>
<tr>
<th>Sampling number</th>
<th>Location</th>
<th>N</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (28 Dec 06)</td>
<td>EDW</td>
<td>10</td>
<td>3.9</td>
<td>0.04</td>
<td>3.9</td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Mitchell</td>
<td>9</td>
<td>4.2</td>
<td>0.01</td>
<td>4.2</td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Brooking</td>
<td>8</td>
<td>4.4</td>
<td>0.04</td>
<td>4.4</td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Site B</td>
<td>10</td>
<td>4.5</td>
<td>0.18</td>
<td>4.4</td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>EDW</td>
<td>7</td>
<td>2.7</td>
<td>0.08</td>
<td>2.8</td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>Mitchell</td>
<td>7</td>
<td>4.3</td>
<td>0.04</td>
<td>4.3</td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>Brooking</td>
<td>7</td>
<td>4.5</td>
<td>0.04</td>
<td>4.5</td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>Site B</td>
<td>11</td>
<td>4.9</td>
<td>0.12</td>
<td>4.1</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>EDW</td>
<td>11</td>
<td>4.1</td>
<td>0.12</td>
<td>4.1</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Mitchell</td>
<td>10</td>
<td>4.3</td>
<td>0.21</td>
<td>4.2</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Brooking</td>
<td>7</td>
<td>4.0</td>
<td>0.02</td>
<td>4.0</td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Site B</td>
<td>11</td>
<td>4.9</td>
<td>0.19</td>
<td>5.0</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>EDW</td>
<td>8</td>
<td>5.2</td>
<td>0.96</td>
<td>5.0</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Mitchell</td>
<td>7</td>
<td>4.8</td>
<td>0.23</td>
<td>4.8</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Brooking</td>
<td>6</td>
<td>5.0</td>
<td>0.07</td>
<td>5.0</td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Site B</td>
<td>10</td>
<td>5.9</td>
<td>0.33</td>
<td>5.9</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>EDW</td>
<td>8</td>
<td>3.2</td>
<td>0.56</td>
<td>3.0</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Mitchell</td>
<td>7</td>
<td>3.2</td>
<td>0.69</td>
<td>3.0</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Brooking</td>
<td>6</td>
<td>3.7</td>
<td>0.71</td>
<td>3.4</td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Site B</td>
<td>10</td>
<td>4.8</td>
<td>0.76</td>
<td>4.5</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>EDW</td>
<td>10</td>
<td>5.3</td>
<td>0.10</td>
<td>5.3</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Mitchell</td>
<td>9</td>
<td>5.3</td>
<td>0.14</td>
<td>5.4</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Brooking</td>
<td>7</td>
<td>5.4</td>
<td>0.13</td>
<td>5.4</td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Site B</td>
<td>10</td>
<td>6.0</td>
<td>0.11</td>
<td>6.0</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>EDW</td>
<td>8</td>
<td>4.5</td>
<td>0.26</td>
<td>4.6</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Mitchell</td>
<td>6</td>
<td>4.6</td>
<td>0.17</td>
<td>4.5</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Brooking</td>
<td>6</td>
<td>4.7</td>
<td>0.14</td>
<td>4.7</td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Site B</td>
<td>10</td>
<td>5.6</td>
<td>0.15</td>
<td>5.7</td>
</tr>
</tbody>
</table>
There were similar patterns for conductivity values to the salinity data with the greatest range occurring after freshwater flow events (Figure 9).

**Figure 9** Box plots for conductivity for each site and sampling date.

### 4.4.3 Site and depth

Salinity data for each site and depth is presented in Figure 10. The range of salinity values was generally greatest at the surface depth. The lowest salinity values were at sites EDW (5.4 ppt) and Brooking (6.2 ppt) at 0.5 m depth on 14 March 2007.
Similarly, Figure 11 shows low values of salinity occurred at the surface or near surface depths during the 14 March and 28 March 2007 samplings. However, the consistently lowest salinity values throughout the profile occurred at the EDW, Brooking and Mitchell sites on the 8 February 2007 sampling, after the commencement of flow at the Elizabeth River gauge (Figure 11). Even minor inflows before the 25 January 2007 sampling were associated with minor changes to salinity.

To illustrate the effects of inflows on salinity, for example and for simplicity, selected data prior to freshwater inflows and after the large wet season inflow are presented in Figure 12. Prior to freshwater inflows, the water column at all sites has very similar and uniform salinity. After large freshwater inflows in mid March, salinity is reduced, particularly at the EDW and Brooking sites at 0.5 m depth, showing the effects of the freshwater plume in the upper part of the water column.
Figure 11 Depth and sampling for each site for salinity.
Figure 12 Depth, sampling for dry season prior to inflows (28 December 2006) and sampling for wet season inflow (14 March 2007) for each site for salinity.

Dissolved oxygen concentrations for each site and depth are shown in Figure 13. The greatest range occurred at the surface depth at the EDW site. A wide range of values at other depths also occurred at the EDW site.
4.4.4 Site

Turbidity was only measured at the surface depth per site, so is presented in Figure 14. The maximum turbidity value (45.8 NTU) occurred at the 27 February 2007 sampling, after several initial freshwater inflows had occurred.
4.4.5 Statistical analysis

Site

The differences between the four locations for physical measurements are summarised with means and confidence intervals in Table 15. An example for salinity is also shown in Figure 15. For turbidity the differences between the four sites were not significant.
Table 15 Means, standard errors and confidence intervals of physical measurements for location.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Location</th>
<th>Mean</th>
<th>Std.err.</th>
<th>-95%CI</th>
<th>+95%</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (ppt)</td>
<td>EDW</td>
<td>28.4</td>
<td>0.30</td>
<td>27.8</td>
<td>29.0</td>
<td>82</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Mitchell</td>
<td>30.0</td>
<td>0.31</td>
<td>29.3</td>
<td>30.6</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brooking</td>
<td>29.4</td>
<td>0.33</td>
<td>28.8</td>
<td>30.1</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site B</td>
<td>31.1</td>
<td>0.31</td>
<td>30.5</td>
<td>31.7</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Conductivity (uS/cm)</td>
<td>EDW</td>
<td>43900</td>
<td>430</td>
<td>43100</td>
<td>44800</td>
<td>82</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Mitchell</td>
<td>46100</td>
<td>453</td>
<td>45200</td>
<td>46900</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brooking</td>
<td>45300</td>
<td>480</td>
<td>44400</td>
<td>46300</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site B</td>
<td>47600</td>
<td>448</td>
<td>46800</td>
<td>48500</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>EDW</td>
<td>6.8</td>
<td>1.7</td>
<td>3.3</td>
<td>10.3</td>
<td>8</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Mitchell</td>
<td>11.1</td>
<td>1.7</td>
<td>7.6</td>
<td>14.6</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brooking</td>
<td>7.4</td>
<td>1.7</td>
<td>3.8</td>
<td>10.9</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site B</td>
<td>5.6</td>
<td>1.8</td>
<td>1.8</td>
<td>9.4</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

Figure 15 Means and confidence intervals for salinity for location.

Sampling

The differences between sampling dates for physical measurements are summarised with means and confidence intervals in Table 16. An example for salinity is also shown in Figure 16.
Table 16: Means, standard errors and confidence intervals of physical measurements for sampling date.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Sampling</th>
<th>Mean</th>
<th>Std.err.</th>
<th>-95%CI</th>
<th>+95%CI</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (ppt)</td>
<td>1 (28 Dec 06)</td>
<td>34.5</td>
<td>0.44</td>
<td>33.7</td>
<td>35.4</td>
<td>37</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>2 (25 Jan 07)</td>
<td>32.2</td>
<td>0.59</td>
<td>31.0</td>
<td>33.3</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (8 Feb 07)</td>
<td>25.8</td>
<td>0.43</td>
<td>25.0</td>
<td>26.6</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (27 Feb 07)</td>
<td>31.2</td>
<td>0.31</td>
<td>30.6</td>
<td>31.8</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 (14 Mar 07)</td>
<td>25.1</td>
<td>0.47</td>
<td>24.2</td>
<td>26.0</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 (28 Mar 07)</td>
<td>26.9</td>
<td>0.48</td>
<td>25.9</td>
<td>27.8</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (11 Apr 07)</td>
<td>30.0</td>
<td>0.44</td>
<td>29.2</td>
<td>30.9</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 (26 Apr 07)</td>
<td>32.1</td>
<td>0.49</td>
<td>31.1</td>
<td>33.1</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Conductivity (uS/cm)</td>
<td>1 (28 Dec 06)</td>
<td>52500</td>
<td>632</td>
<td>51300</td>
<td>53700</td>
<td>37</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>2 (25 Jan 07)</td>
<td>49000</td>
<td>848</td>
<td>47300</td>
<td>50700</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (8 Feb 07)</td>
<td>40300</td>
<td>617</td>
<td>39100</td>
<td>41600</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (27 Feb 07)</td>
<td>47800</td>
<td>444</td>
<td>47000</td>
<td>48700</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 (14 Mar 07)</td>
<td>39200</td>
<td>680</td>
<td>37900</td>
<td>40600</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 (28 Mar 07)</td>
<td>41800</td>
<td>692</td>
<td>40400</td>
<td>43200</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (11 Apr 07)</td>
<td>46200</td>
<td>641</td>
<td>44900</td>
<td>47500</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 (26 Apr 07)</td>
<td>49000</td>
<td>703</td>
<td>47600</td>
<td>50400</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>1 (28 Dec 06)</td>
<td>4</td>
<td>2.4</td>
<td>0</td>
<td>9</td>
<td>4</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>2 (25 Jan 07)</td>
<td>6</td>
<td>2.8</td>
<td>1</td>
<td>12</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (8 Feb 07)</td>
<td>6</td>
<td>2.4</td>
<td>1</td>
<td>11</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (27 Feb 07)</td>
<td>27</td>
<td>2.4</td>
<td>22</td>
<td>32</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 (14 Mar 07)</td>
<td>7</td>
<td>2.4</td>
<td>2</td>
<td>12</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 (28 Mar 07)</td>
<td>6</td>
<td>2.4</td>
<td>1</td>
<td>11</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (11 Apr 07)</td>
<td>2</td>
<td>2.4</td>
<td>0</td>
<td>7</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 (26 Apr 07)</td>
<td>3</td>
<td>2.4</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Figure 16: Means and confidence intervals for salinity for sampling dates.
As discussed in section 3.4, the depth data had to be classified for the purposes of the statistical analysis due to sampling inconsistencies. The means and variability estimates between depths for physical measurements are summarised in Table 17. Differences between depths for dissolved oxygen (P=0.08) however were not significant at P<0.05. An example for salinity is also shown in Figure 17.

**Table 17** Means, standard errors and confidence intervals of physical measurements for depth.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Depth</th>
<th>Mean</th>
<th>Std.err.</th>
<th>-95%CI</th>
<th>+95%CI</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (ppt)</td>
<td>s</td>
<td>25.7</td>
<td>0.88</td>
<td>23.9</td>
<td>27.4</td>
<td>31</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>30.3</td>
<td>0.88</td>
<td>28.5</td>
<td>32.0</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>30.8</td>
<td>0.88</td>
<td>29.1</td>
<td>32.6</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Conductivity (uS/cm)</td>
<td>s</td>
<td>39800</td>
<td>1280</td>
<td>37300</td>
<td>42400</td>
<td>31</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>46500</td>
<td>1280</td>
<td>43900</td>
<td>49000</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>47500</td>
<td>1280</td>
<td>44900</td>
<td>50000</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Dissolved oxygen (mg/L)</td>
<td>s</td>
<td>4.92</td>
<td>0.161</td>
<td>4.60</td>
<td>5.24</td>
<td>26</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>4.58</td>
<td>0.157</td>
<td>4.26</td>
<td>4.89</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>4.42</td>
<td>0.157</td>
<td>4.11</td>
<td>4.74</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

Figure 17 Means and confidence intervals for salinity for depth.
(s surface; m middle; b bottom of water column)
4.5  Nutrients

4.5.1  Summary of all data

Summary statistics across all sites and samplings are presented in Table 18. Further details are presented in the following sections. A statistical analysis is presented in section 4.5.4.

Table 18 Summary statistics of all nutrient data.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std.Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP (mg/L)</td>
<td>61</td>
<td>0.018</td>
<td>0.020</td>
<td>0.003</td>
<td>0.035</td>
<td>0.008</td>
</tr>
<tr>
<td>FRP (mg/L)</td>
<td>54</td>
<td>0.006</td>
<td>0.005</td>
<td>0.001</td>
<td>0.016</td>
<td>0.004</td>
</tr>
<tr>
<td>Nitrite as N (mg/L)</td>
<td>61</td>
<td>0.007</td>
<td>0.002</td>
<td>0.001</td>
<td>0.004</td>
<td>0.012</td>
</tr>
<tr>
<td>Nitrate as N (mg/L)</td>
<td>61</td>
<td>0.017</td>
<td>0.008</td>
<td>0.001</td>
<td>0.057</td>
<td>0.017</td>
</tr>
<tr>
<td>Ammonia-N (mg/L)</td>
<td>60</td>
<td>0.011</td>
<td>0.005</td>
<td>0.003</td>
<td>0.060</td>
<td>0.013</td>
</tr>
<tr>
<td>NO\textsubscript{x} -N (mg/L)</td>
<td>61</td>
<td>0.011</td>
<td>0.005</td>
<td>0.003</td>
<td>0.060</td>
<td>0.013</td>
</tr>
<tr>
<td>TKN (mg/L)</td>
<td>61</td>
<td>1.23</td>
<td>1.32</td>
<td>0.25</td>
<td>2.13</td>
<td>0.52</td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>61</td>
<td>1.26</td>
<td>1.34</td>
<td>0.25</td>
<td>2.14</td>
<td>0.53</td>
</tr>
</tbody>
</table>

N is number of samples

4.5.2  Site and samplings

NO\textsubscript{x} values for each site and sampling date are shown in Figure 18. The samplings of the 14 and 28 March 2007 had the greatest NO\textsubscript{x} ranges at the EDW, Mitchell and Brooking sites. These samplings occurred after the largest freshwater flow event at the Elizabeth River gauge prior to the sampling on the 14 March 2007. The lowest values of median NO\textsubscript{x}, TN and TP occurred in the samplings prior to freshwater inflows. Median values for NO\textsubscript{x} and other measurements for each sampling are summarised in Table 27 in the appendix.
Figure 18 Box plots for NOx for each site and sampling date.
TN values for each site and sampling date are shown in Figure 19 and Table 27 (in appendix). The samplings with the greatest range of values varied depending on site, but were generally 8 February 2007 to 28 March 2007. As with NO\textsubscript{x}, there was little variation during the December 2006 and April 2007 samplings. TP values for each site and sampling date are shown in Figure 20. There were similar patterns to TN.

Figure 19 Box plots for total nitrogen for each site and sampling date.
4.5.3 Site and depth

TN values for each site and depth (surface, middle and bottom) are shown in Figure 21 and Table 28. The surface depth had the greatest range per site, but with the exception of the bottom depth at EDW. TN values for each depth and sampling date are shown in Figure 22.
Figure 21 Box plots for TN for each site and depth. 
(s surface; m middle; b bottom of water column)

Figure 22 Box plots for TN for each sampling and depth. 
(s surface; m middle; b bottom of water column)
Further statistics for nutrients for each site and depth are presented in Table 19 and Table 28 (in appendix). NO\textsubscript{x} values for each site and depth (surface, middle and bottom) are shown in Figure 23. In contrast to TN results, the surface depth had the smallest range per site.

**Figure 23** Box plots for NO\textsubscript{x}-N for each site and depth. (s surface; m middle; b bottom of water column)
Table 19 Statistics for TP and FRP for each site and depth.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (m)</th>
<th>Mean</th>
<th>N</th>
<th>Std.Dev.</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Phosphorus (mg/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDW</td>
<td>s</td>
<td>0.013</td>
<td>9</td>
<td>0.007</td>
<td>0.015</td>
</tr>
<tr>
<td>EDW</td>
<td>m</td>
<td>0.017</td>
<td>5</td>
<td>0.009</td>
<td>0.015</td>
</tr>
<tr>
<td>EDW</td>
<td>b</td>
<td>0.017</td>
<td>5</td>
<td>0.010</td>
<td>0.020</td>
</tr>
<tr>
<td>Site B</td>
<td>s</td>
<td>0.015</td>
<td>6</td>
<td>0.007</td>
<td>0.018</td>
</tr>
<tr>
<td>Site B</td>
<td>m</td>
<td>0.025</td>
<td>2</td>
<td>0.014</td>
<td>0.025</td>
</tr>
<tr>
<td>Site B</td>
<td>b</td>
<td>0.025</td>
<td>2</td>
<td>0.000</td>
<td>0.025</td>
</tr>
<tr>
<td>Mitchell</td>
<td>s</td>
<td>0.017</td>
<td>8</td>
<td>0.007</td>
<td>0.020</td>
</tr>
<tr>
<td>Mitchell</td>
<td>m</td>
<td>0.021</td>
<td>4</td>
<td>0.008</td>
<td>0.020</td>
</tr>
<tr>
<td>Mitchell</td>
<td>b</td>
<td>0.023</td>
<td>3</td>
<td>0.008</td>
<td>0.025</td>
</tr>
<tr>
<td>Brooking</td>
<td>s</td>
<td>0.017</td>
<td>8</td>
<td>0.007</td>
<td>0.020</td>
</tr>
<tr>
<td>Brooking</td>
<td>m</td>
<td>0.020</td>
<td>4</td>
<td>0.006</td>
<td>0.020</td>
</tr>
<tr>
<td>Brooking</td>
<td>b</td>
<td>0.022</td>
<td>5</td>
<td>0.006</td>
<td>0.020</td>
</tr>
</tbody>
</table>

(s surface; m middle; b bottom of water column)

FRP (mg/L)

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (m)</th>
<th>Mean</th>
<th>N</th>
<th>Std.Dev.</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDW</td>
<td>s</td>
<td>0.007</td>
<td>7</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>EDW</td>
<td>m</td>
<td>0.008</td>
<td>4</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>EDW</td>
<td>b</td>
<td>0.006</td>
<td>4</td>
<td>0.006</td>
<td>0.006</td>
</tr>
<tr>
<td>Site B</td>
<td>s</td>
<td>0.004</td>
<td>5</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>Site B</td>
<td>m</td>
<td>0.004</td>
<td>2</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Site B</td>
<td>b</td>
<td>0.004</td>
<td>2</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Mitchell</td>
<td>s</td>
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<td>7</td>
<td>0.002</td>
<td>0.005</td>
</tr>
<tr>
<td>Mitchell</td>
<td>m</td>
<td>0.008</td>
<td>4</td>
<td>0.006</td>
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</tr>
<tr>
<td>Mitchell</td>
<td>b</td>
<td>0.012</td>
<td>3</td>
<td>0.005</td>
<td>0.013</td>
</tr>
<tr>
<td>Brooking</td>
<td>s</td>
<td>0.004</td>
<td>7</td>
<td>0.002</td>
<td>0.004</td>
</tr>
<tr>
<td>Brooking</td>
<td>m</td>
<td>0.006</td>
<td>4</td>
<td>0.004</td>
<td>0.006</td>
</tr>
<tr>
<td>Brooking</td>
<td>b</td>
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<td>5</td>
<td>0.004</td>
<td>0.006</td>
</tr>
</tbody>
</table>

4.5.4 Statistical analysis

Site

The differences between the four locations for nutrients are summarised with means and variability estimates in Table 20. For TN, ammonia and TP the differences between the four sites were not significant. Site B had significantly lower mean NOₓ (Table 20 and Figure 24).
Table 20 Means, standard errors and confidence intervals of nutrients for location.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Location</th>
<th>Mean</th>
<th>Std.err.</th>
<th>-95%CI</th>
<th>+95%CI</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN (mg/L)</td>
<td>EDW</td>
<td>1.15</td>
<td>0.09</td>
<td>0.97</td>
<td>1.33</td>
<td>19</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Site B</td>
<td>1.17</td>
<td>0.12</td>
<td>0.92</td>
<td>1.42</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mitchell</td>
<td>1.26</td>
<td>0.10</td>
<td>1.06</td>
<td>1.46</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brooking</td>
<td>1.26</td>
<td>0.10</td>
<td>1.07</td>
<td>1.45</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>NO\textsubscript{x}-N (mg/L)</td>
<td>EDW</td>
<td>0.0220</td>
<td>0.005</td>
<td>0.012</td>
<td>0.032</td>
<td>19</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Site B</td>
<td>0.0004</td>
<td>0.007</td>
<td>0</td>
<td>0.014</td>
<td>10</td>
<td></td>
</tr>
<tr>
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<td>Mitchell</td>
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<td>0.009</td>
<td>0.030</td>
<td>17</td>
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<tr>
<td>Ammonia-N (mg/L)</td>
<td>EDW</td>
<td>0.0127</td>
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<td>0.0081</td>
<td>0.0172</td>
<td>19</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Site B</td>
<td>0.0051</td>
<td>0.0032</td>
<td>0</td>
<td>0.0115</td>
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<td></td>
</tr>
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<td>0.0026</td>
<td>0.0048</td>
<td>0.0151</td>
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<td></td>
</tr>
<tr>
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<td>Brooking</td>
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<td>0.0029</td>
<td>0.0133</td>
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<td></td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>EDW</td>
<td>0.014</td>
<td>0.001</td>
<td>0.013</td>
<td>0.016</td>
<td>19</td>
<td>NS</td>
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<tr>
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<td>Site B</td>
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<td>0.001</td>
<td>0.012</td>
<td>0.017</td>
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</tr>
<tr>
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<td>Mitchell</td>
<td>0.016</td>
<td>0.001</td>
<td>0.014</td>
<td>0.019</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brooking</td>
<td>0.016</td>
<td>0.001</td>
<td>0.014</td>
<td>0.018</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 24** Means and confidence intervals for NO\textsubscript{x}-N for sites.

**Sampling date**

The differences between the sampling dates for selected nutrients are summarised with means and variability estimates in Table 21. Examples for TN and NO\textsubscript{x} are shown in Figure 25 and Figure 26. For NO\textsubscript{x}, for example, there were significant differences between the sampling dates of 14 and 28 March 2007 and the other samplings.
Figure 25 Means and confidence intervals for TN for sampling dates.

Figure 26 Means and confidence intervals for NO$_x$ for sampling dates.
Table 21 Means, standard errors and confidence intervals of selected nutrients for sampling dates.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Sampling Date</th>
<th>Mean</th>
<th>Std.err.</th>
<th>-95% CI</th>
<th>+95% CI</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN (mg/L)</td>
<td>1a (13 Dec 06)</td>
<td>0.41</td>
<td>0.22</td>
<td>0.86</td>
<td>0.39</td>
<td>4</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>1 (28 Dec 06)</td>
<td>0.39</td>
<td>0.18</td>
<td>0.76</td>
<td>0.03</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 (25 Jan 07)</td>
<td>1.74</td>
<td>0.21</td>
<td>2.17</td>
<td>1.32</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (8 Feb 07)</td>
<td>1.15</td>
<td>0.13</td>
<td>1.40</td>
<td>0.90</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (27 Feb 07)</td>
<td>1.52</td>
<td>0.10</td>
<td>1.73</td>
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</tr>
<tr>
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<td>6 (28 Mar 07)</td>
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</tr>
<tr>
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<td>7 (11 Apr 07)</td>
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<td>1.83</td>
<td>1.10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 (26 Apr 07)</td>
<td>1.81</td>
<td>0.18</td>
<td>2.17</td>
<td>1.45</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>NOₓ-N (mg/L)</td>
<td>1a (13 Dec 06)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>3</td>
<td>P&lt;0.05</td>
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<tr>
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<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 (25 Jan 07)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (8 Feb 07)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>9</td>
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<tr>
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<td>4 (27 Feb 07)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>12</td>
<td></td>
</tr>
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<td>5 (14 Mar 07)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>10</td>
<td></td>
</tr>
<tr>
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<td>6 (28 Mar 07)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>12</td>
<td></td>
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<tr>
<td></td>
<td>7 (11 Apr 07)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>4</td>
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</tr>
<tr>
<td></td>
<td>8 (26 Apr 07)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Ammonia-N (mg/L)</td>
<td>1a (13 Dec 06)</td>
<td>0.001</td>
<td>0.006</td>
<td>0.013</td>
<td>3 P&lt;0.001</td>
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<td></td>
</tr>
<tr>
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<td>0.005</td>
<td>0.02</td>
<td>0.01</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 (25 Jan 07)</td>
<td>0.01</td>
<td>0.005</td>
<td>0.02</td>
<td>0.01</td>
<td>9</td>
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<tr>
<td></td>
<td>3 (8 Feb 07)</td>
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<td>0.003</td>
<td>0.01</td>
<td>0.01</td>
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<td>4 (27 Feb 07)</td>
<td>0.01</td>
<td>0.003</td>
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<td>5 (14 Mar 07)</td>
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<td>0.003</td>
<td>0.02</td>
<td>0.01</td>
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<td>6 (28 Mar 07)</td>
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<td>0.003</td>
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<td>0.005</td>
<td>0.02</td>
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<tr>
<td></td>
<td>8 (26 Apr 07)</td>
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<td>0.005</td>
<td>0.02</td>
<td>0.01</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>1a (13 Dec 06)</td>
<td>0.003</td>
<td>0.002</td>
<td>0.008</td>
<td>3 P&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 (28 Dec 06)</td>
<td>0.003</td>
<td>0.002</td>
<td>0.007</td>
<td>0.002</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 (25 Jan 07)</td>
<td>0.018</td>
<td>0.002</td>
<td>0.023</td>
<td>0.013</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 (8 Feb 07)</td>
<td>0.016</td>
<td>0.001</td>
<td>0.019</td>
<td>0.013</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 (27 Feb 07)</td>
<td>0.024</td>
<td>0.001</td>
<td>0.026</td>
<td>0.021</td>
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<td>5 (14 Mar 07)</td>
<td>0.015</td>
<td>0.001</td>
<td>0.017</td>
<td>0.012</td>
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<td>0.018</td>
<td>0.002</td>
<td>0.022</td>
<td>0.013</td>
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<tr>
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<td>8 (26 Apr 07)</td>
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<td>0.002</td>
<td>0.023</td>
<td>0.015</td>
<td>4</td>
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</table>

Depth

The differences between depths for nutrients are summarised with means and variability estimates in Table 22. For TN, NOₓ, and TP there were significant differences between depths. An example for TN is also shown in Figure 27.
Figure 27 Means and confidence intervals for TN for depth intervals. (s surface; m middle; b bottom of water column)

Table 22 Means, standard errors and confidence intervals of selected nutrients for depth.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Depth</th>
<th>Mean</th>
<th>Std.err.</th>
<th>-95%CI</th>
<th>+95%</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN (mg/L)</td>
<td>s</td>
<td>1.11</td>
<td>0.09</td>
<td>0.93</td>
<td>1.29</td>
<td>31</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>1.43</td>
<td>0.13</td>
<td>1.16</td>
<td>1.69</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>1.46</td>
<td>0.13</td>
<td>1.20</td>
<td>1.73</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>NOx-N (mg/L)</td>
<td>s</td>
<td>0.012</td>
<td>0.005</td>
<td>0.002</td>
<td>0.021</td>
<td>31</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>0.033</td>
<td>0.007</td>
<td>0.019</td>
<td>0.046</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.038</td>
<td>0.007</td>
<td>0.024</td>
<td>0.051</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Ammonia-N (mg/L)</td>
<td>s</td>
<td>0.007</td>
<td>0.002</td>
<td>0.002</td>
<td>0.012</td>
<td>30</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>0.014</td>
<td>0.003</td>
<td>0.007</td>
<td>0.020</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.014</td>
<td>0.003</td>
<td>0.008</td>
<td>0.021</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>s</td>
<td>0.016</td>
<td>0.001</td>
<td>0.013</td>
<td>0.018</td>
<td>31</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>0.020</td>
<td>0.002</td>
<td>0.016</td>
<td>0.024</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>0.021</td>
<td>0.002</td>
<td>0.017</td>
<td>0.025</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

(s surface; m middle; b bottom of water column)

4.6 Chlorophyll-a and pheophytin

Chlorophyll-a box plots for each site and sampling are presented in Figure 28, with further details and pheophytin results in Table 23. Chlorophyll-a range and medians were greatest after the freshwater inflow events. Median values were high during the 27 February 2007 sampling, namely 31 µg/L at EDW, 15 µg/L at Site B, 24 µg/L at Mitchell, and 5.5 µg/L at Brooking.
Figure 28 Box plots for chlorophyll-a for each site and sampling date.

Table 23 Statistics for chlorophyll-a and pheophytin for each site and depth.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (m)</th>
<th>Mean</th>
<th>N</th>
<th>Std.Dev.</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll-a (µg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDW</td>
<td>s</td>
<td>4.1</td>
<td>9</td>
<td>2.7</td>
<td>4.5</td>
</tr>
<tr>
<td>EDW</td>
<td>m</td>
<td>11.9</td>
<td>5</td>
<td>11.4</td>
<td>11.0</td>
</tr>
<tr>
<td>EDW</td>
<td>b</td>
<td>12.8</td>
<td>5</td>
<td>14.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Site B</td>
<td>s</td>
<td>4.0</td>
<td>6</td>
<td>3.6</td>
<td>2.5</td>
</tr>
<tr>
<td>Site B</td>
<td>m</td>
<td>10.3</td>
<td>2</td>
<td>6.7</td>
<td>10.3</td>
</tr>
<tr>
<td>Site B</td>
<td>b</td>
<td>19.3</td>
<td>2</td>
<td>19.4</td>
<td>19.3</td>
</tr>
<tr>
<td>Mitchell</td>
<td>s</td>
<td>10.3</td>
<td>8</td>
<td>8.9</td>
<td>7.5</td>
</tr>
<tr>
<td>Mitchell</td>
<td>m</td>
<td>15.1</td>
<td>4</td>
<td>10.0</td>
<td>16.5</td>
</tr>
<tr>
<td>Mitchell</td>
<td>b</td>
<td>19.5</td>
<td>3</td>
<td>23.9</td>
<td>8.0</td>
</tr>
<tr>
<td>Brooking</td>
<td>s</td>
<td>11.1</td>
<td>8</td>
<td>25.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Brooking</td>
<td>m</td>
<td>3.4</td>
<td>4</td>
<td>1.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Brooking</td>
<td>b</td>
<td>15.8</td>
<td>5</td>
<td>21.9</td>
<td>3.0</td>
</tr>
</tbody>
</table>

| Pheophytin (µg/L) | | | | | |
|:-:|:-:|:-:|:-:|:-:|
| EDW | s | 6.1 | 9 | 10.3 | 2.0 |
| EDW | m | 4.7 | 5 | 4.2 | 3.0 |
| EDW | b | 5.0 | 5 | 4.8 | 2.0 |
| Site B | s | 1.3 | 6 | 1.4 | 0.5 |
| Site B | m | 1.8 | 2 | 0.4 | 1.8 |
| Site B | b | 1.8 | 2 | 0.4 | 1.8 |
| Mitchell | s | 3.3 | 8 | 2.5 | 2.8 |
| Mitchell | m | 3.1 | 4 | 1.7 | 2.8 |
| Mitchell | b | 5.7 | 3 | 5.5 | 2.5 |
| Brooking | s | 2.9 | 8 | 6.5 | 0.6 |
| Brooking | m | 0.9 | 4 | 0.8 | 0.8 |
| Brooking | b | 3.3 | 5 | 3.9 | 1.0 |

(s surface; m middle; b bottom of water column)
4.6.1 Statistical analysis

Site and sampling date

The differences between the four locations for chlorophyll-a (Figure 29) and pheophytin were not significant. The differences between the sampling dates for chlorophyll-a (Figure 30) and pheophytin were also not significant.

![Figure 29](image1.png)

**Figure 29** Means and confidence intervals for chlorophyll-a for sites.

![Figure 30](image2.png)

**Figure 30** Means and confidence intervals for chlorophyll-a for samplings.

Depth

The differences between the three depths for chlorophyll-a and pheophytin were not significant.
4.7 Photosynthetically active radiation

The dry season profiles of photosynthetically active radiation (PAR) typically had greater PAR at equivalent depths than during the wet season, but the rate of reduction rate was less uniform. Some typical PAR profiles with depth for selected dry and wet season samplings are shown in Figure 31.

![Graph showing PAR profiles](image)

**Figure 31** PAR for selected pre and during wet season samplings and sites with depth.

4.7.1 Euphotic depth

The euphotic depths (99% extinction coefficients) for sites are shown in Figure 32, and for sampling dates in Figure 33. Median euphotic depth did not vary greatly between sites. Median euphotic depths were Brooking 5.6 m, EDW 5.9 m, Mitchell 5.6 m and Site B 6.4 m. Data for only two sites were used for the 25 January 2007 sampling so strong conclusions cannot be made for that sampling date. Median euphotic depth was lowest at the 25 January and 27 February 2007 samplings. Further results are shown in the Appendix.
4.8 Phytoplankton

4.8.1 Phytoplankton taxa composition

116 phytoplankton taxa were identified in 29 samples from four sites in the 2006/07 wet season. These included 44 taxa of diatoms (Bacillariophyceae), 66 taxa of dinoflagellates (Dinophyceae) and small numbers of taxa of Chlorophyceae (1), Euglenophyceae (1), Cryptophyceae (2) and Cyanobacteria (2).
Most phytoplankton taxa were identified to at least the level of genus. There were 51 different genera; 11 taxa (mostly dinoflagellates) were assigned a taxacode name. Most of these 62 taxa were rare, only 12 taxa comprised >1% of the total number of estimated cells (Table 24). Two taxa (the diatom *Odontella* and dinoflagellate 103) comprised 65% of the total number of estimated cells. Subsequent discussion of taxa richness refers to the genus or taxacode level of data aggregation.

### Table 24 Percentage of total cell density of common taxa in phytoplankton samples.

<table>
<thead>
<tr>
<th>Phytoplankton class</th>
<th>Taxon name</th>
<th>Percent total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacillariophyceae</td>
<td><em>Odontella</em></td>
<td>39.8</td>
</tr>
<tr>
<td>Dinophyceae</td>
<td>Dinoflagellate 103</td>
<td>24.7</td>
</tr>
<tr>
<td>Bacillariophyceae</td>
<td><em>Thalassionema</em></td>
<td>6.4</td>
</tr>
<tr>
<td>Bacillariophyceae</td>
<td><em>Coscinodiscus</em></td>
<td>6.0</td>
</tr>
<tr>
<td>Bacillariophyceae</td>
<td><em>Navicula</em></td>
<td>3.9</td>
</tr>
<tr>
<td>Dinophyceae</td>
<td><em>Protoperidinium</em></td>
<td>3.1</td>
</tr>
<tr>
<td>Bacillariophyceae</td>
<td><em>Rhizosolenia</em></td>
<td>2.5</td>
</tr>
<tr>
<td>Dinophyceae</td>
<td><em>Dinophys</em></td>
<td>2.3</td>
</tr>
<tr>
<td>Dinophyceae</td>
<td><em>Gyrodinium</em></td>
<td>1.9</td>
</tr>
<tr>
<td>Bacillariophyceae</td>
<td><em>Chaetoceros</em></td>
<td>1.6</td>
</tr>
<tr>
<td>Dinophyceae</td>
<td><em>Prorocentrum</em></td>
<td>1.1</td>
</tr>
<tr>
<td>Cyanobacteria</td>
<td><em>Oscillatoria</em></td>
<td>1.0</td>
</tr>
</tbody>
</table>

#### 4.8.2 Differences between sites

Total estimated phytoplankton density in surface samples differed between sites and sampling occasions (Figure 34). Cell density was highest in February at sites EDW, Brooking Creek and Mitchell Creek. There were no samples from Site B in February.

The estimated cell density of the five most abundant taxa in surface phytoplankton samples varied between sites and sampling occasions (Figure 35 to Figure 38). Site B differed from the other three sites. Dinoflagellate 103 was abundant in December and March at Site B, but was not common in any month at other sites. In contrast the diatom *Odontella* dominated February samples at sites EDW, Brooking Creek and Mitchell Creek.
Figure 34 Estimated total cell density (cells/L) in surface phytoplankton samples from 4 sites in the 2006/07 wet season.

Figure 35 Estimated cell density (cells/L) of common phytoplankton taxa in surface samples from Site B in the 2006/07 wet season.
**Figure 36** Estimated cell density (cells/L) of common phytoplankton taxa in surface samples from Brooking Creek in the 2006/07 wet season.

**Figure 37** Estimated cell density (cells/L) of common phytoplankton taxa in surface samples from Site EDW in the 2006/07 wet season.
Figure 38 Estimated cell density (cells/L) of common phytoplankton taxa in surface samples from Mitchell Creek in the 2006/07 wet season.

4.8.3 Patterns of taxa richness

The number of taxa within pooled samples across all depths and sites varied slightly between sampling occasions. There were 29 taxa in December 2006, 29 taxa in February 2007, 38 taxa in March and 36 taxa in April 2007. The number of taxa of phytoplankton in surface samples varied between sites and sampling occasions, and was lower in most months at Site EDW (Figure 39).

Figure 39 Taxa richness at each site on each sampling occasion in surface phytoplankton samples.
4.8.4 Variation in cell density with depth

Total estimated cell density in March 2007 varied between sites and sampling depth. Cell densities were relatively high in the middle part of the water column in Brooking Creek and Site B (Figure 40). The abundance of the five most abundant phytoplankton taxa in March varied between sites and depths (Figure 41 to Figure 43). Dinoflagellate 103 was abundant in surface samples at Site B and middle water column samples at all sites.

Figure 40 Variation in cell density (cells/L) with depth at four sites in March 2007 phytoplankton samples.
**Figure 41** Cell density (cells/L) of common taxa in surface phytoplankton samples in March 2007.

**Figure 42** Cell density (cells/L) of common taxa in mid-water phytoplankton samples in March 2007.
Figure 43 Cell density (cells/L) of common taxa in bottom water phytoplankton samples in March 2007.

4.9 Comparison to water quality objectives

The Water Quality Protection Plan being developed for Darwin Harbour (see section 2.2) has established locally-derived guidelines called water quality objectives (WQOs). WQOs have been developed for protection of water quality in the Darwin region.

For comparison with water quality objectives, it is preferable to compare indicator values collected at regular intervals over a period of time, such as one year. In this report, values are compared from only a limited number of samplings over a short period (i.e., one wet season), so some caution should therefore be used when interpreting these results.

In this section, median water quality values from field data are compared with water quality objectives for upper estuaries in Darwin Harbour. Water quality objective values were complied with for median values of pH, NO$_x$, ammonia, TP and FRP (Table 25). Median chlorophyll-a and TN values over all samplings did not comply with water quality objectives (Table 25).

Samplings where site median values for water quality indicators did not comply with WQOs are summarised in Table 25. The EDW and Mitchell site median values, for example, exceeded chlorophyll-a WQOs for six of the samplings. Median TN values at all sites exceeded the WQO (Table 25).
Table 25 Comparison of surface water quality indicators and water quality objectives.

<table>
<thead>
<tr>
<th>Indicator and units</th>
<th>Water quality objective for upper estuary</th>
<th>Elizabeth River estuary sites median in this report</th>
<th>Sample number</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6-8.5</td>
<td>7.9</td>
<td>294</td>
<td>Tick</td>
</tr>
<tr>
<td>Chlorophyll-a (µg/L)</td>
<td>&lt;4</td>
<td>4.5</td>
<td>61</td>
<td>x</td>
</tr>
<tr>
<td>NO₃ (µg N/L)</td>
<td>&lt;20</td>
<td>10</td>
<td>61</td>
<td>Tick</td>
</tr>
<tr>
<td>Ammonia (µg N/L)</td>
<td>&lt;20</td>
<td>5</td>
<td>60</td>
<td>Tick</td>
</tr>
<tr>
<td>Total nitrogen (µg N/L)</td>
<td>&lt;300</td>
<td>1340</td>
<td>61</td>
<td>x</td>
</tr>
<tr>
<td>Total phosphorus (µg P/L)</td>
<td>&lt;30</td>
<td>20</td>
<td>61</td>
<td>Tick</td>
</tr>
<tr>
<td>FRP (µg P/L)</td>
<td>&lt;10</td>
<td>5</td>
<td>54</td>
<td>Tick</td>
</tr>
</tbody>
</table>

'x' indicates the WQO was not complied with.

Table 26 Samplings when site median values for each sampling for indicators did not comply with WQOs.

<table>
<thead>
<tr>
<th>Sampling number</th>
<th>Location</th>
<th>NO₃</th>
<th>TN</th>
<th>Ammonia</th>
<th>TP</th>
<th>FRP</th>
<th>Chlorophyll-a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a (13 Dec 06)</td>
<td>EDW</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>EDW</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Site B</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Mitchell</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (28 Dec 06)</td>
<td>Brooking</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>EDW</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>Mitchell</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (25 Jan 07)</td>
<td>Brooking</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>EDW</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Mitchell</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (8 Feb 07)</td>
<td>Brooking</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>EDW</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>Site B</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>Mitchell</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 (27 Feb 07)</td>
<td>Brooking</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>EDW</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Site B</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Mitchell</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 (14 Mar 07)</td>
<td>Brooking</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>EDW</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Site B</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Mitchell</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 (28 Mar 07)</td>
<td>Brooking</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>EDW</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Site B</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Mitchell</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 (11 Apr 07)</td>
<td>Brooking</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>EDW</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Site B</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Mitchell</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 (26 Apr 07)</td>
<td>Brooking</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

'x' indicates the WQO was not complied with.
4.10 Comparison with Elizabeth River gauge station data

Concentration data collected during storm sampling at the Elizabeth River gauge station reached a maximum of 0.85 mg N/L and 0.025 mg P/L during the 2007 wet season (Table 11).

In contrast, during the current study, maximum values for the Elizabeth River estuary at the four sites reached 2.14 mg N/L and 0.025 mg P/L (Table 18). The flow-weighted event mean concentrations at the gauge station over the whole 2006/07 wet season were 0.74 mg N/L for TN and 0.012 mg P/L for TP. Median concentrations from the Elizabeth River estuary at the four sites in this report were 1.34 mg N/L and 0.02 mg P/L (Table 18). This is discussed in the next section.
5 Discussion

5.1 Water quality

In general, the largest range in values of the physical indicators and the nutrients occurred during the largest freshwater inflow events. All sites had minimal variation in salinity and conductivity prior to wet season freshwater inflows, and during the two April samplings. Although there are exceptions, in general, site EDW had the greatest range of values during freshwater inflows from the catchment overall. In contrast the catchment draining Brooking and Mitchell Creeks was much smaller. In general, NO\textsubscript{x} had low variation at all sites except for the March samplings. It is likely that sufficient rainfall volume and time were needed for soil water infiltration to transport nitrate to the estuary. In contrast, TN was likely to have also been associated with surface runoff transport at several sites during the February rainfall events.

In general the surface 0.5 m of depth had the greatest variation in physical measurement values, particularly at site EDW. However, for other sites, this was not always the case. Indeed, the statistical analyses indicate that for salinity and conductivity measurements, the surface depth was significantly different from either the middle or bottom depths. Similarly, in general the surface 1 m of depth had the greatest variation in nutrient measurement values, but this is not always the case. NO\textsubscript{x} for example, commonly had the largest range at bottom sampling depths. Overall, there were significant differences between the depths sampled for TN, NO\textsubscript{x}, TP, salinity and conductivity.

The results suggest an influence of freshwater inflows associated with rainfall events from the catchment as measured at the Elizabeth River gauge station. It is difficult to draw strong conclusions quantifying the rate and extent of mixing due to variations in tidal influence and sampling times associated with tides, as discussed in section 3. Many samplings were associated with incoming tides or near high tides. However, there is evidence to indicate a salinity gradient or halocline in the estuary as influenced by freshwater inflows in the wet season. Similarly, other studies have also reported estuarine haloclines and stratification associated with inflows (Dong et al. 2004; Eyre 1998). For several sites in Darwin Harbour including the Blackmore River, salinity was lower during the 2003 wet season than in the dry season, and many nutrient concentrations were greater in the wet season than in the dry season (McKinnon et al. 2006).

Some studies have reported changes in nutrient behaviour and concentration at the interface of salt and freshwater. Nitrate, for example, has been observed to be high in freshwater due to its richness in nutrients and to decrease under the salt-freshwater interface (salt wedge) in the marine water (Sierra et al. 2002). Similarly, Sierra et al. (2002) indicate chlorophyll-a levels may be lower near an estuary mouth associated with greater turbulence and suspended sediment. Other processes resulting in changes in nutrient concentrations include breakdown of freshwater phytoplankton as salinity rises resulting in decomposition, nutrient mineralisation and ammonia production (Sierra et al. 2002). However, the nature of the relationships of some nutrients with salinity varies greatly with the time interval of estuary flushing (Eyre 1998).
Median euphotic depth was lowest at a sampling associated with freshwater inflows, and when turbidity at the surface depth was also greatest. Light attenuation can limit photosynthesis. Higher plants such as seagrasses generally require more light than phytoplankton (Kelble et al. 2005). Light attenuation is commonly attributed to seawater, phytoplankton, dissolved organic matter and non phytoplanktonic particulate material (Kelble et al. 2005). Given the evidence for some stratification and poor mixing for some wet season samplings, reduction of PAR with depth is not likely to be as uniform as in the dry season, where the water column is likely to be well mixed.

5.2 Phytoplankton

The dinoflagellate *Prorocentrum mexicanum* was present at the sites on Mitchell Creek and EDW during March and April sampling occasions in 2007. *Prorocentrum mexicanum* is a widely distributed marine dinoflagellate commonly found in tropical waters. Although some species of *Prorocentrum* are associated with toxins, *Prorocentrum mexicanum* is not of concern (WADOH and DOF 2007).

Vertical gradients of nutrients and light can play a role in the vertical distribution of phytoplankton (Klausmeier and Litchman 2001). Some species can actively choose their position in the water column by actively swimming (flagellates) or altering buoyancy (cyanobacteria). After the wet season flows become negligible, resulting in reduced sediment loads and turbidity and good light attenuation through the water column. The phytoplankton community was more diverse in taxa in March and April 2007 than the previous samplings during the wet season.

5.3 Comparison with water quality objectives

Chlorophyll-a, TN and dissolved oxygen have been shown to exceed water quality objectives in the Elizabeth River estuary (Fortune et al. 2009). Similarly, data from this study showed that median values across all samplings in this study for chlorophyll-a and TN exceeded water quality objectives. For other indicators, the site median values within each sampling exceeded WQOs much less frequently for several key water quality indicators.

In this study, TN is mostly organic N, while NO$_x$ is only a small proportion of TN. For all data, median NO$_x$ is <1% of median TN. NO$_x$ as a proportion of TN was greatest (9%) at the EDW site on 15 March 2007. Inflow of NO$_x$ as shown in this study is unlikely to contribute to non compliance of the TN water quality objective.

This study shows that median values of TN were clearly much less prior to the wet season than during the wet season. The median value of TN prior to the wet season inflows (i.e. for 13 and 28 December 2006 samplings) was 0.403 mg/L. TN however, did also not comply with WQOs prior to the wet season. The other samplings from this study were during the wet season, so this is likely to have also biased the non compliance with water quality objectives for some indicators such as TN. For comparison with water quality objectives, it is preferable to compare indicator values collected at regular intervals over one year for example. Some caution should therefore be used when interpreting these results.
In a recent study of water quality in the Darwin Harbour region (Fortune et al. 2009), current condition for TN in the Elizabeth River estuary was evaluated from data mainly collected during the 2006-07 wet season (unpublished data). This may lead to a bias in the number of incidences of non compliance of current condition with WQOs. Of note is that TN did not comply with WQOs prior to the wet season in this study. Seasonal relationships for marine ambient WQOs in the Darwin Harbour region upper estuaries have not been evaluated and warrant future research as data becomes available. Consequently, comprehensive marine water quality monitoring at 28 sites in Darwin Harbour during wet and dry seasons is being undertaken to help evaluate these issues (Drewry and Fortune 2010). More recent monitoring indicated all water quality objectives used in the ‘Darwin Harbour Region Report Cards 2010’ were complied with (Drewry et al. 2010).

Proposed urban and industrial developments surrounding the upper Elizabeth River estuary may increase the number of indicators that do not comply with water quality objectives, and the frequency with which they do not comply.

5.4 Comparison with Elizabeth River gauge station data

Comparison of data from the estuary in this report with Elizabeth River gauge station data indicates that TN and TP concentrations in the estuary may be greater than for freshwater.

However, strong conclusions cannot be made explaining the greater concentrations in the estuarine water than at the gauge station. It may be possible that greater concentrations of TN and TP may be transported from other sources than the catchment draining to the gauge station. Resuspension of sediments or ecological differences between marine and freshwater environments may also be factors. Note that the concentrations in the gauge station freshwater composite samples are an average over the collection period (e.g. 2 to 23 day periods), and so concentrations during high flow may therefore be greater than reported here. In contrast, sampling in the estuary waters were point samples.

Greater concentrations of TN and TP may occur from point sources and from diffuse sources from urban land such as the suburbs of Palmerston City draining into Mitchell Creek, or industrial and agricultural land draining to the estuary. Urban, developed and agricultural land uses produce greater N, P and sediment generation rates and loads than less intensive land uses in the Darwin Harbour region (Skinner et al. 2009) and in other regions (e.g. Drewry et al. 2006). Further proposed urban and industrial developments surrounding the upper Elizabeth River estuary are likely to increased total pollutant loads in the future.

5.5 Lessons and recommendations for further research

The study increased our understanding of several water quality processes associated with wet season freshwater inflows. Development of future studies should also consider consistent sampling regimes, turbidity at depth to enable further analyses to be undertaken, and data-logged measurements. Data-logged measurements of selected indicators such as salinity would be useful in conjunction with grab samples of nutrients and other indicators to improve understanding and in relation to tidal flows, and also for potential modelling purposes. Further sites would also be
worthwhile in future to better characterise water quality. Given the proposed
development in the catchment and surrounding the estuary, further investment and
monitoring to help understand the natural processes of the estuary would also be
worthwhile.
6 CONCEPTUAL UNDERSTANDING

6.1 Introduction

Scientifically-based conceptual diagrams are used to identify and depict major processes, threats or impacts in catchments and associated waterways. They provide an effective way of communicating conceptual understanding and often complex scientific findings and their implications. The diagrams are a valuable tool for scientists to discuss and agree on the key messages to be communicated to the wider community.

6.2 Elizabeth River processes

Several conceptual diagrams developed for the Elizabeth River estuary region are presented in this section. The conceptual diagrams focus on pollutant inputs, pathways and key estuarine processes, such as salinity levels.

The conceptual diagrams of Elizabeth River estuary pollution sources, processes and ecology are presented in Figure 44. The diagram shows pollutant sources and transport pathways in both the wet and dry seasons. Sediment and nutrient sources to waterways (shown by arrows) include natural bushland, agriculture, and urban areas. The upper parts of the harbour estuary have deposition and resuspension of sediment, and can be poorly flushed by tidal flow.

Seasonal variation is distinct in the estuary particularly in the case of inflows. During the dry season this is negligible and the salinity is quite uniform in the water column and the estuary well mixed. This is in contrast to wet season conditions where the salinity gradient is met in the upper parts of the estuary by a buoyant plume of freshwater which can persist for some time depending on flows from rivers and tributaries in the catchment, and tidal flows.
**Figure 44** Elizabeth River estuary pollution sources, processes and ecology in the wet and dry seasons.
Information from this report and other studies can be summarised into the conceptual diagrams as follows:

Tidal flow and water quality
- Many nutrients for plant and algae growth arise from resuspension of sediment and detritus from large tidal flow;
- Although the water in the harbour can appear cloudy from tidal mixing, the water quality is generally high; and
- Wet season freshwater inflows result in a plume of freshwater from the catchment over water of greater salinity.

Salinity
- The diagram show that water quality in the Elizabeth River estuary differs between the wet and dry seasons. During the dry season the salinity is quite uniform and the estuary well mixed. This contrasts with wet season conditions where the salinity is met in the upper estuary by a buoyant plume of freshwater (from the catchment); and
- A strong longitudinal and vertical salinity gradient can persist during and after rainfall events in the upper reaches of the estuary and the tidal creeks, until freshwater flow ceases and there is sufficient tidal mixing.

Nutrient inflows
- Sources such as runoff and drainage entering the Elizabeth River estuary from the urban and rural area increases available nutrients such as nitrate which can result in increased algal growth; and
- Larger freshwater inflow events were associated with greater ranges and levels of dissolved nitrogen and other dissolved and particulate nutrient forms.

Turbidity, dissolved oxygen and phytoplankton
- Turbidity is at its highest in the wet season. Rainfall events result in the first flush of more turbid freshwater into the estuary influencing water clarity, light attenuation, productivity and oxygen demand. During these periods it is not unusual for dissolved oxygen to decrease dramatically; and
- After the wet season flows become negligible. This results in reduced sediment loads and turbidity and good light attenuation through the water column. The resulting phytoplankton community is typically more diverse in species.

The cross section diagram (Figure 45) was also developed from this study. The diagram focuses on the effect of freshwater flows from the catchment on receiving waters of the estuary. The cross section illustrates the following processes:
- freshwater inflows from the catchment;
- marine water inflows associated with tidal influx;
- effect of freshwater inflows on salinity gradient;
- light availability with increased sediment load from the catchment;
- limitations to vertical mixing by a buoyant plume of freshwater; and
- oxygen availability through the water column.
Figure 45 Elizabeth River estuary processes in the wet and dry seasons – cross section view.
7 CONCLUSIONS

All sites had low variation in physical measurements such as salinity, turbidity and conductivity, and nutrient measurements prior to wet season freshwater inflows. NO\textsubscript{x} generally had the greatest variation at all sites in the March 2007 samplings. In contrast, TN and turbidity, for example, were likely to have also been associated with surface runoff transport during the much greater February 2007 freshwater inflow events.

In general, the surface one metre of depth had the greatest variation in nutrient measurement values versus deeper depths. Statistical analyses indicated significant differences between the surface depth and the middle or bottom depths sampled for TN, NO\textsubscript{x}, total phosphorus (TP), salinity and conductivity.

A comparison of data from the estuary with freshwater from the Elizabeth River gauge station data indicates that TN and TP concentrations in the estuary may be greater than in freshwater inflows, but strong conclusions cannot be made. Other pollutant sources surrounding the estuary, resuspension of marine sediments, tidal mixing and movement may be influencing factors. Further research may be warranted to understand these processes more.

Upper estuary water quality objective values were complied with for median values of pH, NO\textsubscript{x}, ammonia, TP and filterable reactive phosphorus (FRP). Median chlorophyll-a and TN values over all samplings did not comply with upper estuary water quality objectives. This study shows that median values of TN were much less prior to the wet season than during the wet season. TN however, did not comply with water quality objectives prior to the wet season. TN is mostly organic N. Inflow of NO\textsubscript{x} is unlikely to contribute to non compliance of the TN upper estuary water quality objective.

The phytoplankton taxa of all sites was dominated by two taxa, the diatom Odontella and dinoflagellate 103. A large proportion of the cell density occurred in the mid profile of the water column at some sites. Samples collected after the peak of the wet season as flows reduced had greater number of taxa recorded.
8 REFERENCES


9 FURTHER READING

For further reading, various reports on water quality, biological health and indicators in the Darwin Harbour region from the Aquatic Heath Unit can be found at:

For further information on water quality, the National Water Quality Management Strategy, and ANZECC guidelines and related publications:
10 ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym and abbreviation</th>
<th>Definition</th>
</tr>
</thead>
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<tr>
<td>DO</td>
<td>Dissolved oxygen</td>
</tr>
<tr>
<td>FRP</td>
<td>Filterable reactive phosphorus</td>
</tr>
<tr>
<td>NWQMS</td>
<td>National Water Quality Management Strategy</td>
</tr>
<tr>
<td>TN</td>
<td>Total nitrogen</td>
</tr>
<tr>
<td>TP</td>
<td>Total phosphorus</td>
</tr>
<tr>
<td>WQO</td>
<td>Water quality objective</td>
</tr>
<tr>
<td>WQPP</td>
<td>Water Quality Protection Plan</td>
</tr>
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</table>
# Glossary

Key water quality indicators were described in an earlier section.

<table>
<thead>
<tr>
<th>Terms</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient water quality</td>
<td>Background water quality levels in waterways. In freshwater streams this commonly refers to low flow (non event) conditions.</td>
</tr>
<tr>
<td>Beneficial Use</td>
<td>The <em>Water Act</em> defines uses to protect waterways as Beneficial Uses and a given waterbody may have none, one, a number, or all of the following Beneficial Uses: agriculture, aquaculture, public water supply, environment, cultural, industry, and rural stock and domestic.</td>
</tr>
<tr>
<td>Diffuse source</td>
<td>Refers to transport (such as run-off) from non-point sources such as urban paved or non-paved areas, hillslopes, agricultural land and forest.</td>
</tr>
<tr>
<td>Euphotic depth</td>
<td>Euphotic depth is a measure of how deep light penetrates through the water. Euphotic depth extends from the atmosphere-water interface downwards at a depth where light intensity falls to 1% of that measured at the surface.</td>
</tr>
<tr>
<td>Flushing</td>
<td>The capacity of tidal movement to dilute a body of water.</td>
</tr>
<tr>
<td>Pheophytin</td>
<td>A pigment produced by digestion or degradation of chlorophyll-a. The ratio of pheophytin to chlorophyll a can provide an indication of the decline or growth in microphytobenthos populations.</td>
</tr>
<tr>
<td>Phytoplankton</td>
<td>Microscopic aquatic plants.</td>
</tr>
<tr>
<td>Point source</td>
<td>Discharge from a single point, such as an outlet pipe. Can refer to runoff or wastewater discharges.</td>
</tr>
<tr>
<td>Sewage treatment plant</td>
<td>A facility that processes wastewater and partially removes materials that damage water quality.</td>
</tr>
<tr>
<td>Water quality objective</td>
<td>Water quality objectives act as local waterbody guideline levels and/or reference levels to help guide planning and water management. Water quality objectives describe the water quality needed to protect Beneficial Uses identified by the community.</td>
</tr>
</tbody>
</table>
# Appendix

**Table 27** Median values for NO$_x$-N, TN, ammonia-N, TP and FRP (mg/L) for each site and sampling.

<table>
<thead>
<tr>
<th>Sampling number</th>
<th>Location</th>
<th>NO$_x$-N (mg/L)</th>
<th>TN (mg/L)</th>
<th>Ammonia-N (mg/L)</th>
<th>TP (mg/L)</th>
<th>FRP (mg/L)</th>
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<td>1a (13 Dec 06)</td>
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<td>0.005</td>
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<td>0.020</td>
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<tr>
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<td>0.001</td>
</tr>
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<td>0.020</td>
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</tr>
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<td>0.004</td>
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<td>1.36</td>
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<td>0.018</td>
<td>0.005</td>
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<tr>
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<td>1.68</td>
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<td>0.025</td>
<td>0.005</td>
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<tr>
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Table 28 Summary statistics for ammonia, NOx and TN for each site and depth.

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<tr>
<th>Location</th>
<th>Depth (m)</th>
<th>Mean</th>
<th>N</th>
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**NO\textsubscript{x}-N (mg/L)**

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<th>N</th>
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**TN (mg/L)**

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(s surface; m middle; b bottom of water column)
Table 29 Summary statistics for euphotic depth for each sampling.

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