Identification and development of a water quality improvement and monitoring program for the major catchments supplying Port Curtis

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# Table of contents

1. Introduction.................................................................................................................. 3  
   1.1 Gladstone Ports Biodiversity Offset Strategy ......................................................... 3  
   1.2 Context ....................................................................................................................... 3  
   1.3 Project approach and stakeholder consultation ....................................................... 4  
2. Study area .................................................................................................................... 6  
   2.1 Location ...................................................................................................................... 6  
   2.2 Landuse and population .......................................................................................... 6  
   2.3 Climate and weather ............................................................................................... 7  
   2.4 Hydrology ................................................................................................................ 8  
       2.4.1 Calliope River .................................................................................................. 9  
       2.4.2 Boyne River .................................................................................................... 9  
   2.5 Receiving waters ..................................................................................................... 10  
3. Current condition and values .................................................................................... 11  
   3.1 Calliope .................................................................................................................... 11  
       3.1.1 Water quality ................................................................................................... 11  
       3.1.2 Catchment condition and values ................................................................... 19  
   3.2 Boyne ....................................................................................................................... 22  
       3.2.1 Water quality ................................................................................................... 22  
       3.2.2 Catchment condition and values ................................................................... 29  
4. Water quality threats and issues ............................................................................... 31  
   4.1 Calliope .................................................................................................................... 31  
       4.1.1 Sediment and nutrients .................................................................................... 31  
       4.1.2 Contaminants .................................................................................................. 32  
   4.2 Boyne ....................................................................................................................... 32  
       4.2.1 Sediment and nutrients .................................................................................... 32  
       4.2.2 Pollutants ......................................................................................................... 33  
5. Improving water quality ............................................................................................ 34  
   5.1 Existing initiatives .................................................................................................... 34  
   5.2 Objectives and targets ............................................................................................ 35  
   5.3 Recommendations for improving water quality .................................................... 36  
   5.4 Monitoring ............................................................................................................... 37  
References ....................................................................................................................... 40
1. Introduction

1.1 Gladstone Ports Corporation’s Biodiversity Offset Strategy

Gladstone Ports Corporation recently completed a substantial part of the Western Basin Dredging and Disposal Project (WBDDP). The project was essential for the economic development of the region and to support emerging industries such as the natural gas liquefaction plants on Curtis Island. The WBDDP involved the deepening and widening of existing channels and swing basins as well as the creation of new channels, basins and berths. The dredged material was deposited offshore at the East Banks Sea Disposal Site and into the combined Fisherman’s Landing Northern Expansion and Western Basin Reclamation Areas. Stage 1 of this project was completed in September 2013 after 29 months of dredging.

The project has been approved at State and Federal Government levels under respective formal approval processes and following the preparation of impact assessment documents. As part of the conditions of approval by the federal government Department of Sustainability Environment, Water, Population and Communities (DSEWPaC) (now the Department of Environment (DoE)), a Biodiversity Offset Strategy (BOS) was prepared (Gladstone Ports Corporation 2012). Section 5.14 of the approved BOS outlines the requirements for a number of projects, including a project titled “Upper to lower catchment water quality monitoring and improvement of water quality in the Boyne or Calliope Rivers”.

The aim of this project is to, through a review of existing information and consultation with stakeholders, identify the most appropriate approach to both improving water quality and engaging local stakeholders.

1.2 Context

Development in the catchments that discharge to the Great Barrier Reef World Heritage Area has resulted in elevated levels of sediments and pollutants being transported into the reef. In recognition of the need to improve water quality in the catchments and reef, the Reef Water Quality Protection Plan (Reef Plan), a joint initiative of State and Federal governments was first endorsed in 2003. Subsequent progress and revision have led to the most recent Reef Plan being released in 2013 (State of Queensland 2013).

Reef Plan has a long term goal to ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental impact on the health and resilience of the Great Barrier Reef. Three water quality targets have been set to achieve this long term goal. By 2018:

- At least a 50 percent reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads in priority areas.
- At least a 20 percent reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients in priority areas.
- At least a 60 percent reduction in end-of-catchment pesticide loads in priority areas.

Actions within the Reef Plan are focussed primarily on diffuse pollution sources from broadscale land use, with recognition that point sources such as industrial discharges, urban stormwater and sewage are managed through existing regulatory and policy instruments (State of Queensland 2013). Some of the components of Reef Plan are:

- **Research and development** – coordination and alignment of major research and development programs to target user needs;
- **Reef Protection Program** – extension, research and regulations to ensure unsustainable land management practices are eliminated;
- **Reef Rescue** – planning, extension, financial incentives and research for land managers to encourage improved land management practices; and
- **Paddock to Reef program** – measures progress towards Reef Plan goals and targets.
One of the priority actions in Reef Plan 2013 is the water quality improvement planning process, whereby water quality improvement plans are to be developed for catchments that discharge into the Great Barrier Reef. Reef Plan identifies regional NRM agencies as the lead organisations for this task, and to this end the Fitzroy Basin Association (FBA) is in the process of planning for a Water Quality Improvement Plan for the Fitzroy Catchment (Tom Coughlin, FBA, personal communication). Although the Calliope and Boyne Catchments are separate from the Fitzroy catchment, they are within the FBA management area and it is expected that the outcomes of this preliminary water quality management and monitoring project for the Calliope and Boyne catchments could inform the broader Fitzroy Water Quality Improvement Plan.

1.3 Project approach and stakeholder consultation
The following steps were involved in the development of this report:

1. Review of existing information
Information in the scientific and grey literature relevant to water quality, catchment condition and monitoring in the Calliope and Boyne catchments was collated and reviewed. A summary of existing water quality, with comparisons with the recently released draft water quality guidelines for the Capricorn Coast is provided. Known threats and risks were identified and an assessment of current monitoring programs was undertaken. Key knowledge gaps were identified.

2. Stakeholder engagement – gathering information
Key stakeholders from the following organisations were identified and contacted:
• Boyne Island Environmental Education Centre
• Central Queensland University
• Department of Environment and Heritage Protection
• Department of Natural Resources and Mines
• Department of Science, Information Technology, Innovation and the Arts
• Fitzroy Basin Association
• Fitzroy Partnership for River Health
• Fitzroy River and Coastal Catchments
• Gladstone Area Water Board
• Gladstone Healthy Harbour Partnership
• Gladstone Industry Leadership Group
• Gladstone Local Marine Advisory Committee
• Gladstone Regional Environmental Advisory Network
• Gladstone Regional Council
• Great Barrier Reef Marine Park Authority
• Infofish
• Port Curtis Coral Coast Aboriginal Corporation
• Port Curtis integrated Monitoring Program

A series of face-to-face meetings were held in March 2014, with the following key questions:
• Do you know of any addition information related to water quality in the Calliope and / or Boyne catchments?
• What are the important values in relation to water quality in each of the catchments?
• What are the major threats to water quality in these catchments?
• Are their any known point sources of pollution?
• What needs to be done to improve water quality in each catchment?
• What sort of water quality monitoring is important / required?

3. Stakeholder engagement – testing the outcomes
Information gathered from the desktop review and initial stakeholder meetings was used to develop a draft report documenting existing condition and values, the key threats to water quality in the Calliope and Boyne Catchments and recommended management and monitoring actions. This was circulated to stakeholder individual and groups to:
• Test the level of understanding and acceptance (of the analysis and recommendations)
• Seek suggested improvements
• Test the alignment with respective organisations and their plans / strategies / aspirations
• Test the level of support of the monitoring and improvement plan
• Test stakeholder willingness to contribute / align their activities to support or become involved in implementation
• Identify what they need into the future to understand / support / contribute to the implementation of these plans

4. Finalising the report
The report was finalised following review and comments received form stakeholders and GPC.
2. Study area

2.1 Location
The Calliope and Boyne catchments are located just south of the Tropic of Capricorn in Queensland, discharging to the Port Curtis Area and the Great Barrier Reef Marine Park. They are small coastal catchments, comprising approximately 2200 km$^2$ (Calliope) and 2500 km$^2$ (Boyne). Although they lie south of the Fitzroy Basin, they are included in the Fitzroy natural resource management region. This water quality improvement and monitoring program covers the Calliope catchment in its entirety and the Boyne Catchment downstream of Awoonga Dam (Figure 1).

![Figure 1: Location of the Calliope and Boyne River Catchments.](image)

2.2 Landuse and population
The Gladstone region (an area slightly bigger than the combined Calliope and Boyne catchments) has a population of approximately 63,000 people (Australian Bureau of Statistics 2011). Over 85 percent of the population live in urban centres, and Gladstone city has a population of over 35,000. From 2006 to 2011, the population in the region increased by nearly 17 percent (Australian Bureau of Statistics 2011).

It is estimated that over 80 percent of the land in the Calliope catchment has been cleared of native vegetation, and 75 percent of the Boyne Catchment (Australian Bureau of Statistics 2010). Land use is dominated by grazing of beef cattle, which comprises approximately two thirds of the land area in each catchment (Figure 2) with very small amounts of horticulture.

Rates of adoption of riparian management practices for beef graziers is estimated at about 25 percent for the Calliope catchment, with 12 percent of graziers fully fencing riparian zones.
from livestock. Approximately 20 percent of grazing properties maintained 40 percent or more ground cover in riparian zones. In the Boyne, only 10% of grazing properties fenced riparian zones. However, 40 percent of properties maintained greater than 40 percent ground cover in riparian zones (Australian Bureau of Statistics 2010).

Figure 2: Land use on the Calliope (left) and Boyne (right) catchments (Australian Bureau of Statistics 2010).

There is considerable industry in the coastal zone surrounding the City of Gladstone including an international port facility within Port Curtis and a prominent heavy industrial strip that has been in operation for many years. Examples include (Apte et al. 2005):

- The world’s largest alumina refinery has been operating near South Trees Inlet since 1964;
- Australia’s largest aluminium smelter has operated at Boyne Island since 1982;
- Queensland’s largest coal-fired power station is located on the Calliope River and commenced operation in 1976;
- Petroleum terminals are located at Auckland Point;
- Australia’s largest cement kiln is at Fisherman’s Landing and commenced operation in 1982; and
- Sodium cyanide manufacture at Targinnie.

2.3 Climate and weather
The climate is tropical, with temperatures remaining warm year round. Average annual maximum temperature is approximately 28 °C and average annual minimum temperature approximately 18.5 °C (Bureau of Meteorology 2012). Average annual relative humidity at 9 am is 68 percent. The climate is dominated by a wet-dry season with most rain falling
between October and March. Despite the high relative humidity, average monthly evaporation exceeds average monthly rainfall year round (Figure 3).

![Figure 3: Average monthly rainfall and evaporation (millimetres) at Gladstone airport from 1959 to 2012 (data from Bureau of Meteorology 2012).](image)

Annual rainfall averages around 880 mm per year. However, there is a high degree of inter-annual variability, with rainfall over the period 1959 to 2012 ranging from less than 450 mm to over 1700 mm (Figure 4).

![Figure 4: Average annual rainfall (millimetres) at Gladstone airport from 1959 to 2012 (data from Bureau of Meteorology 2012).](image)

2.4 Hydrology

The episodic nature of rainfall in the region is reflected in river flow in both the Calliope and Boyne Rivers. However, hydrology in the two systems is markedly different.
2.4.1 Calliope River

The Calliope River catchment comprises the main stem of the Calliope River and a number of named creeks as tributaries including Paddock Creek, Larcom Creek and Oaky Creek. There are also a number of intermittent smaller creeks that discharge directly to the ocean north of the Calliope River including Munduram, Mosquito and Sandy Creek. There is no hydrological data available for any of the tributaries or smaller watercourses in the catchment, although many flow only after significant rainfall, drying to a series of in channel pools in the dry season (frc environmental 2012).

A long term record exists for flow in the Calliope River from the gauging station at Castlehope in the mid-catchment approximately 25 kilometres upstream of the mouth. Mean daily discharge at this station suggests that periods of no flow are rare, but that low flow occurs often, with flow of < 10 ML/day approximately one third of the time. Conversely, there are large floods at irregular intervals with large volumes of water discharging to Port Curtis and the Great Barrier Reef Marine Park (Figure 5).

Figure 5: Mean daily flow in the Calliope River at Castlehope (data from Department of Natural Resources and Mines 2013).

2.4.2 Boyne River

This report encompasses only the portion of the Boyne River system that lies below Awoonga Dam. The dam on the Boyne River was commissioned in 1985 as a 255,000 megalitre capacity storage for water supply and industry in the city of Gladstone. In 2002, the height of the wall was increased and the storage capacity trebled to 770,000 megalitres.

The construction of Awoonga Dam has had a significant impact on the downstream flow regime, which is now episodic in nature, with long periods of dry conditions and infrequent large flows following extreme rainfall (Figure 6).

Downstream of Awoonga Dam, the Boyne bifurcates into two distributary channels, forming “Boyne Island” between the two channels. The southerly channel retains the name Boyne River, while the northerly channel discharges through South Trees Inlet.
Figure 6: Mean daily flow in the Boyne River at Awoonga dam outflow (data from Department of Natural Resources and Mines 2013). Note that this gauging station was closed in June 2012.

2.5 Receiving waters

The Boyne and Calliope Rivers discharge into the ocean within Port Curtis and the adjacent Great Barrier Reef Marine Park. Port Curtis is a relatively shallow embayment, with water depths naturally, less than five metres, deepened in places for shipping channels to depths of 15 metres.

Tides are dominant semi-diurnal, that is, there are two high and two low tides per day with one of the high tides being larger than the other. The tides undergo a two-weekly cycle of spring tides and neap tides, with a four metre average during spring tides, reducing to just one metre for neap tides (Herzfeld et al. 2004).

The hydrodynamic model developed for Port Curtis indicates that it is well mixed, due to the relatively large tidal regime. However, flushing of material out of the waterway is not straightforward, with movement of water (and suspended material) occurring in a back and forth nature. That is, material is carried out of Port Curtis on one tidal cycle only to be moved back into the area on the returning tide. As a consequence, the time required to reduce the mass of suspended material in the water column by one third is in the order of 19 days (Herzfeld et al. 2004).

The coastal zone influenced by the discharge of the Boyne and Calliope Rivers contains a mosaic of marine and coastal wetlands that include mangrove, seagrass, saltmarsh, rocky and sandy shore, open water and sub-tidal benthic habitats. The site is largely adjacent to the Great Barrier Reef Marine Park, the Port Curtis area west of Facing Island is within the Marine Park and areas of the coast are within the Great Barrier Reef Coastal Park. While most of the marine park within direct influence of the two river systems is designated as a general use zone; the Narrows (area between the shore and Curtis Island) is designated as a habitat protection zone to protect the 27,500 hectares of mangrove, saltmarsh and mudflats that occur in this area. In addition discharge from the river systems could also influence the Rodd’s Bay Dugong Protection Area.

The variety of habitats supports a diversity of flora and fauna. The seagrass beds are important for grazing dugongs and marine turtles; the mangroves provide fish and invertebrate nursery habitat, while the extensive saltmarsh and mudflat habitat support internationally migratory shorebirds. The diversity of fish is high compared to other coastal environments in Queensland. The shorelines of Facing and Curtis Islands, as well as the mainland, contain nesting sites for marine turtles and cetaceans are observed within the coastal zone (Apte et al. 2005).
3. Current condition and values

3.1 Calliope

3.1.1 Water quality

Information on water quality from the Calliope River and associated tributaries is limited. Electrical conductivity is measured at the gauging station on the Calliope River at Castlehope, but only regularly in the past few years. Comparisons with the Draft Capricorn Coast Water Quality Guidelines (DSITIA 2014) indicate that annual median salinity (as indicated by conductivity) is consistently above the guideline value of 950 µS/cm and appears to have been slowly increasing over time (Table 1). Although river salinity and rainfall are often linked, the steady increase in median salinity does not appear to correspond to changing patterns in rainfall and flow.

Table 1: Median electrical conductivity in the Calliope River at Castlehope (data from Department of Natural Resources and Mines 2013) and annual rainfall at Calliope Station (data from Bureau of Meteorology 2013). Values above water quality guidelines shown shaded.

<table>
<thead>
<tr>
<th>Year</th>
<th>Median electrical conductivity (µS/cm)</th>
<th>Number of records</th>
<th>Annual rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1049</td>
<td>295</td>
<td>783</td>
</tr>
<tr>
<td>2001</td>
<td>965</td>
<td>219</td>
<td>491</td>
</tr>
<tr>
<td>2002-2008</td>
<td>Insufficient data to calculate median</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>1012</td>
<td>194</td>
<td>658</td>
</tr>
<tr>
<td>2010</td>
<td>1090</td>
<td>335</td>
<td>1701</td>
</tr>
<tr>
<td>2011</td>
<td>1280</td>
<td>345</td>
<td>939</td>
</tr>
<tr>
<td>2012</td>
<td>1293</td>
<td>346</td>
<td>839</td>
</tr>
<tr>
<td>2013</td>
<td>1284</td>
<td>343</td>
<td>1544</td>
</tr>
</tbody>
</table>

There is no information available about other water quality parameters in the freshwater reaches of the Calliope River and DSITIA (2014) found that there was insufficient data from upland freshwaters in the Calliope catchment to derive local water quality guidelines.

The Department of Environment and Heritage Protection (DEHP) has been conducting monthly water quality monitoring in a number of estuaries along the east coast since 1993 (DERM 2012). This includes sites in the Calliope estuary, with measures of salinity, temperature, pH, dissolved oxygen, turbidity, secchi depth, organic nitrogen, ammonium, nitrate plus nitrite, total nitrogen, total phosphorus, filterable reactive phosphorus and chlorophyll a. Not all parameters were collected at all sites in all months. A summary of this information as supplied by the Department of Science, Information Technology, Innovation and the Arts (DSITIA) for the period June 1993 to November 2012 is provided below for two sites:

- Calliope River 12.9 km from mouth (upstream of the urban and industrial areas of Gladstone); and
- Calliope River at the mouth (downstream of the urban and industrial areas of Gladstone).

Data are graphed to show patterns in water quality and potential changes over time and the relevant water quality guidelines (DSITIA 2014) are provided for illustrative purposes only. Consistent with Queensland and Australian Guidelines for water quality (ANZECC and ARMCANZ 2000, DERM 2009) exceedence of water quality guidelines should trigger further investigation and management actions.

**Dissolved oxygen, pH, water clarity**

Dissolved oxygen is influenced by temperature, salinity and biological activity and can vary considerably over short periods of time. In most aquatic systems dissolved oxygen follows a daily cycle. Aquatic plants, including algae (phytoplankton) are net producers of oxygen during the day (as a by-product of photosynthesis) and consumers of oxygen during darkness.
(when respiratory consumption exceeds photosynthetic production). Thus factors that affect photosynthesis can influence dissolved oxygen concentrations. In addition to the daily cycle of dissolved oxygen concentration there is a longer term pattern that is balanced by diffusion of oxygen from the atmosphere and consumption of oxygen by biota. The former is influenced by factors such as wind, which can increase turbulence and facilitate movement of oxygen into the water column, and temperature which affects the total amount of oxygen water can hold.

Dissolved oxygen concentrations in the upper estuary (Figure 7) are often outside guideline values, both by being greater than 100% saturation and below 80% saturation. Actual concentrations of dissolved oxygen never fell below 5 mg/L and so were not at levels likely to cause direct effects to aquatic biota. Concentrations of dissolved oxygen in the lower estuary (Figure 8) Calliope Estuary are mostly within water quality guideline values, with little indication of significant changes or shifts over time.

**Figure 7:** Dissolved oxygen concentrations (percent saturation) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red lines indicate the relevant water quality guidelines, i.e. dissolved oxygen concentrations should remain between 85 and 100 percent saturation.

**Figure 8:** Median (50th percentile) dissolved oxygen concentrations (percent saturation) in the Calliope River at the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guideline, i.e. median dissolved oxygen concentrations should be below 97 percent saturation.
Acid sulphate soils in the catchment and along the coastal zone have been identified as a potential risk to water quality and ecology of the region (Vincente-Beckett et al. 2006). Although marine and estuarine waters have a large buffering capacity for changes in pH, due to high carbonate concentrations, low pH can affect release of nutrients and contaminants from sediments and particularly during periods when there are large amounts of freshwater entering the system.

Measures of pH in the upper (Figure 9) and lower (Figure 10) Calliope Estuary are mostly within water quality guideline values. There is some indication that pH may be decreasing over time, but not to levels that would be considered harmful to aquatic biota.

Figure 9: pH in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red lines indicate the relevant water quality guidelines, i.e. pH should remain between 7.0 and 8.2.

Figure 10: Median (50th percentile) pH in the Calliope River at the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guideline, i.e. median pH should be between 7.9 and 8.0.
Water clarity is important for maintaining productivity in aquatic systems, through adequate light availability for photosynthesis, and is also important for public amenity and aesthetic purposes. In addition, the amount of suspended particulate matter in the water column (as indicated by total suspended solid concentrations) can negatively influence the health of aquatic fauna by physical action on gills (Jenkins and McKinnon 2006), and also negatively affect filter-feeding organisms.

Turbidity in both the upper (Figure 11) and lower (Figure 12 and Figure 13) Calliope Estuary is highly dependent on river flows, with peaks in turbidity (and low water clarity) during large flow events as sediment is washed from the catchment through the estuary into Port Curtis. In recognition of this, there are lower water quality guideline values for turbidity in the lower estuary for the dry season (May to October) than in the wet season (November to April). Turbidity is often above water quality guidelines in both the dry and wet seasons, particularly in the lower estuary.

![Figure 11: Turbidity (NTU) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 24 NTU).](image)

![Figure 12: Median (50th percentile) turbidity in the Calliope River at the mouth during the dry season (data supplied by DSITIA). Red line indicates the relevant water quality guideline (8 NTU).](image)
Figure 13: Median (50th percentile) turbidity in the Calliope River at the mouth during the wet season (data supplied by DSITIA). Red line indicates the relevant water quality guideline (13 NTU).

**Nutrients and chlorophyll-a**

Nutrients in aquatic ecosystems are significant for the role they play in primary production. Deciphering patterns and trends in nutrients in aquatic systems is difficult as they cycle through various forms within the water column, sediments and biota. Aquatic plants and phytoplankton take up nutrients in dissolved inorganic forms (e.g. oxidised nitrogen, ammonium, filterable reactive phosphate) and dissolved organic forms (e.g. urea). Measures of total nitrogen and total phosphorus include dissolved organic forms and inorganic particulate forms, as well as nutrients within the cells of phytoplankton and zooplankton. To try and understand the complete picture, nutrients are assessed not only through the direct measures of concentrations in the water column, but also through their effect on primary production, by examining chlorophyll-a concentrations.

Data for nutrient concentrations are only available for the upstream site in the Calliope River. Concentrations of total nitrogen (Figure 14) and total phosphorus (Figure 17) are higher during periods of high river flow as nutrients attached to sediment and soils are washed from the catchments through the rivers and into the estuary. Although there does not appear to be any significant shift in total or dissolved nutrient concentrations over time (i.e. concentrations have followed the same pattern and remained similar over the past two decades), they are often above the water quality guideline values. This is particularly the case for the dissolved, bioavailable nutrients ammonium (Figure 15), oxidised nitrogen (Figure 16) and filterable reactive phosphorus (Figure 18) which are above guideline values during both periods of high and low flow. The proportion of phosphorus that is in bioavailable form is particularly high ranging to nearly 100 percent on occasions.
Figure 14: Total nitrogen (µg/L) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 280 µg/L).

Figure 15: Ammonium (µg/L) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 18 µg/L).
Figure 16: Oxidised nitrogen (µg/L) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 29 µg/L).

Figure 17: Total phosphorus (µg/L) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 40 µg/L).
Figure 18: Filterable reactive phosphorous (µg/L) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 11 µg/L).

Chlorophyll-a concentrations are indicative of the amount of phytoplankton within the water column. There appears to be little trend over time in either the upper (Figure 19) or lower estuary (Figure 20). In the upper estuary, this is by and large below water quality guidelines. This is somewhat surprising given the amount of bioavailable nutrients in the water column that could be taken up by the cells. While nutrient and phytoplankton dynamics are notoriously difficult to interpret, it may be that the high turbidity in the system limits primary production, with algae being light limited rather than nutrient limited for most of the time.

Chlorophyll-a concentrations in the lower estuary are more often above guideline values. However, this is more a reflection of the lower guideline values for the lower estuary, and phytoplankton biomass is less in the lower estuary than upstream.

Figure 19: Chlorophyll-a (µg/L) in the Calliope River 12.9 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 5 µg/L).
Contaminants
Data for contaminants in the study areas is restricted by and large to heavy metals and for the period October 2011 to January 2013. Total metal concentrations are of limited use as they are generally considered poor indicators of metal toxicity and in terms of the Calliope and Boyne Rivers are mostly a reflection of total suspended sediments and river inflows (Angel et al. 2012). Therefore only dissolved (potentially bio-available) metal concentrations have been considered.

Dissolved metal concretions in the Calliope Estuary are generally less than water quality guideline values (and often below the level that can be reported by laboratories). The exception to this are a small number of exceedences of guideline values for aluminium, and copper (Table 2). All were isolated incidents, lasting only a single sampling occurrence and unlikely to have caused significant biological impacts.

Table 2: Exceedences of ANZECC and ARMCANZ trigger values for dissolved metals in the Calliope Estuary (October 2011 to January 2013). Site codes are shown together with concentrations in µg/L. *Indicates low reliability trigger value.

<table>
<thead>
<tr>
<th>Location</th>
<th>Al</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calliope River 1.6 km upstream of mouth</strong></td>
<td>January 2012 (16) March 2012 (18)</td>
<td>October 2011 (2)</td>
</tr>
<tr>
<td><strong>Calliope River 6.4 km upstream of mouth</strong></td>
<td>March 2012 (2)</td>
<td></td>
</tr>
</tbody>
</table>

3.1.2 Catchment condition and values
Values associated with water and water quality in the Calliope Catchment have been identified by the Fitzroy Basin Association (Flemming and Coughlin 2014) and are summarised in Table 3. In addition, stakeholder consultation indicated that the Calliope catchment is highly valued by the local community, with a strong perception that it was by and large in natural condition. Nominated values of the system included:

- Highly natural system with no significant barriers or dams (unregulated river)
- Important for fish passage
- Valued for barramundi fishing
- Recreational / aesthetic values
- Important in terms of looking after the harbours by looking after the catchments.
An assessment of the values and condition of the Calliope catchment was undertaken as part of the water resource planning process in 2005 (C&R Consulting 2005). This study indicated that the catchment is of high ecological value as an unregulated river system. Despite extensive clearing and a floodplain considered to be in generally poor condition, a narrow, but nearly continuous riparian corridor remains. This is dominated by blue gum (*Eucalyptus tereticornis*) forests and woodlands. Riparian zones are important features in the landscape, not only for their role in providing habitat and wildlife corridors, but also for their effect on river health. There is a general consensus in the literature of the mechanisms by which riparian zones can contribute to river health and water quality. Price and Tubman (2007) summarise these as follows:

- Shading (reducing light for phytoplankton and aiding in the prevention of algal blooms, and moderating temperature fluctuations);
- Providing a food source for native fauna (e.g. detritivores feeding on leaf litter; important source of organic carbon);
- Increasing bank stability (prevention of erosion, slumping);
- Provision of habitat (in the form of woody debris, or structural habitat for juvenile fish and macroinvertebrates when inundated); and
- Filtering of nutrient and sediments (acting as a buffer for inputs carried in overland flow, helping to improve instream water quality).

There are also records of extensive areas of in-channel freshwater macrophytes, of high diversity, with a total of 43 native aquatic species recorded within the catchment (C&R Consulting 2005). Evidence from a small number of aquatic surveys in the 1990s indicated a diverse macroinvertebrate assemblage, possibly related to the intact riparian vegetation and high diversity of in-stream habitats. Similarly, a healthy and viable native fish population has been recorded in the Calliope River, including a number of species such as the longfinned eel (*Anguilla reinhardtii*) that migrate between fresh and marine waters for breeding. Of note, is the lack of exotic fish species recorded in the Calliope catchment (Veitch et al. 2005).

There is a lack of recent information on the values and condition of the freshwater aquatic ecosystems of the Calliope catchment. Almost all information that could be sourced on the freshwater river habitats flora and fauna were over a decade old.

The estuarine reaches of the Calliope River contain areas of mangrove, saltmarsh and intertidal flats. Walker and Houston (1996) describe four main mangrove and saltflat communities within the Calliope Estuary:

<table>
<thead>
<tr>
<th>Aquatic ecosystems</th>
<th>Irrigation</th>
<th>Farm supply</th>
<th>Stock water</th>
<th>Aquaculture</th>
<th>Human consumer</th>
<th>Primary recreation</th>
<th>Secondary recreation</th>
<th>Visual recreation</th>
<th>Drinking water</th>
<th>Industrial use</th>
<th>Cultural values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Calliope River (including tributaries)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mid Calliope River (including tributaries)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Lower Calliope River (including tributaries)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Groundwater</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Estuaries and Bays</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
• Claypans with sparse cover of saltmarsh vegetation dominated by *Tecticornia* sp. and *Sueda australis*;
• Extensive mangrove thickets dominated by *Rhizophora stylosa* with occasional *Avicennia marina*;
• Thin bands of smaller mixed mangrove communities; and
• Salt grass communities dominated by *Sporobolus* sp.

In the late 1970s, there were reports of mangrove, particularly *A. marina*, suffering from dieback, thought to be caused by the fungus *Phytophthora* sp. An estimated 70 percent of the species had died by 1980 (Pegg et al. 1980). In 1994, mangroves in the lower estuary suffered from extensive hail damage causing defoliation and death of many trees (Houston 1999). Recovery has been slow, with monitoring in 2008 indicating that new recruitment of mangroves was occurring, albeit a decade after the damage was sustained (Vision Environment 2011).

A diversity of fauna also occur within the estuarine reaches of the Calliope River, with 89 species of fish and 15 species of squid and crustaceans recorded (C&R Consulting 2005). The estuarine reaches of the river supports both commercially and recreationally important fish species such as barramundi (*Lates calcarifer*), mangrove jack (*Lutjanus argentimaculatus*) and yellowfin bream (*Acanthopagrus australis*) (Sawynok et al. 2013).
3.2 Boyne

3.2.1 Water quality
The study area for this project in the Boyne River is downstream of Awoonga Dam. The tidal limit extends within a kilometre of the dam wall and data on water quality in the freshwater reach between this tidal limit and the dam wall is not publically available. Estuarine water quality data as supplied by DSITIA for the period June 1993 to November 2012 is summarised below for two sites:

- Boyne River 12 km from mouth (upstream of the urban and industrial areas of Gladstone); and
- Boyne River at the mouth (downstream of the urban and industrial areas of Gladstone).

As for the Calliope River in section 3.1.1, data are graphed to show patterns in water quality and potential changes over time and the relevant water quality guidelines (DSITIA 2014) are provided for illustrative purposes only. Statistical comparisons with water quality guidelines are provided in Appendix A.

Dissolved oxygen, pH, water clarity
Dissolved oxygen concentrations in the upper Boyne Estuary appear to show an increasing trend over time (Figure 21). This may be related to primary productivity within the water column from phytoplankton or seagrass. Concentrations are above the water quality guideline approximately 20 percent of the time, and while elevated dissolved oxygen does not in itself represent a risk to marine biota, it does warrant some investigation. Similarly, dissolved oxygen concentrations in the lower Boyne Estuary (Figure 22) are also above water quality guideline values, with some indication of increased levels in more recent years.

Figure 21: Dissolved oxygen concentrations (percent saturation) in the Boyne River 12.0 km upstream of the mouth (data supplied by DSITIA). Red lines indicate the relevant water quality guidelines, i.e. dissolved oxygen concentrations should remain between 80 and 95 percent saturation.
Figure 22: Median (50th percentile) dissolved oxygen concentrations (percent saturation) in the Boyne River at the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guideline, i.e. median dissolved oxygen concentrations should be below 96 percent saturation.

Measures of pH in the upper (Figure 23) and lower (Figure 24) Boyne Estuary are mostly within water quality guideline values with little indication of change over time.

Figure 23: pH in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red lines indicate the relevant water quality guidelines, i.e. pH should remain between 7.0 and 8.4.
Figure 24: Median (50th percentile) pH in the Boyne River at the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guideline, i.e. median pH should be between 7.9 and 8.2.

Turbidity in both the upper (Figure 25) and lower (Figure 26 and Figure 27) Boyne Estuary are mostly within guideline values. The exception is during high flow events (when water overspills Awoonga Dam). For the majority of the time, Awoonga Dam acts as a sediment sink, capturing the sediment from catchment inflows and this is reflected in water clarity downstream.

Figure 25: Turbidity (NTU) in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 9 NTU).
**Figure 26:** Median (50th percentile) turbidity in the Boyne River at the mouth during the dry season (data supplied by DSITIA). Red line indicates the relevant water quality guideline (4 NTU).

**Figure 27:** Median (50th percentile) turbidity in the Boyne River at the mouth during the dry season (data supplied by DSITIA). Red line indicates the relevant water quality guideline (9 NTU).

**Nutrients and chlorophyll-a**

Data for nutrient concentrations is only available for the upstream site on the Boyne River. Concentrations of total nitrogen (Figure 28) and total phosphorus (Figure 31) are higher during periods of high river flow when water flows over the top of the dam spillway carrying sediments and attached nutrients from the catchment. For the remainder of the time, nutrients, like sediments are trapped within the dam. During times of low or no flow, concentrations of nutrients are lower, however, ammonium (Figure 29) and oxidised nitrogen (Figure 30) concentrations are often above guideline values.
Figure 28: Total nitrogen (µg/L) in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 320 µg/L).

Figure 29: Ammonium (µg/L) in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 12 µg/L).
Figure 30: Oxidised nitrogen (µg/L) in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 12 µg/L).

Figure 31: Total phosphorus (µg/L) in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 22 µg/L).
Figure 32: Filterable reactive phosphorous (µg/L) in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 5 µg/L).

Chlorophyll-a concentrations are indicative of the amount of phytoplankton within the water column. There appears to be little trend over time with regular peaks above guideline concentrations (Figure 33). The comparatively clearer water in the Boyne estuary (compared to the Calliope) may result in less light limitation on algal growth.

Awoonga Dam is known for regular spring / summer algal blooms, with blue-green algal counts often exceeding alert levels of 100,000 cells per ml (Gladstone Area Water Board [http://www.gawb.qld.gov.au/blue-green-algae](http://www.gawb.qld.gov.au/blue-green-algae)). It is not known if this extends to areas below the dam, but potentially during summer high flow events, when water overtops the dam spillway, it is possible that algae are discharged downstream (noting that this is not a frequent occurrence). Given the change in salinity, freshwater algae are not expected to survive in estuarine waters, but if in significant numbers, toxins could be released into the water column prior to being diluted by tidal flushing.

Figure 33: Chlorophyll-a (µg/L) in the Boyne River 12 km upstream of the mouth (data supplied by DSITIA). Red line indicates the relevant water quality guidelines (< 4 µg/L).
Contaminants
Data for contaminants in the study areas is restricted to heavy metals and for the period October 2011 to January 2013. Dissolved metal concentrations in the Boyne Estuary are generally less than water quality guideline values. The exception to this was an incident in January 2013, when concentrations of aluminium were up to 1000 times above guideline values. Interestingly, the incident occurred across the entire estuary from the dam wall to the mouth (data from DERM):

- 12 km upstream = 555 µg/L
- 5.1 km upstream = 302 µg/L
- 4.7 km upstream = 437 µg/L
- 2.7 km upstream = 292 µg/L
- At mouth = 334 µg/L

This occurred during a peak flow when very large volumes of water were flowing over the Awoonga Dam wall. An investigation by DSITIA (Holmes et al. 2013) suggested that the aluminium in the Boyne Estuary was of catchment origins. Testing in subsequent months indicated that it was an isolated and non-persistent incident.

3.2.2 Catchment condition and values

Values associated with water and water quality in the Boyne Catchment have been identified by the Fitzroy Basin Association (Flemming and Coughlin 2014) and are summarised in Table 4. In addition, stakeholder consultation indicated that the Boyne River downstream of Awoonga Dam is highly valued, particularly for recreational fishing, with Pikes Crossing nominated by a variety of stakeholders as an important fishing location for barramundi.

Table 4: Values associated with water quality in the Calliope Catchment (summarised from Flemming and Coughlin 2014).

<table>
<thead>
<tr>
<th>Aquatic ecosystems</th>
<th>Irrigation</th>
<th>Farm supply</th>
<th>Stock water</th>
<th>Aquaculture</th>
<th>Human consumer</th>
<th>Primary recreation</th>
<th>Secondary recreation</th>
<th>Visual recreation</th>
<th>Drinking water</th>
<th>Industrial use</th>
<th>Cultural values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Boyne River and tributaries (freshwater)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Groundwater</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boyne River Estuarine reaches</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There is little freshwater habitat in the Boyne River downstream of Awoonga dam. In the estuarine areas there are patches of mangrove dominated by *Rhizophora stylosa* with occasional *Avicennia marina* and smaller areas of saltmarsh. Within the mangroves, mangrove crabs (*Metopograpsus frontalis*) are abundant as are small fish species such as the estuary perchlet (*Ambassis marianus*). Over 40 species of fish have been recorded within the Boyne estuary (Yezdani 1996).

The Boyne estuary is important for recreational and commercial fishing, with an abundance of mud crabs (*Scylla serrata*) and prawn species (Yezdani 1996). The Boyne estuary periodically supports large populations of barramundi. During periods when Awoonga Dam overflows over the spillway, barramundi are observed to leave the lake and enter the estuary. The Gladstone Area Water Board estimated that 20,000 Barramundi left Lake Awoonga from Dec 2010-Jan 2011 with approximately 1,200 perishing, principally due to physical trauma during the early stages of the spill event (Sawynok et al. 2013). This led to a large increase in the recreational and commercial catch of barramundi in the region during 2011, with an estimated commercial catch value of nearly $2 million.
In 2011, there were reports of barramundi fish (and other species) being caught in the Boyne River and Port Curtis with obvious signs of disease, including bulging/red eyes, blindness, severe skin lesions and skin discolouration. Government testing indicated two conditions affecting barramundi in the area (Gladstone Fish Health Scientific Advisory Panel 2012):

1. Red-spot disease (epizootic ulcerative syndrome (EUS)), which is a fungus endemic to fin fish species of mainland Australia. This condition was only confirmed in one fish from Port Alma.
2. External parasitism due to the fluke Neobenedenia sp., which was affecting the eye and skin particularly in the barramundi in Gladstone Harbour.

Water quality issues including decreased salinity, increased sediments and potentially pollutants were hypothesised as underlying contributing factors to the prevalence of the fish disease. However, the scientific panel concluded that there was insufficient evidence to determine if water quality was a factor in the fish disease (Gladstone Fish Health Scientific Advisory Panel 2012).
4. Water quality threats and issues

4.1 Calliope

4.1.1 Sediment and nutrients

An assessment of baseline pollutant loads from catchments discharging to the Great Barrier Reef has estimated a significant increase in sediment, nitrogen and phosphorus discharging from the catchment over natural conditions (Kroon et al. 2010). This equates to a 10 fold increase in sediment, a 13 times increase in total nitrogen and a 25 times increase in total phosphorus (Table 5). While these figures are certainly high, they are comparatively low when considered in the context of the sediment load discharged through the Fitzroy River (Table 6), which are two orders of magnitude higher.

Table 5: Sediment and nutrient loads (tonnes per year) discharged from the Calliope River under natural and current conditions (Kroon et al. 2010).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Natural</th>
<th>Current</th>
<th>Increase factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids</td>
<td>20,000</td>
<td>211,000</td>
<td>10.6</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>46</td>
<td>596</td>
<td>13.0</td>
</tr>
<tr>
<td>Dissolved inorganic nitrogen</td>
<td>20</td>
<td>43</td>
<td>2.2</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>6</td>
<td>155</td>
<td>25.8</td>
</tr>
<tr>
<td>Dissolved inorganic phosphorus</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Sediment and nutrient loads (tonnes per year) discharged from the Fitzroy River under natural and current conditions (Kroon et al. 2010).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Natural</th>
<th>Current</th>
<th>Increase factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids</td>
<td>1,141,000</td>
<td>3,409,000</td>
<td>3</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>1,311</td>
<td>12,974</td>
<td>10</td>
</tr>
<tr>
<td>Dissolved inorganic nitrogen</td>
<td>607</td>
<td>818</td>
<td>1.3</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>144</td>
<td>3,547</td>
<td>24.6</td>
</tr>
<tr>
<td>Dissolved inorganic phosphorus</td>
<td>7</td>
<td>146</td>
<td>21</td>
</tr>
</tbody>
</table>

Conversations with stakeholders as a part of the consultation process indicated that most were surprised by the magnitude of the sediment loads being discharged through the Calliope River. Many indicating that although the river flowed a dark turbid brown, particularly during the first high flow of the season, they did not expect the amount of sediment and nutrients coming from the catchment to be so high.

There is some conjecture over the magnitude of sediment discharge from these systems, with results of different modelling and load estimations varying significantly (e.g. Moss et al. 1992, Brodie et al. 2003, Cogle et al. 2006). However the results of Kroon et al (2010) that are provided in Tables 5 and 6, are consistent with the recent review by Brodie et al. (2010), although they have been assigned a low level of confidence. It is our understanding that more recent modelled results, undertaken as part of the out as part of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program, indicate lower, but still significant natural and current loads from the Fitzroy, Calliope and Boyne catchments (Stephen Lewis, James Cook University, Pers. comm.).

In addition, the loads presented are consistent with the findings of the independent science panel that reviewed the major risks to the Great Barrier Reef water quality (Brodie et al. 2013). They concluded that fine sediments that coat seagrass and increased nitrogen associated with algal growth and an increase in Crown of Thorn Starfish are the most significant threats to reef water quality. Further, that over three quarters of the sediments entering the Great Barrier Reef system are from grazing lands and must be tackled through catchment management initiatives.

Sources of sediment and nutrients are more difficult to define. There is little water quality data available for the upstream freshwater reaches of the Calliope River and tributaries and none could be sourced for water clarity or nutrients. A comparison of turbidity results from the lower
estuary and upper estuary (Wilcoxon matched pairs ranked test) indicates that downstream turbidity is significantly higher than upstream ($p = 0.01$). While this may indicate that some sediments (and associated nutrients) are discharged from the urban and industrial areas of the City of Gladstone; it is more likely that re-suspension of sediments from tidal action is contributing to the higher turbidity in the lower estuary. However, by and large the sediment and nutrient loads are of catchment origin.

An assessment of sediment risks identifies the main stem of the Calliope River as the potentially greatest source of sediment in the two catchments (Figure 34). This was based on four measures (maps supplied by FBA, 2014):

- Gully density;
- Soil erodability;
- Plant cover at the end of the previous drought; and
- Topography (slope).

There is little information at a finer scale on “hotspots” of erosion or sources of sediment and nutrients. Stakeholders raised the following potential sources in discussions:

- Unregulated camp on the Bruce Highway crossing of the Calliope River where many campers and trailers stop, with concern of inappropriate dumping of wastewater.
- Road construction.
- Residential pressure from the large increase in urban areas in recent times.
- Industrial discharges.
- Actively eroding gullies in the catchment.
- Unfenced riparian zones.
- Extensive land clearing in the catchment.

### 4.1.2 Contaminants
There is little evidence of a large contaminant problem in the Calliope River. Although there is little data from the freshwater reaches of the system, analysis of metals data from the estuary indicates that water quality remains below guideline values for almost all metals for the overwhelming majority of the time.

Pesticides may be a knowledge gap and Kroon et al. (2010) calculated an annual pesticide load of 18 tonnes per annum from the Calliope catchment. This is comparatively small (compared to over 2000 tonnes from the Fitzroy River) and reflects the very low degree of horticulture and cropping in the catchment. There is little or no current mining activity in the Calliope catchment and sources of contaminants (with the exception of the industrial areas of the lower estuary) are small to non-existent.

### 4.2 Boyne

#### 4.2.1 Sediment and nutrients
Modelling suggests that the increase in sediment and nutrient discharge from the Boyne to the Great Barrier Reef has been moderate (Kroon et al. 2010) reflecting the role of Awoonga Dam in acting as a sink. This equates to an approximate doubling of nitrogen and phosphorus, but little increase in sediment (Table 7).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Natural</th>
<th>Current</th>
<th>Increase factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids</td>
<td>41,000</td>
<td>43,000</td>
<td>1</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>90</td>
<td>191</td>
<td>2.0</td>
</tr>
<tr>
<td>Dissolved inorganic nitrogen</td>
<td>38</td>
<td>73</td>
<td>1.9</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>14</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>Dissolved inorganic phosphorus</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Conversations with stakeholders as a part of the consultation process indicated that most did not believe that the Boyne had significant water quality issues with respect to sediment and nutrients. The risk assessment undertaken by the FBA indicated that the sub-catchment of the Boyne River below Awoonga Dam was medium/low risk for sediment discharge (Figure 34).

4.2.2 Pollutants

There is also little evidence of a large contaminant problem in the Boyne River. Despite the January 2013 incident of elevated aluminium, the majority of metals remain below guideline values for the majority of the time. The source of the high aluminium is of academic interest, but is unlikely to represent a threat to the ecology of the system or receiving waters unless repeated again in the future.

Figure 34: Priority risk areas in the Calliope and Boyne sub-catchments (as supplied by FBA 2014).
5. Improving water quality

5.1 Existing initiatives

There are a large number of existing initiatives and active programs related to water quality in the Calliope and Boyne catchments, and receiving waters. The most effective and efficient mechanism to improving water quality in the Calliope and Boyne would be to integrate actions within these existing programs. Not only does this reduce the risk of duplication of effort, with different organisations attempting to implement the same types of measures; studies have shown that trust in the lead agency is the most important factor in the success of on-ground catchment related conservation measures (Greiner et al. 2005). Local NRM agencies and programs have worked hard to build relationships with the community and stakeholder groups and it is important that this is supported in future actions.

Some of the existing agencies and initiatives that should be integrated into the implementation of water quality improvement and monitoring activities in the Calliope and Boyne catchment include (but are by no means limited to):

**Fitzroy Basin Association (FBA) Water Quality Improvement Plan and Regional Natural Resource Management Plan**
FBA has a planning process in place for the management and improvement of water quality and catchment condition in the FBA region, which include the Calliope and Boyne catchments. They have recently completed and released a draft of the values associated with water quality in the Capricorn Coastal catchments (including the Calliope and Boyne) as a step towards implementing the actions of Reef Plan (Flemming and Coughlin 2014). Water quality monitoring and improvement in the Calliope and Boyne should be integrated into the broader FBA planning process.

**Fitzroy River and Coastal Catchments (FRCC)**
FRCC is a non-profit community-based Natural Resource Management group funded by FBA to implement sustainable land management practices. They implement a large number of on-ground and capacity building projects aimed at meeting the goals and targets of reef plan. Activities include (http://www.frcc.org.au/projects/neighbourhood-catchments/):

- Riparian fencing adjacent to waterways and off-stream watering systems on grazing properties to improve the quality of water leaving the catchment and entering the Reef environment.
- Improving the management of degraded and poor land condition areas by bringing back ground cover to provide a sustainable and productive land and reduce the loss of soils from land ending up in our waterways.
- Improving the management of wetlands by establishing infrastructure to control grazing and minimise the impacts production on our wetlands.
- Water use efficiency and chemical efficiency initiatives on horticultural properties to keep soil and chemical on farm and reduce the amount of runoff.
- Strategic weed control support and education to help identify, control and stop the spread of nationally significant weeds in our catchment.
- Improving cropping practices through water use efficiency methods and zero till adoption to reduce the sediment leaving the land.
- Protecting remnant vegetation and biodiversity on property to ensure a long term diversity of species.

FRCC is the face of land and water management activities in the Calliope and Boyne catchments and it is through supporting their existing initiatives that water quality can be improved.

**Gladstone Healthy Harbour Partnership**
Although focussed on the receiving waters of the marine environment, Gladstone Healthy Harbour Partnership (GHHP) is an initiative that is integrating existing monitoring and management activities to improve the health of Gladstone Harbour. Improvements in catchment based management activities will be realised in the marine receiving waters and
monitoring outputs of the Gladstone Healthy Harbour Partnership could be used as indicators of catchment water quality improvement success. In addition, a whole-of-system model referred to as the ‘Gladstone Harbour Model’ will be developed during 2014-16 and will include a receiving waters model component. The Gladstone Harbour Model is primarily designed to be used for scenario analysis. Scenario analysis activities will assist the GHHP in providing management recommendations based on the annual Gladstone Harbour Report Card results. This process is likely to involve consideration of catchment influences.

Gladstone Regional Council Stormwater Management Plan
Gladstone Regional Council is in the process of developing a regional stormwater management plan. This will be important for the improvement of the quality of water discharged from the urban areas of the Boyne and Calliope Catchments. As such, actions in the improvement and monitoring program for the Calliope and Boyne catchments should seek to complement the council’s management of stormwater, by integrating monitoring initiatives.

Port Curtis Integrated Monitoring Program (PCIMP)
PCIMP is a collaborative initiative, also focussed on the marine environment. It has a large number of industry partners and a vision to:

“foster coordination of monitoring activities among stakeholders of Port Curtis and to share and disseminate information to improve our capacity to manage our natural resources in a sustainable and balanced way for the prosperity of our communities and the health of our natural environment.”

Any management or monitoring in the Calliope and Boyne catchments should seek to complement that undertaken by PCIMP.

5.2 Objectives and targets
Objectives and targets have been developed to be consistent with Reef Plan (State of Queensland 2013) and the outcomes of stakeholder consultation. The objectives of water quality improvement actions in the catchments supplying Port Curtis are:

• To instigate on ground management actions to meet Reef Plan targets of reduced sediment and particulate nitrogen loads by 20% by 2018\(^1\). That is end of system loads in the Calliope Catchment by 2018 of:
  - 169,000 tonnes of sediment / annum; and
  - 153 tonnes of total nitrogen / annum.
• To instigate management actions to meet relevant water quality objectives and guidelines for the Calliope and Boyne Rivers;
• To support landholders to introduce best management practices to reduce sediment and particular nutrients leaving their properties;
• To foster relationships between NRM agencies and landholders;
• To integrate management of water quality in catchments and receiving waters;
• To implement effective monitoring of water quality to inform progress against targets; and
• To develop and implement monitoring of on-ground management actions to determine effectiveness and inform adaptive management of water quality in the catchments.

*It is recommended that these objectives be reviewed in conjunction with FBA following development of the Water Quality Improvement Plan for the Fitzroy Basin, to ensure consistency.*

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\(^1\) As a catchment dominated by grazing, dissolved nitrogen loads have not increased significantly and are not considered a priority for this catchment. Reef Plan indicates that reduced dissolved nutrient and pesticide loads are a focus for cropped catchments.
5.3 Recommendations for improving water quality

While the original scope of works and proposal for this project was to develop a water quality improvement and monitoring program (GPC Project Brief), a water quality improvement plan (WQIP) for the Fitzroy region (including the Calliope and Boyne catchments) will be undertaken by FBA as part of a Caring for our Country grant (see section 5.1 above). In addition, FBA are identified as the responsible organisation for implementing water quality improvements in their catchment. It was the overwhelming view of stakeholders that catchment works were best developed and implemented by FBA, FRCC and associated partner organisations. GPC has no jurisdiction, authority or relevant experience to undertake works in the catchment. In addition, a WQIP would require assigning responsibilities and timelines to each action. It would be highly inappropriate for GPC to identify responsibilities and timelines for other organisations. As such, to avoid duplication of effort and any infringement of FBA responsibilities, a series of recommendations are made here that outline how GPC can contribute to the water quality planning process in these catchments. These should be considered in the development of the wider WQIP for the region.

There are five recommendations aimed at improving water quality in the catchments supplying Port Curtis and meeting the objectives and targets. These recommendations are general in nature, and not directly linked to the BOS for GPC. Rather, they should be considered as a guide for future development of a WQIP and potential support / investment by GPC:

**Recommendation 1: Focus on-ground management in the Calliope Catchment to improve water quality in receiving waters of Port Curtis.**

**Rationale:**  
To date, this report has considered both the Calliope (entire catchment) and the Boyne (downstream of Lake Awoonga). However, the limited spatial extent of the study area in the Boyne, the role of Awoonga Dam as a sediment and nutrient sink, and the lack of significant water quality issues in the lower Boyne, limit the need for management actions in this system. In addition, extensive grazing and clearing in the Calliope catchment have resulted in large increases in sediment and associated nutrient loads, which should be considered a higher priority with respect to improving water quality and meeting Reef Plan targets.

**Recommendation 2: Support initiatives for identifying sources of sediment and develop and implement a prioritisation process for on-ground management actions through FBA and FRCC.**

**Rationale:**  
There was consensus from stakeholders that the management of water quality in the Calliope and Boyne catchments needed to have a holistic vision; that is, an integrated catchment management approach, but that specific management activities needed to be targeted. There was a view that in the past on-ground works such as riparian fencing had been implemented in the absence of information about the requirement for such works and the effectiveness in bringing about desired water quality improvements.

This is by no means unique to the Calliope and Boyne catchments. The effectiveness of land management practices in achieving water quality and river health outcomes has been questioned in a number of places (Capon and Dowe 2007, Hale et al. 2007, Roberts and Hale 2013). A process that identifies high priority sites and integrates on-ground action with monitoring of outcomes is desirable.

However, a review of the available literature and stakeholder knowledge indicated that little is known of the likely sources of sediment or sites that would benefit from management interventions. While a complete census or survey of the catchment for likely sources of sediment is unlikely to be feasible, a process that gives sites that are most likely to realise significant load reductions a higher priority with respect to funding and on-ground works would likely improve effectiveness. To this end a prioritisation process or decision support tool that considers risk of sediment and nutrient discharge, current condition of the land and likelihood of achieving reduction in sediment and nutrient loads should be developed and implemented.
Recommendation 3: Support existing FBA and FRCC land management in the Calliope catchments at high priority sites.

Rationale:
The scientific review of Reef Plan (Brodie et al. 2013) concluded that sediment loads from grazing lands are reduced by:

- Setting stocking rates that maintain ground vegetation cover and biomass (particularly during droughts and at the end of the dry season) and vegetation diversity (including maintaining some tree cover particularly in riparian areas); and
- Managing stock access to, and increasing ground cover in, riparian or frontage country and wetlands.

These are the focus of existing FBA / FRCC initiatives, albeit with limited resources. FBA and FRCC have developed relationships with the community and landholders and supporting these existing initiatives provides the greatest opportunities for success in realising Reef Plan goals and targets.

Recommendation 4: Fund an investigation to assess the effectiveness of different actions on reducing active gully erosion.

Rationale:
The scientific review of Reef Plan also suggested that techniques for managing gully and streambank erosion, which are known to be a significant source of sediments in grazing lands, are important and require further investigation as to their economic viability and effectiveness. Conversations with stakeholders indicated that there are a number of active eroding gullies in the Calliope Catchment, particularly on the main stem of the Calliope River. These should be targeted for action to prevent stock (and pest animal) access and investigate mechanisms to stabilise these features.

Recommendation 5: Integrate water quality improvement in the Calliope Catchment through an existing collaborative group such as the FRCC, FBA or GHHP

Rationale:
There are a number of existing initiatives that are addressing urban and industrial sources of water quality decline in the Calliope catchment. This includes the development of a regional stormwater management plan by the Gladstone Regional Council and management of industrial discharges by EHP. The management of water quality in the Calliope catchment should seek to integrate management of water quality in the system through effective communication between agencies and stakeholders. There are already a number of collaborative forums, including the GHHP and the Port Curtis Integrated Monitoring Program (PCIMP). It would seem counterproductive to introduce a new group or body and integration of water quality management should be investigated through existing channels involving FBA and FRCC as primary organisations responsible for managing freshwaters and catchments.

5.4 Monitoring
There are five recommendations related to monitoring aimed at measuring progress towards targets and adaptive management of water quality:

Recommendation 6: Establish monitoring in freshwater reaches to determine progress towards meeting water quality guidelines and identify priority sub-catchments

Rationale:
Water quality in the freshwater reaches of the Calliope catchment is a significant knowledge gap. Identification of priority sub-catchments (see Figure 34 above) has been through modelling only and does not include any actual water quality measurements. Identification of priority catchments would be better informed by a more complete measurement of at least turbidity (as a surrogate for sediment). While it is tempting to suggest a community based monitoring program, such as the Priority Neighbourhood Catchment Monitoring Program (FBA 2011) a review of this program indicated that it was very difficult to implement and gather sufficient data to effectively inform management (Hale and Box 2013).

Water quality monitoring in the freshwater reaches could be more easily implemented by the installation of turbidity loggers at existing gauging sites (currently active gauging station at
Castlehope; and potentially two closed sites further up the catchment). Establishing turbidity logging at hydrological gauging stations would allow for measurements not only of water clarity, but also validation of modelled sediment load calculations. The proportion of sediment discharged under different flow conditions and different parts of the catchment could be better described with this data.

The outcomes of this monitoring could then be used to more specifically identify priority areas for on-ground management actions. Into the future, the data could also be used, together with the estuarine water quality data currently collected by DISTIA, to inform on the effectiveness of water quality management measures in the catchment.

**Recommendation 7: Support modelling of end of system loads**

*Rationale:*
Current estimates of end of system loads for the Calliope catchment are of low confidence (Brodie et al. 2010) and not well accepted by the community. However, these load estimates are used to determine targets for Reef Plan and set the baseline against which progress towards water quality improvements are assessed. The outputs of sediment and nutrient monitoring in the catchment (recommendation 6) together with research into sediment sources (recommendation 2) could be used as inputs to a modelling analysis of nutrient and sediment loads from the Calliope catchment with a greater degree of certainty. This would also inform the need and priority of on-ground management actions in this catchment, as compared to the larger loads discharging from the Fitzroy River.

**Recommendation 8: Develop and implement monitoring of the effectiveness of on ground management actions**

*Rationale:*
As stated above, evidence from the Calliope catchment and elsewhere suggests that the effectiveness of on-ground management actions are rarely objectively assessed. This hampers the ability to improve management practices and implement the most cost effective management measures to achieve water quality improvements. Given that maintaining ground cover, biomass and diversity of vegetation in grazing and riparian lands are considered to be the best mechanism for preventing movement of sediment from grazing lands to the reef (Brodie et al. 2013) then a monitoring program that measures these variables both before and periodically after implementing management actions should be considered.

Elsewhere the Rapid Appraisal of Riparian Condition (RARC) has been used as a tool for assessing the suitability of riparian lands for improvement works (Jansen et al. 2005, Dixon et al. 2007, Roberts and Hale 2013) and could also be used as a crude measure of success. The method is easy to implement, manuals are already available for temperate (Jansen et al. 2005) and tropical (Dixon et al. 2007) systems and could be undertaken by landholders or community groups as part of a capacity building initiative.

**Recommendation 9: Annual review of monitoring and management**

*Rationale:*
Adaptive management is an important part of natural resource management and it is increasingly important that future management is informed by the outcomes for past actions and monitoring. There are a large number of stakeholders and initiatives that are related to water quality in the catchments supplying Port Curtis. The most effective management would come from an integrated understanding of all the component parts including freshwater and catchment management initiatives, urban water management, industrial discharge management, and the effect that water quality is having on receiving waters.

An annual review in the form of a workshop involving all relevant stakeholders would be beneficial to the effective management of water quality in these systems. Ideally, each program would be represented and a brief outline of achievements or outcomes from the previous year presented. A discussion of potential linkages between programs and effective future management could then ensue.
There is already a forum for integrated management of the marine components of the system through PCIMP and Gladstone Healthy Harbour Partnership. A similar forum for managing the water quality of the waters entering the harbour that includes catchment management activities, it would better inform managers of all aquatic ecosystems in the region.

**Recommendation 10: Communication of monitoring and management outcomes through incorporation of catchment indicators into existing report cards produced in the region**

**Rationale:**
An important aspect in maintaining interest and enthusiasm for natural resource management is relevant communication of progress towards achieving success. There are examples of report card type communication products for the marine environments in the Gladstone region through both PCIMP and the Gladstone Healthy Harbour Partnership. Similarly the Fitzroy Partnership for River Health produces a report card of water quality in the catchments of the Fitzroy River.

Integrating some measures of catchment condition into an existing report card for the marine areas would broaden the current scope to a more holistic approach to water quality management. Ideally it would show: the status of water quality in the catchments, what measures have been undertaken to improve water quality and what is planned for the future. A clear indication of progress towards the 20% reduction in sediment and nitrogen targets should be included. This would undoubtedly be beneficial for maintaining community awareness and support for water quality improvements in the catchments.
References


