

Developing Water Quality Guidelines for the Protection of the Freshwater Aquatic Ecosystems in the Fitzroy Basin

Phase 1

2011

Prepared by: Healthy Waters Policy, Department of Environment and Resource Management

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Jones M-A, Moss A, 2011. Developing water quality guidelines for the protection of the freshwater aquatic ecosystems in the Fitzroy Basin. Brisbane: Department of Environment and Resource Management, Queensland Government

September 2011

#29903

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Definitions and abbreviations

AHD	Australian height datum
Australian water quality guidelines	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, ARMCANZ 2000)
Cumecs	Cubic metres per second: a measure of flow
DERM	Department of Environment and Resource Management
EC	Electrical conductivity: is the measure of the ability of a solution to conduct an electric current. The conductivity of a water solution is highly dependent on its concentration of dissolved salts, and other chemical species that ionise in the solution. Electrical conductivity of water samples is used as an indicator of how much salt the sample has; the purer the water, the lower the conductivity.
EPA	Environmental Protection Agency
El Niño	A phase associated with the atmospheric phenomenon known as the southern oscillation and which brings drought to eastern Australia.
FBA	Fitzroy Basin Association
Guideline	A numerical concentration limit or descriptive statement <i>recommended</i> for the support and maintenance of a designated water use (ANZECC/ARMCANZ, 2000). Can be determined using either biological effects data for a contaminant (toxicity guidelines) or background water quality data for a local area of interest (referential guidelines).
HD	Highly disturbed waters
HEV	High ecological value waters
MD	Moderately disturbed waters
PCA	Principal component analysis: a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. It operates to reveal the internal structure of the data in a way which best explains the variance in the data.
Percentile	This is the value of a variable below which a certain percent of observations fall. So the 75th percentile is the value (or score) below which 75 percent of the observations may be found.
pH	A measure of the acidity or basicity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. The pH scale commonly in use ranges from 0 to 14.
QWQG	Queensland water quality guidelines
SD	Slightly disturbed waters
Streams	Riverine wetlands - wetlands and deepwater habitats within a channel. The channels are naturally or artificially created, periodically or continuously contain moving water, or form a connecting link between two bodies of standing water. (Queensland Wetlands Program, < www.derm.qld.gov.au >)
TSS	Total suspended solids

1 Background

Concerns about water quality in the Fitzroy Basin emerged in 2008 following releases of mine-affected water into the Nogoia River and then onto the Mackenzie and Fitzroy Rivers, which are downstream. Earlier that year, widespread rainfall and unprecedented runoff had caused major flooding of the Ensham mine near Emerald. This resulted in mine closure and subsequent lay-off of many workers, which in turn affected the local economy. Ultimately, sizeable mine discharges over several months were needed and these were authorized to allow operations of the mine to resume and assist recovery of the local economy. Downstream water users, including residents of Blackwater, Bluff and Rockhampton noticed a change in water quality and raised concerns about the potential impacts on human health and the environment as a result of these ongoing releases of mine-affected water.

In response, Premier Anna Bligh commissioned Professor Barry Hart to examine the management of water quality in the Fitzroy Basin (Hart, Greenfield *et al.* 2008). The Queensland Government also directed its own Environmental Protection Agency (EPA, now DERM) to investigate the cumulative impacts of mining on water quality of the Fitzroy River system.

Hart *et al.* (2008) found inconsistencies in the licensing of mine releases within the Fitzroy Basin. The EPA study suggested this was linked to the absence of locally-relevant guidelines for water quality of the Fitzroy (DERM 2009c). Based on the recommendations of these studies, DERM initiated a project in 2009 to develop sub-regional water quality guidelines to protect the aquatic ecosystem environmental value (EV) of the Fitzroy Basin.

This report deals with the development of sub-regional water quality guidelines for freshwater riverine systems in the Fitzroy Basin. It lists the locally-derived guideline values at the moderately disturbed level of aquatic ecosystem protection in terms of management intent. The guidelines are derived from existing data using the referential approach recommended in the Australian water quality guidelines (ANZECC & ARMCANZ 2000a). A draft of this report was released for technical peer review by three reviewers in 2010, and was publicly released from December 2010-April 2011. This final report addresses matters raised by reviewers (refer Attachment). Separate to this report, sub-regional guidelines have also been derived for groundwaters, fish species in main river trunks, and for Secchi depth and turbidity in upper reaches of the Fitzroy estuary. These are available from <www.derm.qld.gov.au>, and are not discussed in this report.

2 The Fitzroy Basin

The Fitzroy Basin straddles the Tropic of Capricorn in eastern Australia. It is a very large and complex system with a catchment area of approximately 142 000 km² (about twice the size of Tasmania). This comprises numerous rivers, streams, waterholes and impoundments. Its major tributaries are the Nogoia, Comet, Mackenzie, Isaac, Connors and the Dawson Rivers, and Callide Creek. Flows in this system are largely from runoff during rainfall, which is summer-dominant. Some flows, however, originate from springs, as in the case of the upper Dawson and Nogoia Rivers, and Carnarvon and Mimosa Creeks. Others emanate from alluvial reserves. In sections of the Nogoia, Mackenzie, Dawson and Fitzroy Rivers, flows are regulated by various dams and weirs, which in all capture up to 1500 gigitalres of water for agriculture, industry and town supply (NR&M 2004). This is equivalent to three times the volume of Sydney Harbour.

Because of the size and topography of the Fitzroy Basin, climate varies from one catchment area to another. For example, mean annual rainfall decreases from about 1200 mm in the north east to around 600 mm in the west of the basin. A strong temporal variation in rainfall also occurs in association with the *El Niño* southern oscillation. Since climate determines flow patterns, stream flows in the Fitzroy Basin vary considerably between catchments, seasons, years and even decades. The last decade, for instance, was dominated by *El Niño* and this resulted in below average annual discharges from the Fitzroy River for all years, except 2008. This contrasts with that found in the 1970s, when higher than average annual discharges occurred except in 1972 (record 1965 – 2011; Figure 1). Furthermore, it contrasts greatly with the wet season of 2010/11, which saw the record flows and widespread flooding across most of the Fitzroy River system. Accordingly, water quality within the Fitzroy River is highly variable given the unpredictability of flow and runoff from rainfall (Rustomji, Bennett *et al.* 2009).

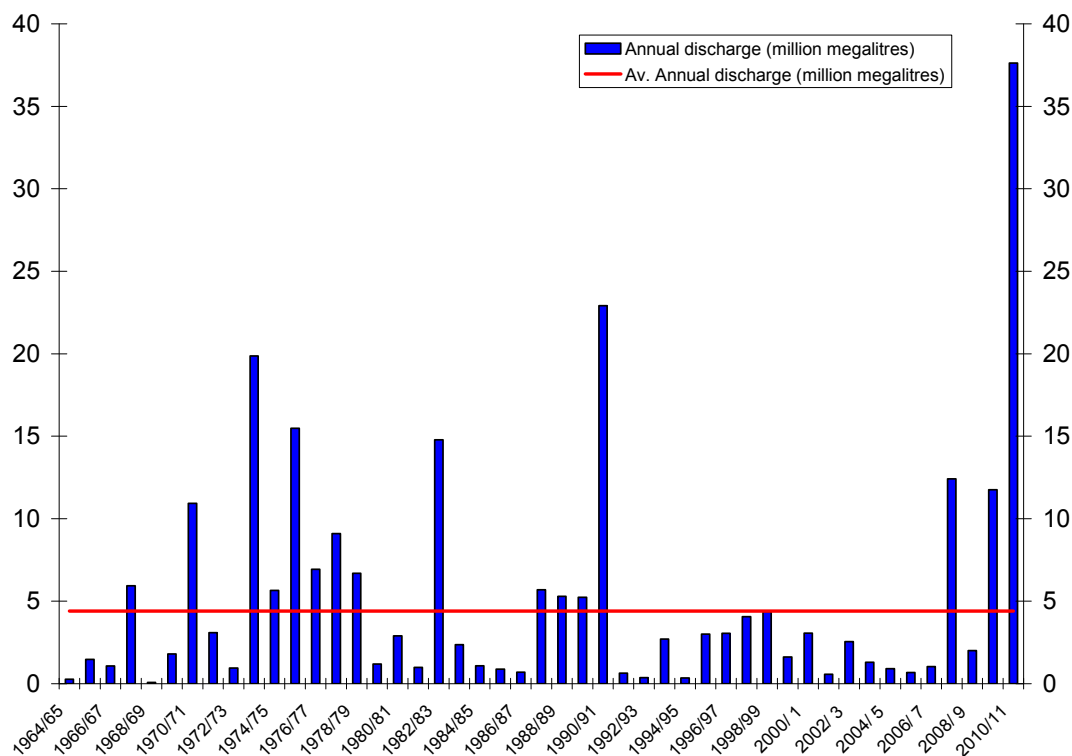


Figure 1. Annual Fitzroy River flows for water years from 1964 to 2011 compared to the average annual flow (red line). Records are from the gauging station at The Gap.

Geology also affects the quality of runoff from rainfall and flows from springs and alluvial reserves. It too varies across the Fitzroy Basin. For example, basalt is prominent in the Nogoia catchment, whereas sandstone-based rock formations are characteristic of the Upper Dawson (Douglas, Ford *et al.* 2006). Such differences can have a marked effect on water chemistry of streams and aquifers (McNeil, Cox *et al.* 2005).

While climate and geology are two natural forces affecting water quality, human activities also contribute markedly to changes in water quality within the Fitzroy Basin. This is especially so concerning major land-uses of mining, coal seam gas extraction and agriculture. Large reserves of coal and coal seam gas take in a considerable portion of the Fitzroy Basin and hence mining and extraction are prominent industries that are growing within the region. Possible water quality impacts from these include elevated salinities, changes in hydrogen ions (pH) and inorganic contamination related to accumulation of sulfides and metals transferred in discharges and runoff to river systems (Akiwumi 1997; Atkinson 2002; Farag, Harper *et al.* 2010; Rikard and Kunkle 1990; Tiwary 2001). Meanwhile, cattle grazing and cropping, which facilitate the delivery of sediment, nutrient and pesticides to waterways, are historically important and remain major industries within the basin. Given their extent, without proper management, these major land uses of the Fitzroy Basin have the potential to degrade water quality of the region, including adjacent waters of the Great Barrier Marine Park (Brodie, Christie *et al.* 2001; Thornton, Cowie *et al.* 2007).

3 Derivation of sub-regional (local) water quality guidelines for aquatic ecosystems

The preferred hierarchy for deriving WQ guidelines for the aquatic ecosystem EV is to use sub-regional (or local) information over regional water quality guideline values. Only where little or no local information exists are the Australian water quality guidelines applicable (ANZECC & ARMCANZ 2000a). Presently, the Australian water quality guidelines refer to four large regions of Australia (Figure 2) and the Fitzroy Basin straddles two of these, namely Tropical and South-East regions. Consequently, the use of these national guidelines in the Fitzroy is confounding. A brief comparison of water quality in the Fitzroy with the Australian water quality guidelines for either of these regions clearly shows that for some indicators at least, the national guidelines are inappropriate for the Fitzroy Basin. The main aim of this project was to derive more appropriate guidelines for the protection of (surface) freshwater riverine aquatic ecosystems in the Fitzroy Basin.

Two main approaches are defined for this purpose in the Australian water quality guidelines (ANZECC & ARMCANZ 2000a). The first involves eco-toxicity testing using local biota and the other, local reference conditions. This study uses the latter approach of using reference information to derive sub-regional water quality guidelines. This method is especially suited to water quality parameters that indirectly affect aquatic ecosystem health.

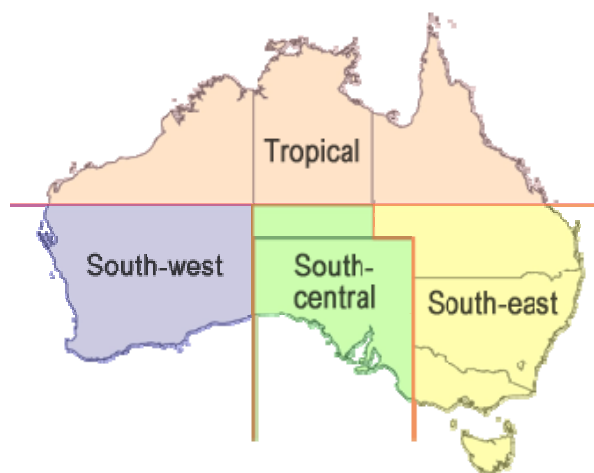


Figure 2. The four regions of the Australian water quality guidelines.

Source: environment.gov.au

example, are upper/lower thresholds used by authorities in Australia and the United States of America, and the 75th percentile is the upper value for salinity in Queensland (DERM 2009b; US EPA 2000; Vic EPA 2003). In highly impacted regions, much lower percentiles are used as upper value (e.g. the 25th percentile of impacted sites) because reference site conditions are not available (US EPA 2000). The Australian water quality guidelines confirms the choice is arbitrary and validates the use of “an appropriate percentile of the reference data distribution to derive the trigger value” (ANZECC & ARMCANZ 2000a, Vol. 1; Section 3.3.2.4).

Once accepted, sub-regional guidelines are incorporated into the Queensland water quality guidelines to provide a sub-set of values for a region that are specific to, and better reflect conditions of, particular waterways within that region.

This referential approach uses the principle that water quality in a stream should fall within a range of values expected at an unmodified (reference) site. The use of 20th/80th percentiles of data at a reference site is the default approach used in Australia (ANZECC & ARMCANZ 2000a) to achieve a desired level of protection for “moderately disturbed” waters (the subject of this study). The higher percentile is a guide for parameters that are potentially harmful at levels above an upper value, while the lower percentile is relevant for parameters like pH and dissolved oxygen (DO) that are ecologically harmful at levels both below and above a certain range of values.

Although the 20th/80th percentiles have been used previously (e.g. QWQG; DERM 2009b), this choice of percentiles is arbitrary and the appropriate approach depends on which percentiles best reflect the “true” statistic of all values possible (Hart 2001; ANZECC & ARMCANZ 2000a). The 75th/25th percentiles, for

4 The approach used to derive Fitzroy sub-regional guidelines

4.1 Existing data

Water quality and flow time-series data were extracted from databases of the Department of Environment and Resource Management (DERM). Because of the large volume and complexity of the data held in these databases, expert opinion was used to extract the best-available data for the least-impacted sites in the Fitzroy Basin.

Data were also collated from the Fitzroy Basin Association (FBA) Neighbourhood Catchment monitoring program and DERM water-quality research projects that monitor the movement of nutrients and sediments through the environment during runoff events.

Suitable reference site data from industry were not available at the time of this initial phase.

4.2 Defining sub-regional catchment areas for surface waters

Because the Fitzroy Basin is vast, the area was divided into sub-basins and major catchments (Figure 3). These were:

- Callide
- Upper Dawson (catchments of the Dawson that are upstream of Glebe Weir, near Taroom)
- Lower Dawson (Dawson catchments below Glebe Weir, near Taroom)
- Comet
- Upper Nogoia (catchments of the Nogoia that are upstream of the Fairbairn Dam)
- Lower Nogoia/Theresa Ck (catchments of the Nogoia that are downstream of the Fairbairn Dam)
- Upper Isaac (above its confluence with the Connors River)
- Lower Isaac (below its confluence with the Connors River)
- Connors
- Mackenzie
- Fitzroy

Because of their large size, some major sub-basins were divided into smaller sub-regions (Figure 3). The Dawson sub-basin, for example, with its size of 50 800 km² was divided into upper and lower catchments, with the divide at Glebe Weir, near Taroom. The Callide Creek catchment (part of the Dawson sub-basin) was considered separately from the Dawson catchment. Similarly, the Nogoia sub-basin, with an area of 28,000 km², was separated into two sub-regions, using the Fairbairn Dam as the divide. The Isaac River was divided into upper and lower regions at its confluence with the Connors River because of the influence of the Connors on waters downstream of this point and results of data analyses that showed different water quality in this section.

4.3 Assessing quality and quantity of data

The sampling protocols and laboratory methods used to obtain the water quality data were interrogated and compared with current valid procedures (ANZECC & ARMCANZ 2000b; DERM 2009a). Subsequently, recordings of nutrients prior to 1995 were omitted because sampling and storage techniques were invalid. Turbidity was also excluded because of insufficient field measurements and laboratory analyses that were not sufficiently sensitive to accurately record high turbidity values.

The quantity of data required for each parameter was based on recommendations in the Queensland water quality guidelines (DERM 2009b). This was set to a minimum of 12 data values collected over a period of two years or more.

4.4 Establishing reference sites for streams of the Fitzroy

Several DERM monitoring sites were identified as potential reference locations for stream conditions based on expert knowledge of the corporate data and local catchments. Forty in total, including two or more from each catchment, were selected in this way.

All stream sites were rated against reference-site selection criteria, as defined in the Queensland water quality guidelines (Attachment 1; DERM 2009b). This was undertaken using the best spatial data and on-ground information available for each of the catchments. Twenty-two sites met the selection criteria (Figure 3). In addition, Coolmaringa (Mackenzie), Riverslea (lower Fitzroy) and Yatton (Lower Isaac) were assessed as “least-impacted” for their downstream catchments. These sites did not entirely meet the selection criteria as they are located within 20 km of upstream cropping. However, based on local knowledge and availability of suitable data, they were rated as “least-impacted” under the definitions of the Queensland water quality guidelines (DERM 2009b) and were deemed suitable for developing guidelines in this study.

Event monitoring sites of the Fitzroy Basin Association (FBA) and DERM were also assessed using the selection criteria. While a few sites met the criteria, most did not. Those that did meet the criteria had too few data to establish reliable guidelines (refer to results section of this report).

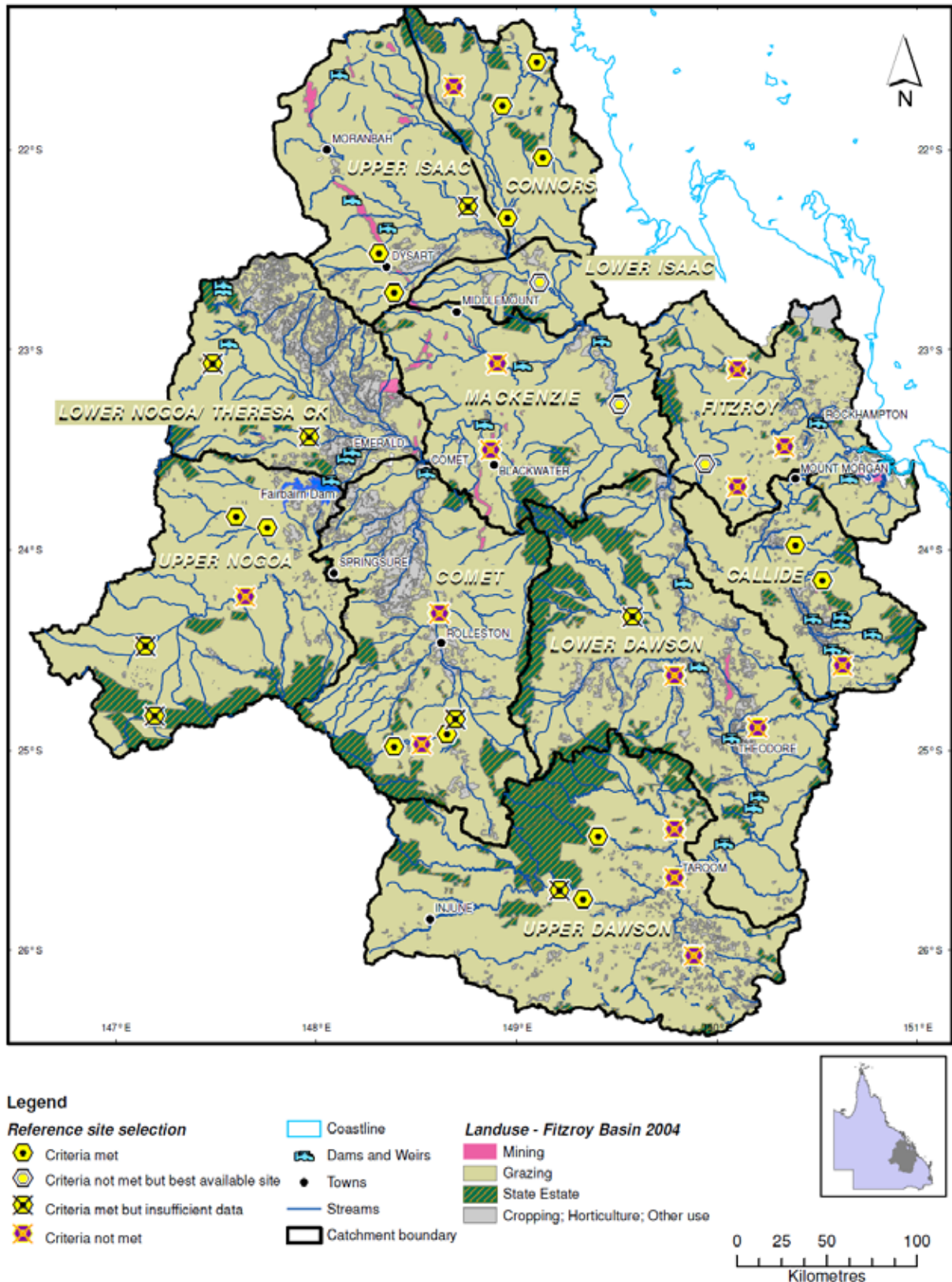


Figure 3. Map of the Fitzroy Basin showing land use and sites assessed for reference site selection. (Yellow markers show those that met the reference-site criteria).

4.5 Defining key water types

Separate guidelines are recommended for lowland and upland streams (ANZECC & ARMCANZ 2000a). The nature of upland areas with their steep gradients and high altitudes give rise to streams with rocky substrates and cooler, clearer and faster flowing waters, compared to lowlands where streams are typically more turbid and slower flowing. Consequently, each displays distinct water quality characteristics. The Australian water quality guidelines proposes a 'default' elevation of 150 m AHD for separating these water types (ANZECC & ARMCANZ 2000a). The Fitzroy Basin, however, covers a vast 142 000 km² and this cut-off point is unsuitable because most of its catchment is situated at elevations greater than 150 m AHD. The Comet River, for example, starts at 237 m AHD and flows approximately 290 km before reaching the Mackenzie River at 144 m AHD. Likewise, the Nogoia River begins at 501 m AHD and meanders a vast 550 km before nearing 150 m AHD. This reflects the step-like landscapes and the large plains that are typical of most of the Fitzroy Basin. Adoption of the 'default' 150 m AHD elevation would therefore mean that streams in these large areas would be identified as 'upland' despite the predominance of low relief. True upland streams in the Fitzroy exist in marginal areas of the basin where higher relief is evident.

Since low relief likely associates with all the available water quality data for the Fitzroy, separate guidelines for upland and lowland were considered invalid. This was tested, however, by categorising the initial 40 sites as either 'upland' or 'lowland' by defining the former as those sites directly adjacent to or within mountainous areas. Position and topography were determined using satellite imagery and contour maps and five sites were categorised as 'upland'.

A Principal Component Analysis (PCA) was used to examine the variation among sites in relation to multiple variables of electrical conductivity (EC), total suspended solids (TSS), sulfate, hardness and total alkalinity, which were chosen because their records had the most consistent and prevalent data among sites. Notably, turbidity data were limited by laboratory techniques (refer to section on assessing quality and quantity of data) and values for water temperature were unsuitable because they were taken at varying times of the day.

The chosen data were square-root transformed and normalised before running the PCA, which converted the multiple variables into two principal components (PCs) that accounted for 85% of the variation in the dataset (eigenvalues of 3.25 for PC1, 1.02 for PC2). No clear separation among sites was apparent in relation to the upland/lowland definition (Figure 4, a), but clustering of sites corresponded to sub-regions/catchments, albeit with some overlap (Figure 4, b). Most variation was owing to trends in EC and hardness (first axis), followed by differences in TSS (second axis). In this respect, Callide and Isaac catchments related to comparatively high values of EC, sulfate and hardness, and Nogoia was associated with high TSS. Consequently, the study centred on separate guidelines for sub-regional catchments rather than the water types of 'upland' and 'lowland', described by the Australian water quality guidelines.

Further to this, a separate guideline for the major water storages on the main tributaries was included in this study as the Fitzroy Basin has several of these water bodies, which are important refuges for aquatic organisms of the region.

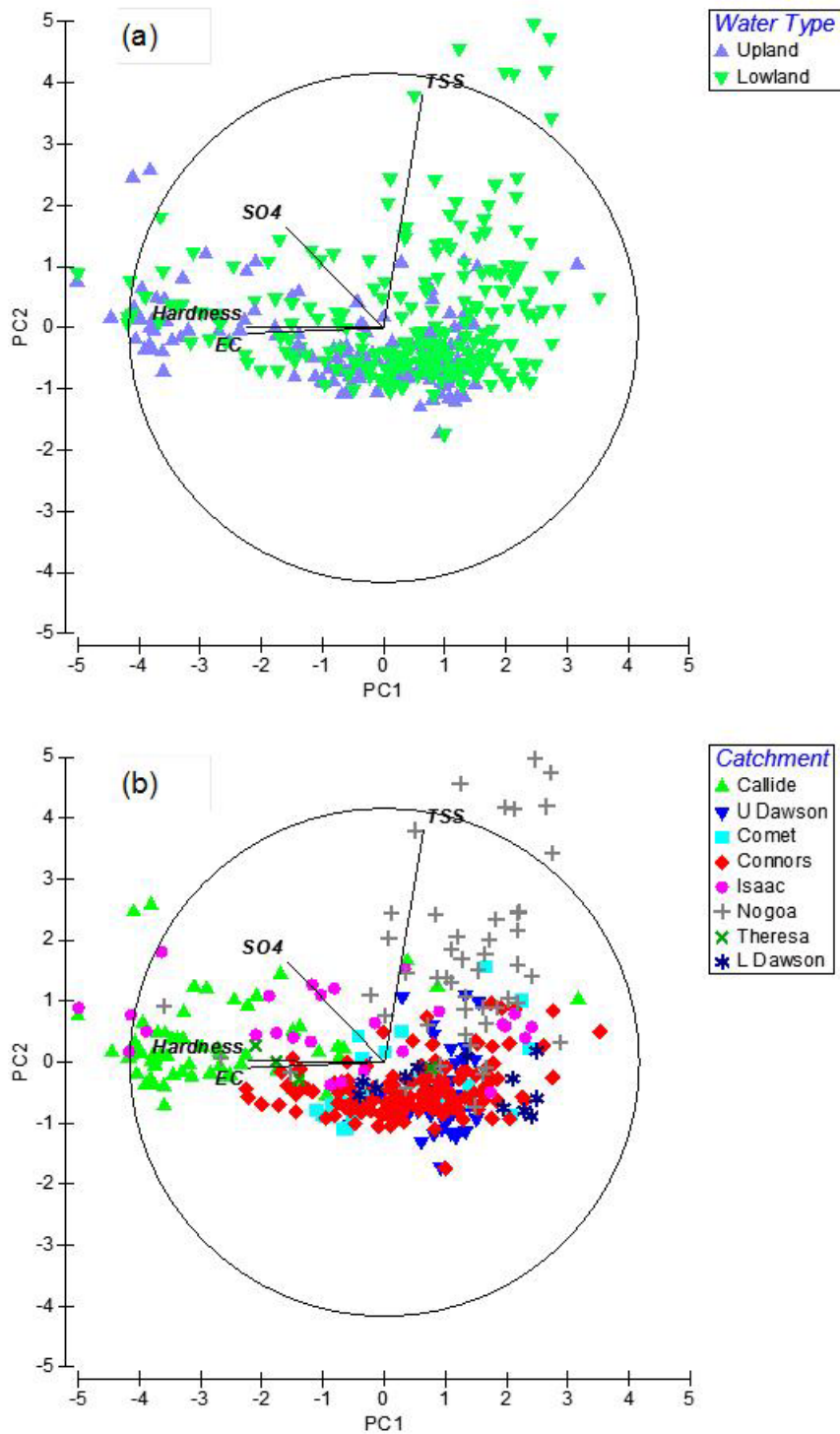


Figure 4. Principal Component Analysis (PCA) plots showing patterns in Fitzroy water quality data.

Note: Plots show (a) no clear separation between upland/lowland sites as defined in this report and (b) the differences and overlaps between sub-regions/catchments. Vectors show water quality variables that highly correlated (> 0.5) with PC axes. Higher values of electrical conductivity (EC), sulfate (SO₄) and hardness distinguish the Callide and Isaac catchments, while elevated total suspended solids (TSS) concentrations separate the Nogo from the rest.

4.6 Defining indicators of interest

Water quality indicators were based on present-day land use activities in the Fitzroy Basin (Figure 3; Negus 2007; Rowland, van den Berg *et al.* 2006) and their likely effect on water quality (Akiwumi 1997; Brodie, Christie *et al.* 2001; DERM 2009c; Farag, Harper *et al.* 2010; Rikard and Kunkle 1990; Thornton, Cowie *et al.* 2007; Tiwary 2001). These were the following physical and chemical indicators:

- Electrical conductivity (EC = measure of salinity)
- Turbidity
- Total suspended solids (TSS)
- pH
- Sulfate (SO₄)
- Nutrients (e.g. total nitrogen [TN], nitrogen oxides, ammonia, total phosphorus [TP] and filterable reactive phosphorus)
- Metals
- Pesticides
- Chlorophyll *a*
- Dissolved oxygen (DO)

Apart from SO₄, these parameters have been recognized previously as indicators of potential impacts of land use within the Fitzroy Basin (Jones, Duivenvoorden *et al.* 2000). Sulfate is a known indicator of the impact of coal-mining (Rikard and Kunkle 1990) and was included because coal mining is now a prominent industry within the Fitzroy Basin. Chlorophyll *a* was included in the list for consistency with the QWQG (DERM 2009b), which recognizes it as an important indicator.

Biological indicators were not included in this phase, but will be considered in a future stage of developing water quality guidelines for the Fitzroy Basin.

4.7 Flow regimes for surface water

It is well known that certain indicators, including salinity and suspended sediments, can vary considerably with flow regime. Ideally, there should be separate guidelines for varying flow conditions. The Queensland water quality guidelines report discusses the differences in low, high and nil flows (Section 2.5, DERM 2009b). The possibility of determining separate guidelines for each flow regime was investigated, but in order to do this, a method of stratifying flows was necessary. Instead of using a standard percentile (i.e. top 10th or 20th percentile) based on a flow duration curve at a site (i.e. flow values over time at a site) to separate the data in terms of flow, a more site-specific approach was used. This was deemed necessary because flow duration among the sites varied considerably owing to differences in catchment size, stream order and hydrodynamics. For example, one downstream site may flow 100 % of the time, whereas another further upstream may only flow 5 % of the time, and so a fixed percentile approach was not appropriate.

The site-specific approach involved three main steps. Firstly, a plot of EC against flow rate (cumecs) at each site established a flow rate that logically separated the high flow data from the rest at that particular site. Only EC had sufficient data to do this, since, in contrast to other indicators, it had been regularly tested at reference sites over the entire record period. This indicator is typically low in high-flow conditions, as salts are diluted by rainfall. In plotting EC against flow, an obvious variation in EC values was taken to indicate a change in flow regime. Figure 5 (a) displays this concept. A separate plot was used for each site of this study to identify the specific flow measure that separated water quality data into two sets: high flow and 'nil' or low flow. A plot of actual values is shown in Figure 5 (b) with a vertical line depicting the point along the flow axis that separated the high-flow data from the rest.

Secondly, data associated with zero or 'nil' flow were identified and separated out for the stream sites. This gave three datasets for the streams: 'nil', low and high-flow and two sets for the major storage sites: 'nil' plus low flow and high flow. The sets of data were then examined for outliers. Values were moved from one data set to another when further evidence suggested a different flow regime dominated the result. Time-series flow data

were used for this purpose. For example, if an EC value in a low flow dataset was obviously lower than the rest, then the time-series flow record was investigated for the influence of a rising or falling flow at the time the sample was taken. If such influence was evident, the value was moved to the high flow dataset. Rainfall records of a nearby weather station were used to strengthen evidence when needed.

Finally, for each site, values of all parameters were separated by flow regime to coincide with the separated EC datasets of 'low', 'high' and 'nil' flow for streams and 'nil + low' and 'high' for major storages.

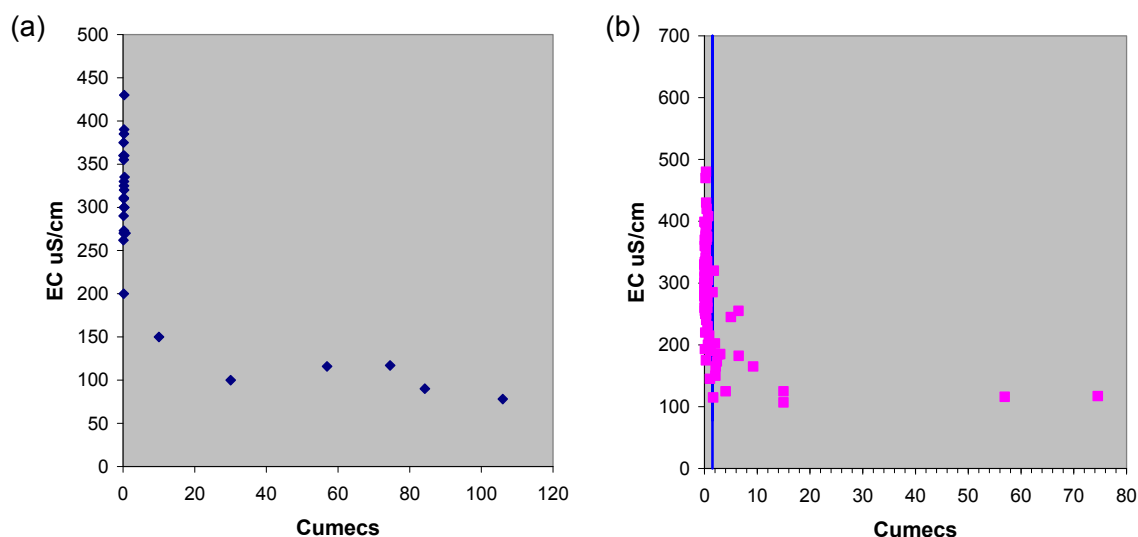


Figure 5. The relationship between electrical conductivity (EC) and flow (cumecs)

(Figure 5 shows a conceptual graph where EC decreases with high flow (a) and an actual plot of electrical conductivity (EC) against flow (cumecs) at Utopia Downs in the Upper Dawson catchment (b). Vertical line on plot shows where data were initially separated into high and low or nil flow conditions.)

4.8 Calculating guideline values

The guidelines were calculated using an upper and/or lower percentile of values at a study site. Percentiles were calculated by first placing the data-points of each indicator for every site in order of scale, then ranking them from lowest to highest and finally, obtaining the values corresponding to percentages of the cumulative sum of these ranks. Hence, the 80th percentile was the value below which 80 % of the data-points were found and the 20th percentile, below which existed 20 % of the data-points.

The data were from records of over 40 years, between 1970 and 2011 and were intermittent recordings for most indicators. For EC, the installation of in-stream loggers allowed inclusion of daily recordings from 2008 onwards. Coolmaringa on the Mackenzie River was a site that presented with extreme outliers in the 2008 EC dataset. This coincided with releases from Ensham Mine in that year. Consequently, EC data for 2008 was excluded from calculations for this site.

There were more EC data recorded at the stream sites in the two years from 2008 onwards (the recent record) than for combined previous years. Automatic logging of data by in-stream recorders gave continuous readings from 2008 onwards, whereas previous years' data (the historic record) were of less-frequent field recordings. To reduce bias and ensure all EC data for a site had equal importance, the percentiles for EC were calculated using a weighted approach (ESRC 2011). This is similar to the method described above, except that rankings for the EC data-points at a site were weighted by the total number of EC data-points for the site divided by the total for the record set pertaining to that particular data-point (i.e. total of either the historic or recent record for that site).

Percentiles were calculated for each indicator for every site and averaged across sites where there were two or more reference sites for a catchment. The upper guideline value for most variables was the 80th percentile of values at a site. For EC, the 75th percentile was used, consistent with the Queensland water quality guidelines (DERM 2009b).

5 Results

5.1 Sites

Data from a total of 17 sites were used to develop aquatic ecosystem EV guidelines for streams of the study area. These entailed three “least-impacted” sites, Coolmaringa (Mackenzie), Riverslea (lower Fitzroy) and Yatton (Lower Isaac), and 14 stream locations that qualified as reference sites (Figure 3; Table 1). Figure 6 displays a selection of these. Note, the Lower Dawson, Lower Nogoia and Theresa Creek had no suitable qualifying sites (Figure 3; Table 1).

Guidelines for the aquatic ecosystem EV in major storages were based on the following sites: Bedford and Bingle Weirs on the Mackenzie, Fairbairn Dam on the Nogoia, Glebe and Theodore Weirs on the Dawson and Eden Bann on the Fitzroy. These had sufficient data to derive guidelines for EC and qualified as ‘least-impacted’. They were deemed representative of all major water storages on rivers of the Fitzroy Basin, except for the Callide. Early investigations suggest storage waters of the Callide differ in EC from the others and too few data made it difficult to establish a reliable EC guideline for storages in this catchment.

5.2 Indicators

As previously stated, the study developed sub-regional freshwater guidelines for protecting aquatic ecosystems at the moderately disturbed level of protection in the Fitzroy Basin. For streams, values were derived for TSS, SO₄, TN, TP and pH under low-flow conditions, and EC under both low and high-flow conditions. The sub-regional guidelines are shown in Table 2. A separate upper EC value was developed for ‘low + nil’ flow conditions in major storages, except in the Callide (Table 2). For major storages, no values were set for indicators other than EC, as there were too few data.

Table 1. List of stream sites that were used to develop Phase 1 of the water quality guidelines for the protection of freshwater aquatic ecosystems in the Fitzroy Basin.

Type	Catchment	Site	Latitude dd.mmm	Longitude dd.mmm	
Freshwater stream	Callide	Don R at Kingsborough	-23.974	150.390	
		Bell Creek at Craiglands	-24.153	150.525	
	Upper Dawson	Dawson R at Utopia Downs	-25.690	149.019	
		Robinson @ Glenleigh	-25.433	149.400	
	Comet	Brown R at Warrinilla	-24.920	148.653	
		Carnarvon Ck at Rewan	-24.979	148.387	
	Upper Nogoia	Nogoia R at Craigmore	-23.886	147.756	
		Medway Ck	-23.830	147.800	
	Upper Isaac	Scott Creek at Norwich	-22.714	148.386	
		Phillips Ck at Tayglen	-22.519	148.311	
	Lower Isaac	Yatton	-22.612	149.116	
	Connors	Connors	Connors R at Mt Bridget	-22.038	149.129
			Connors R at Pink Lagoon	-22.412	148.993
			Funnel Creek at Main Rd	-21.778	148.927
			Funnel Creek at Colston Park	-21.562	149.098
	Mackenzie	Coolmaringa	-23.271	149.510	
Fitzroy	Riverslea	-23.571	149.939		



Figure 6. A selection of sites used as reference sites for Fitzroy Basin sub-regional guidelines. Phase 1

There were insufficient data to derive TN and TP guidelines for low-flow conditions in the freshwater streams of the Fitzroy, Upper Isaac, Theresa Creek, Lower Nogoa, Lower Dawson, Comet and Callide catchments or dissolved nutrients (e.g. nitrates) for freshwater stream of any sub-region. There were also insufficient data to derive guidelines of any flow condition for metals, pesticides, DO, and chlorophyll *a*. Dissolved oxygen (DO) was eliminated because rather than diel measurements, the available data were spot recordings, which poorly reflect the natural range of DO values possible at a site over 24 hours due to changes in biological, physical and chemical processes. The most relevant guidelines for these indicators therefore are the QWQG (DERM 2009b) and related Australian water quality guidelines (ANZECC & ARMCANZ 2000a).

The lower default value of 6.5 for South-east Australia (ANZECC & ARMCANZ 2000b) was deemed suitable for pH because virtually no local pH values were below this value. The upper value was set at 8.5 rather than the default value of 8.0 because it better reflected the local conditions with estimates of 80th percentile values for pH at reference sites being above 8.0, but generally below 8.5.

5.3 Flow regimes

High-flow guidelines were developed for EC, as shown in Table 2. However, there were too few data for developing ‘nil’ or ‘high-flow’ guidelines for streams for most indicators. A review of event monitoring programs of both FBA and DERM revealed insufficient samplings of events to adequately assess the natural range of TSS, TN and TP in high-flow conditions. The study recognised that a much larger dataset was needed for these since they can vary considerably depending on the high-flow phase, that is, whether it is rising, at peak or falling. Antecedent conditions and intensity and location of rainfall also severely affect these indicators (Mitchell, Brodie *et al.* 2005; Packett, Dougall *et al.* 2009).

Data for low and nil flow were combined for major storages on the rivers because the large mass of water contained in these impoundments means concentrating effects of evaporation and groundwater intrusion are minimised and hence EC is much less variable between these flow regimes. High-flow guideline values for EC in major storages were not relevant because they are affected by stream water quality during high flow conditions.

5.4 The sub-regional guidelines

The sub-regional guidelines are shown in Table 2 below.

Table 2: Sub-regional water quality guidelines for protecting freshwater aquatic ecosystems of the Fitzroy Basin. Phase 1. All values shown are sub-regional guideline values, unless otherwise stated (refer notes below).

Fitzroy Basin Streams/Rivers	TSS	EC		SO ₄	TN	TP	pH	
	mg/L	µS/cm		mg/L	µg/L	µg/L		
	Low Flow	Low Flow	High Flow	Low Flow	Low Flow	Low Flow	Low Flow	
	Upper value	Upper value	Upper value	Upper value	Upper value	Upper value	Lower value	Upper value
QWQG 2009*	10	340/720/760¹	none	-	500	50	6.5	8.0
Callide	30	1150	600	20	500 ²	50 ²	6.5	8.5
Upper Dawson	30	370	210	5	620	70	6.5	8.5
Lower Dawson	10 ²	340 ²	210	25	500 ²	50 ²	6.5	8.5
Comet	30	375	210	5	500 ²	50 ²	6.5	8.5
Upper Nogoia	165	350	210	15	1070	390	6.5	8.5
Lower Nogoia	10 ²	340 ²	250	25	500 ²	50 ²	6.5	8.5
Theresa Ck	10 ²	720 ²	250	25	500 ²	50 ²	6.5	8.5
Upper Isaac	55	720 ²	250	25	500 ²	50 ²	6.5	8.5
Lower Isaac	30	410	210	5	455	75	6.5	8.5
Connors	15	430	250	5	485	60	6.5	8.5
Mackenzie	110	310	210	10	775	160	6.5	8.5
Fitzroy	85	445	250	15	500 ²	50 ²	6.5	8.5
Fitzroy Basin Water Storages								
		EC						
		µS/cm						
		"nil + low" Flow						
		Upper value						
QWQG 2009*		340/720/760¹						
All major storages (except Callide) ³		250						

Notes:

* Queensland water quality guidelines for lowland streams of Central Coast Queensland region.

1. These are based on the 75th EC percentiles for Queensland salinity zones listed in Appendix G of the QWQG, i.e. 340 for Fitzroy Central, 720 for Fitzroy North and 760 for Callide.

2. There is insufficient data to derive a sub-regional guideline for these parameters. QWQG regional guidelines apply until sub-regional guidelines are developed. For parameters other than EC, these are QWQG Central Coast regional guidelines. For EC these are based on salinity guidelines in Appendix G of the QWQG.

3. There is insufficient data to derive a sub-regional guideline for parameters other than EC at low-flow for storages. For Callide storages there was insufficient data to derive guidelines for any parameter.

6 Discussion

Because of the complexity and size of the Fitzroy Basin, together with limitations of past efforts in water quality monitoring, not all desired outcomes were achieved in this first phase of guideline development for the Fitzroy. The Upper Isaac, Lower Dawson, Lower Nogoia and Theresa Creek, for example, had very few data at reference or “least impacted” stream sites. For these, regional guidelines for TSS, EC, TN and TP were applied (Table 2; DERM 2009b). Also, there were insufficient data to develop guidelines for streams suited to “nil” flow conditions and nutrient and suspended sediment guidelines at high-flow. Lastly, guidelines were not established for the aquatic ecosystem EV at the high ecological (unmodified) level of protection, because these are typically in headwaters above the selected reference sites and appropriate data were not available.

The sub-regional guideline values derived for EC, TSS and TN and TP of streams were above QWQG regional guidelines in some cases (Table 2). However, sub-regional values were based on existing data of the best available reference (or least-impacted) sites within the Fitzroy Basin and so are considered more reflective of local conditions. The pH data for study sites were all within the diurnal range of values likely for freshwater streams in general (Horne and Goldman 1994). The pH values for the Fitzroy Basin in Table 2 were based on Australian water quality guidelines with a slightly modified upper guideline value relating to the range of values observed at the reference sites.

Table 2 shows sub-regional guideline values for streams varying among catchments, especially TSS and EC. The relatively high value for TSS at Upper Nogoia (Table 2) corresponds to the PCA results mentioned earlier. TSS and the nutrients, TN and TP, are usually positively correlated and so the comparatively high TN and TP values for Upper Nogoia are consistent with having a relatively high TSS value for the same area. These higher values for Upper Nogoia possibly relate to different geology and soil type in this region compared to others. Similar associations could be attributed to the higher EC values at Callide and Upper Isaac compared to others (Table 2) and these also correspond to the PCA results.

Guidelines for EC were also developed for the protection of aquatic ecosystems of major storages within the Fitzroy Basin, except for the Callide catchment. Major water storages provide important habitat for aquatic organisms, particularly during droughts that cause waterholes in the Fitzroy Basin to recede. The development of such guidelines for major storages will protect aquatic species from impacts of elevated EC during low and ‘nil’ flow periods.

Once accepted, these sub-regional (local) guidelines will become sub-regional guidelines in the QWQG (DERM 2009b) and will have precedence over national and regional guidelines. Their application will be set out in an updated version of the Queensland water quality guidelines, corresponding to current version procedures (Section 5 and Appendix D; DERM 2009b). It is also anticipated that they will form the technical basis for scheduled water quality objectives under the EPP (Water).

6.1 Where to from here

Further water quality surveys are proposed by DERM over an 18–24 month period to provide additional reference data in each catchment. This would allow for subsequent review and, if necessary, refinement of the first phase Fitzroy Basin guidelines. It is anticipated the future monitoring project will also support the development of high-flow guidelines for indicators such as TN, TP and TSS, and investigate the possibility of deriving guidelines for streams with nil flow regimes and in upland regions.

7 Acknowledgements

The Department of Environment and Resource Management acknowledges the three reviewers for their peer-review of the science in the draft document. Their comments and recommendations have assisted in the preparation of this final report. Attachment 2 summarises responses to reviewer comments, including the changes made to incorporate peer-reviewed comments.

Thanks also to the following members of DERM for their contribution and expertise towards selecting potential reference sites and assessing event-based guidelines in the Fitzroy Basin:

- Ian Wallace, Long-term knowledge on hydrography, Hydstra database
- Bob Packett, Water quality technical expertise
- Cameron Dougall, Catchment modelling, Neighbourhood Catchments research
- Craig Thornton, Water quality research, Brigalow Research Station
- Dr John Platten, Aquatic biodiversity expertise

Thanks also to Fitzroy Basin Association for providing water quality data from their event monitoring program.

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Attachment 1: Criteria for selecting reference sites for development of water quality guidelines (DERM 2009b)

Freshwaters	
1	No intensive agriculture within 20km upstream. Intensive agriculture is that which involves irrigation, widespread soil disturbance, use of agrochemicals and pine plantations. Dry-land grazing does not fall into this category.
2	No major extractive industry (current or historical) within 20km upstream. This includes mines, quarries and sand/gravel extraction.
3	No major urban area (>5000 population) within 20km upstream. If the urban area is small and the river large this criterion can be relaxed.
4	No significant point source wastewater discharge within 20km upstream. Exceptions can again be made for small discharges into large rivers.
5	Seasonal flow regime not greatly altered. This may be by abstraction or regulation further upstream than 20km. Includes either an increase or decrease in seasonal flow.

Attachment 2: Responses to peer review comments

Section	Issue cited	Response
Figures	Reviewer 3: Figures are below standard for publication; Figure 4 (which was the imagery for Fitzroy) is difficult to read.	DONE - map changed
	Reviewer 3: Figure 3 uses central meridian east of the usual projection for Australia	FIXED
	Reviewer 1: discrepancy about the catchment numbers and what was shown on map	MAP AMENDED - new map includes land use etc.
	Reviewer 3: Figure 6 (this is the PCA)- requires better labelling	DONE
	Reviewer 1: Can map (figure 1) show locations and later comment about removing map	Map taken out and paragraph amended to make it more general.
	Reviewer 1: figure 2 - elaborate on the blue line	Added more words here to cover all comments.
Validity of the methodology		
Percentiles	<p>Reviewer 1: Appropriate.</p> <p>Reviewer 2: I applaud the more conservative approach of using the 75thile values for the guidelines, and agree with the reasoning. Of note here is that decadal changes in parameters may be of significance in setting these guideline levels, hence a more conservative approach is appropriate.</p> <p>Reviewer 3: It is unclear as to why the 20th and 80th percentiles were not applied to the transformed data and then back-transformations used to define the critical values. This would overcome the issue of skewness in the data without the need for arbitrarily specifying a 75th percentile rather than 80th percentile for EC.</p>	<p>NO ACTION as using the method suggested by the reviewer gives the same answers as direct calculation of percentiles. Percentiles are based on ranks - non-parametric statistics - so the distribution of the data is not relevant. Distribution becomes relevant when you use tests of means and variances. Then transformation is applicable if data are not of a normal distribution.</p>
Nil Flows	<p>Reviewer 1: Will therefore guidelines be applicable to pools?</p> <p>Reviewer 3: Values during low flow conditions were omitted because they 'biased' the results but do these extreme values have important impacts on functioning of this system?</p>	Edited report to better reflect the 3 flow regimes in the relevant sections
Flow stratification of data	<p>Reviewer 1: The focus on high and low flow periods is warranted and a step forward in the development of guidelines for rivers and streams. Method for determining high and low was well thought through.</p> <p>Reviewer 2: "Also there may be a better mathematical way of defining “where to put the line” – different people may put it in different points along the gradient. Perhaps in the next phase a mathematical inflection point could be derived. Overall I applaud the approach – having a high and low guideline is a definite improvement".</p> <p>Reviewer 3 - Para 3: The methods are understandable but the decisions are arbitrary as to which data are included and what values are chosen. There is little justification as to why these decisions were made.</p>	<p>The method for stratifying the data into low and high flow was accepted by Reviewer 1 and 2. It involved cut-offs in flow related to changes in salinity.</p> <p>The decisions were based on methods in the QWQG.</p>

Section	Issue cited	Response
Scope of indicators	<p>Reviewer 1: Appropriate. Although lack of data means several cannot be addressed. While this is the case, need to state what can be done with the available data in “calculating guideline values” rather than in “Results and discussion” section.</p> <p>Reviewer 2: I would suggest an explanation is given of why other water quality parameters were not included in this first phase of the work (particularly dissolved oxygen).</p> <p>Reviewer 3: Appropriate.</p>	Additional wording and changes made to sections: defining indicators of interest and Quality and quantity of data
	<p>Reviewer 3: The section on 'defining indicators of interest' is unclear. It suggests that water quality variables were chosen on the basis of land use activities but gives no indication of how these were selected, which subset of variables were allocated to what land uses, why this was done and how it helped drafting of critical values.</p>	Made changes to this section, including citations to appropriate references.
Validity of draft guideline values	<p>Reviewer 1: about pH - Why these limits? Not from ANZECC. I agree with the numbers as the range represents likely or expected range and is not entering “toxic” levels. In Vic would even go down to 6 in upland streams.</p> <p>Reviewer 2: With regard to the upper value of 8.5 for the pH, I note this is a change from the current guidelines and it appears this change has been made without reference to data collected. In my experience in the catchment, a pH of 8.5 can be gained towards the end of the day as a natural consequence of photosynthesis, so I am not particularly concerned with the increase. However, reference to published diel changes in pH would help to support this “blanket” change (I’m not aware of any published studies for the Fitzroy).</p> <p>Reviewer 3: An indication of the confidence (even 'high' versus 'low') in Table 2 would assist the reader with assessing the validity of these values.</p>	Improved section on pH The methods meet the QWQG requirements. Elaborated more on the methods section.
Report communicates methods and results effectively	<p>Reviewer 1: While the method and results are communicated well - suggestions in document - implementation section is included to make it clear how to use the guidelines (minimum data needs, timing and frequency of sampling, etc).</p> <p>Reviewer 2: Results are well presented. I would consider also inserting the current guidelines for comparison, so readers can appreciate the changes this report recommends.</p> <p>Reviewer 3: More details on the Principal Components Analysis are required. Presumably the data points used in the PCA are weekly/monthly values for EC over the length of the data record?</p>	Added reference to the QWQGs regarding implementation. Current guidelines inserted. Added more info in the Section Key water types about the data used in the PCA.
	<p>Reviewer 3: Contrary to the report, the results show considerable overlap among catchments/sub-regions for the Comet, Connors and Lower Dawson.</p>	Added words to say there was some overlap.
	<p>Reviewer 3: In addition, the Callide and Isaac group together and the Upper Nogoia and the Upper Dawson also group. No explanation (for example based on land use) is provided here as to why these particular groupings have occurred</p>	Added words in discussion: "these relatively high values possibly relate to different geology and soil type in this region compared to others"

Section	Issue cited	Response
	Reviewer 3: The results and discussion do not attempt to justify the critical values in terms of impacts on the ecology or receiving waters. What is the scientific evidence that the aquatic ecology is protected by maintaining indicators below these particular critical thresholds?	This is not relevant as the approach is referential and this is stated in the report. Added words to better reflect this in the Section: Derivation sub-regional water quality guidelines.
Comments and future directions	Reviewer 2: Include reference to the next or other phases to put this into perspective - particularly the scope of the work. Reviewer 3: A section on sampling network design that included a comprehensive approach to observation and assessment of critical values would be useful to highlight the gap between what measurements are available now and what are required to establish definitive values in the future. The current conclusion to the report the 50 more reference sites will be measured between May and August, 2010, leaves more questions than answers: Why this time of year (low flow)? what indicators? Which sites and why?	Added a section: "where to from here" and referred to FBA's project to develop an integrated monitoring program.
	Reviewer 3 - Para 4: I recognise this is a first step in the development of these indicators in a region that has little available data, but recommendations in this report as to ways forward are limited. A clear statement of requirements and improvements is needed that outlines what a comprehensive dataset looks like on which critical values could be improved in future.	This was not the aim. Ways forward are being dealt with in FBA's monitoring partnership project. Made reference to FBA's project in the "Where to from here".
other	Incorporate references suggested by Reviewer 2	DONE
	Look at Beckers as per reviewer 2 in the next phase	This may be picked up in the next phase when looking at supplementary sites, as suggested in the "Where to from here".
	Add in regional guidelines to table 2 (Reviewer 1)	DONE
	Comment on some of the limits in the discussion (Reviewer 1)	DONE
Introduction	Reviewer 1: what were Barry Hart's conclusions? Is there a report? What are the conclusions of the Qld Gov. report? Need to spell out what the other projects are.	Added more words here to cover all comments.
	Reviewer 1: can you say how examples of geology relate to runoff.	extra words added with references
	Reviewer 1: add sort of agriculture therefore type of contamination	see above
	Reviewer 2: El Nino is spelt with a capital N	FIXED
	Reviewer 2: It may be worth pointing out here the possible environmental impacts of coal seam gas extraction since this industry is in its infancy at the present time and has the potential to create significant cumulative impacts in the future	Included a few more words with references.
Purpose of Report	Reviewer 1: comment about reference to lowland confusing as intent is to look at all water types Reviewer 2: Could include reference to the next, or other phases to put this one into perspective – particularly the scope of the work	changed wording added a "Where to" at end of report and possibilities for future phases

Section	Issue cited	Response
Derivation of guidelines	Reviewer 1: why are the ANZECC guidelines not appropriate for the Fitzroy	Incorporated more words to address this.
Defining the sub-regions	Reviewer 1: need map Reviewer 2: It may be valuable to comment on the division of the Isaac into upper and lower regions in this section.	NEW MAP added. DONE.
Data requirements	Reviewer 1: summarising the data need, e.g. minimum year, numbers.	Elaborated on this section.
flow regimes	Reviewer 1: use turbidity to establish break? Reviewer 2: In final paragraph, insert “into” after “separated”.	Amended this section.
Base data	Reviewer 2: Two potentially very useful sources to consider would be those gathered by Fitzroy River Water and Stanwell Power station for the lower Fitzroy area given the single reference site (Riverslea) in this sub-region.	These are reservoirs. So this would be different water type.
	Reviewer 2: Of interest in the derivation of guidelines is how the percentiles for the various parameters may vary between the wetter years (1970s) and the drier years (say 1996-2006). If this analysis has not yet been done it may be worth considering for the next phase, given the variability in the system as detailed very well in the background section.	Interesting to consider in future.
Establishing reference sites	Reviewer 2: It is suggested that GPS locations of reference sites could be included for reference.	Added
Key water types	Reviewer 2: It would be useful to list those sites that were considered to be upland, and to clarify what is meant by “close to mountain ranges”.	Sites are listed and wording amended to: "directly adjacent to.."
	Reviewer 2: An explanation of why other water quality parameters were not included should be given.	DONE