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Water quality objectives and targets in the Mackay Whitsunday region to protect water quality to the Great Barrier Reef

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Abstract: This paper presents an overview of the development of water quality objectives (water quality guidelines for local waterways), and water quality targets to protect waterways draining to the Great Barrier Reef (GBR). The Great Barrier Reef World Heritage Area is the world's largest World Heritage Area, and contains the largest single collection of coral reefs in the world, supporting many diverse ecosystems of immense conservation value. The Mackay Whitsunday region occupies only about 2% of the total area of the GBR's catchments but is one of the most intensively farmed sugarcane areas, producing about one third of Australia's annual sugar production. Research indicates that nutrient, sediment and herbicide inputs to the GBR have detrimental effects on water quality and organisms in the GBR lagoon.

An overview of the environmental values (human and ecosystem uses) for protection, ambient and event-based water quality objectives, and water quality targets for 33 subcatchments for the Mackay Whitsunday region is presented. Current water quality for both ambient and events were also evaluated in the subcatchments. Water quality objectives were developed as part of the Water Quality Improvement Plan (WQIP) in the region. Emphasis was placed on long-term event-based loads and event mean concentrations, evaluations of current condition of water quality using SedNet and ANNEX modelling data in conjunction with local knowledge, community engagement and water quality monitoring from up to 13 ambient and event water quality monitoring sites.

Catchment modelling and water quality data were used to evaluate loads across the region. The predominant diffuse source of nutrient and herbicide pollutants is cane farming followed by grazing and conservation areas. Cane farming is the dominant intensive agricultural land use (19% of land area in the region) and produces about half of the regional load of particulate nitrogen and phosphorus. Cane farming produces about 77% of the regional dissolved inorganic nitrogen load. Cane farming produces the majority of filterable reactive phosphorus, and the herbicides atrazine, diuron, hexazinone, and ametryn.

Community engagement was an important component in the development of the water quality objectives and targets, particularly practical targets for achieving load reductions. Other components included economic modelling to assess profitability of improved management practices on cane farms in the region, and development of a strategy to achieve accelerated adoption of improved soil, nutrient and herbicide management practices to meet water quality targets.

Keywords: *water quality, nitrogen, phosphorus, catchment modelling, watershed, index, nutrient export*

1. INTRODUCTION

The Great Barrier Reef (GBR) World Heritage Area (GBRWHA) is the world's largest World Heritage Area, and contains the largest single collection of coral reefs in the world, supporting many diverse ecosystems of immense conservation value. The catchments draining to the GBR cover an area of 423,000 km^2 from Cape York to the Burnett Mary catchment in southern Queensland, Australia. Land uses are diverse including inland savannah grazing, dryland or irrigated cropping and sugarcane, dairying, rainforest and conservation. The Mackay Whitsunday region occupies only about 2% of the total area of the GBR's catchments and is one of the most intensively farmed sugarcane areas, producing about one third of Australia's annual sugar production.

Soil and agricultural diffuse pollutants of main concern in waterways and marine flood plumes include dissolved and particulate forms of nitrogen and phosphorus, sediment, and agricultural herbicides. Nutrient, sediment and herbicide inputs to the GBR have increased with agricultural development in the GBR catchments (Bainbridge *et al.* 2007; Brodie *et al.* 2007; Haynes *et al.* 2005).

To protect the Great Barrier Reef region from these risks, considerable effort is being undertaken to reduce pollutant delivery. The National Water Quality Management Strategy and the Queensland *Environmental Protection (Water) Policy 1997* promotes the sustainable management of water resources by determining environmental values of waterways and corresponding water quality objectives (WQOs; long term guidelines) for water quality indicators (EPA 2005). A WQO is a management objective for a specific waterbody and agreed by stakeholders (NAP 2007). Development of state (EPA 2006), and regional-scale water quality guidelines and targets are considered more appropriate than national guidelines in Australia (Bennett *et al.* 2002; EPA 2005; EPA 2006; Moss *et al.* 2005).

The development of Water Quality Improvement Plans (WQIP) provides an approach to set water quality objectives and targets for reducing pollutant loads. WQIPs are targeted toward the high risk catchments identified in the *Reef Water Quality Protection Plan* (The State of Queensland and Commonwealth of Australia 2003) known as 'Reef Plan'. Water quality objectives developed in the WQIP can be scheduled under the *Environmental Protection (Water) Policy 1997* legislation of the Queensland State Government.

This paper presents an overview of the development of the ambient (low flow) and event-based water quality objectives, and water quality targets in the WQIP for protection of GBR waterways. The paper presents the use of modelling with the SedNet and ANNEX models in conjunction with water quality monitoring programs for the development of the region's water quality objectives and targets. The paper also discusses recommendations for future monitoring and modelling during implementation of the WQIP.

2. THE MACKAY WHITSUNDAY REGION

Grazing is the dominant extensive land use (56% of land area in the region). Cane farming is the dominant intensive agricultural land use (19% of land area in the region). Conservation areas (national parks and reserves) occupy 17% of the region area. Conservation areas generally have a steep topography and high runoff volumes in these natural bushland catchments. The Mackay Whitsunday region was divided into 33 catchment management areas. Management areas were based on catchment hydrological boundaries, and adjacent biophysical catchments with similar land use and management.

3. THE WQIP PROJECT

3.1. Overview And Process

An overview of the WQIP development, components and implementation process is shown in Figure 1. Extensive community consultation was undertaken to establish the Environmental Values (EVs) for the region – these were used to determine sensible water quality objectives and targets (Figure 1). Environmental Values are those qualities of the waterway that make it suitable to support particular aquatic ecosystems and human uses (EPA 2005). Development of WQOs are based on the community's choices for EVs (Figure 1) and the water quality guidelines to protect them (EPA 2005). Once WQOs and concurrently ecological health objectives were developed, management interventions and actions were developed to improve water quality for implementation.

3.2. Community Engagement

A Scientific Taskforce with members from several government agencies and research institutions was established to ensure sound development of the WQIP. Catchment Reference Panels were established in three regions with the assistance of local landcare organisations, providing local stakeholder input to identify waterway EVs and uses through the region. There was considerable community, industry and government consultation during the WQIP development Drewry et al., (2008).

3.3. Development Of Ambient And Event-Based Water Quality Objectives And Targets

The key water quality pollutants of most concern were determined to be dissolved inorganic nitrogen (DIN), particulate nitrogen (PN), filterable reactive phosphorus (FRP), particulate phosphorus (PP), total suspended sediment (TSS), and the herbicides ametryn, atrazine, diuron, hexazinone, and tebuthiuron. These pollutants were evaluated from the comparative risk of 24 potential pollutants using semi-quantitative risk assessment (Standards Australia and Standards New Zealand 2004).

Figure 1. Flow diagram summary of selected components for developing and implementing WQOs and targets in the Mackay Whitsunday WQIP.

The section presents only a brief overview of ambient (low flow) water quality objectives and targets for GBR protection, as the focus on this paper is on event-based WQOs are presented in this paper. Full details on ambient WQOs are presented in Drewry et al., (2008). The ambient WQOs were determined from local water quality determined from a monitoring program established for this purpose (Drewry *et al.* 2008; Galea *et al.* 2008). Ambient water quality was determined monthly at 13 sites. WQOs were developed using the 80th percentile of the ambient data from HEV (High Ecological Value) or other appropriate reference sites (predominantly undisturbed if possible), within a broadly similar geological or catchment classification. The percentile criteria followed recommended procedures for determining WQOs (EPA 2005). HEV areas are often found in national parks or conservation areas and so water quality targets aim to maintain no discernable difference from natural condition. HEV catchments also have 20th, 50th (median) and 80th percentile WQOs, as recommended by the EPA, to ensure current water quality is maintained. The WQOs for ambient aquatic ecosystems developed for the region are, in some cases, more stringent than state or national guidelines. If the assessment of current condition for a catchment represented better condition than the long-term guideline WQO, then the water quality targets and WQOs adopted were equal to current condition values so water quality does not degrade.

The ambient current condition of the waterways was assessed from monitoring data when available, from water samples collected as described above. Current condition was used to determine the extent that improvements in water quality are required, prior to water quality targets being determined. Current condition for water quality pollutant parameters was assessed using the 50th percentile (i.e. median) value. Water quality targets to improve water quality through management actions were determined from evaluation of (i) pollutant reductions that could be expected from widespread adoption of improved cane, grazing and urban management practices, (ii) consideration of the likely reduction in nutrients required to reduce chlorophyll-a concentrations in GBR inshore waters to acceptable levels (Brodie *et al.* 2007), and (iii) consideration and modelling of different land use and land management scenarios that would reduce nutrient and sediment to approximate water quality in reference catchments.

3.4. Event-Based Freshwater

Water Quality Objectives

The event-based WQOs and current condition were determined to provide an estimate of event mean concentrations (EMCs) because large quantities of pollutants are transported during flood events. Development of the event-based WQOs for nutrients and TSS were based on (i) HEV upland or lowland catchment event-based water quality data from appropriate catchments during 2005–2007, (ii) event mean concentrations (EMCs), although flow data was available at only one HEV site, or (iii) 80th percentiles from data where flow data was not available, but pollutant sampling had occurred during an event.

Development of event-based end-of-catchment WQOs and current condition were based on water quality data collected by NRW and community volunteers during 2005 to 2007 inclusive. Full details of the event-based monitoring program, load estimation methods and results are presented in Rohde et al. (2008). The long-term event-based WQO values for TSS and nutrients are summarised in Table 1. If current condition in the management area was assessed as less than the long-term event-based WQO, then the water quality target and WQO adopted was equal to the current condition so water quality does not degrade. Herbicide WQOs were also determined and are presented in Drewry et al. (2008).

Table **1**. Event-based WQOs for TSS and nutrient event mean concentrations. Concentration units are μg L^{-1} for nutrients; TSS concentration units are mg L^{-1}. Species of N and P are reported as μg N L^{-1} and as μg P L^{-1}, respectively.

	DIN	PN	FRP	PP	TSS
Event-based WQO	300	340	30	70	200

Current Condition

End-of-catchment current condition of monitored and non-monitored management areas was required to be assessed. Catchment models are useful for this task and can assist managers to evaluate the likely sources, catchment loads and impacts of land use and management on the long-term sediment and nutrient export from catchments. Conceptual catchment models are suited to long-term prediction in large catchments (Drewry *et al.* 2006).

In the WQIP, the SedNet and ANNEX catchment models were used to model TSS and nutrients. The SedNet and ANNEX catchment models are conceptual (process-based) models with spatial representation based on lumped modelling at linked river reaches and subcatchment units. The SedNet catchment model has been described in detail by Prosser et al. (2001), and the ANNEX model by Sherman et al. (2006). To estimate sources and loads of TSS and nutrients for the region, the Short Term Modelling (STM) project was undertaken (Rohde *et al.* 2006).

Additional scenarios were also modelled in the WQIP to better represent some of the current practices and land cover in the region. SedNet and ANNEX catchment modelling for the WQIP was undertaken by NRW and CSIRO. The modelling in the region was then used to evaluate sediment and nutrient loads over the long-term from management areas, support development of WQIP water quality targets, and evaluate likely effects of management practices, additional scenarios and management practices adoption rates. Modelling results were used to help evaluate likely water quality in management areas where there was no monitored water quality data available. Similarly, the monitored results were useful as several nutrients, for example, modelled FRP EMCs were often greatly underestimated by the model. Model results were adjusted based on three-year mean EMC water quality monitoring results, modelled DIN results and monitoring site characteristics. The modelled scenario most appropriate to the current base situation in the region was a scenario with 80% cover, rather than a lower cover scenario used in the STM project. Further details on the use of these models for the WQIP, and considerations when using such models are discussed in Drewry et al. (2008).

Water Quality Targets

Evaluation of end of catchment EMCs for targets included (i) use of SedNet- and ANNEX-based modelling results for the region, (ii) adjustment of modelled data based on event monitored water quality results as described above and including new 90% and 100% cover scenarios modelled as part of the WQIP project, (iii) development of end-of-catchment target estimates for herbicides using a spreadsheet-model. Monitoring data and management practice adoption rate data to support development of the targets, and the EMC targets and load reductions based on likely adoption rates for cane and grazing practices from local workshops with land managers were also used.

3.5 Catchment Load Reductions To Meet WQOs And Targets

The previous sections detailed water quality expressed as concentrations. The current section presents water quality as end-of-catchment loads and load reduction targets for the four aggregated drainage basins in the region. This section presents a summary of modelled regional loads for current condition and 2014 targets, and load reductions likely through adoption of improved management practices. Loads for WQOs, current condition and targets for nutrients and SS are shown in Table 2. Annual load reductions in this region are more appropriate than daily reductions or limits (e.g., Total Maximum Daily Loads) due to large variations in flow, particularly between the wet and dry seasons. Large daily flow variations also occur within the wet season. Load details and targets for the 33 catchments in the region are presented in Drewry et al. (2008).

Table 2. Loads (tonnes/yr) for drainage basins for WQOs, current condition in 2007 (CC) and end-of-catchment 2014 targets (T) for nutrients and TSS from implementing improved management practices in the Mackay Whitsunday region.

Drainage	DIN			PN			FRP		
Basin	WQO	CC	T	WQO	CC	T	WQO	CC	T
Proserpine	270	480	370	200	210	200	30	80	60
O'Connell	440	730	530	370	390	370	40	100	70
Pioneer	460	630	460	500	950	690	50	120	90
Plane	140	260	180	140	210	150	20	50	30

Drainage	PP			TSS		
Basin	WQO	CC	T	WQO	CC	T
Proserpine	40	50	50	47600	43400	42100
O'Connell	90	130	120	140500	150300	143700
Pioneer	110	390	280	278200	278200	278200
Plane	30	70	50	53300	55800	53900

4. DISCUSSION AND CONCLUSIONS

Setting water quality objectives and targets can be difficult due to uncertainty arising from inherent natural variability, catchment processes, spatial sources and knowledge uncertainty. Issues include seasonality of transport, lags associated with bioavailability and transport through a catchment, and process representation in models. Although there are limitations and uncertainty associated with WQOs and targets, the event-based WQOs developed in the Mackay Whitsunday WQIP are an important step in developing regional water quality guidelines and targets in the GBR region.

Development of the WQIP was a first step in improving water quality to the GBR. A subsequent implementation phase is also important. Adoption of improved management practices will help to improve water quality in the region. Implementation of this and other WQIPs will encourage accelerated adoption of improved practices through implementation of the Australian Government’s Reef Rescue package. The Australian Government’s investment in this package will include mainly direct financial incentives to land mangers to enable accelerated adoption of improved management practices across all GBR catchments, and therefore water quality to the GBR. When implemented, improved management practices are commonly associated with improved on-farm profitability (Drewry et al. 2008).

Future monitoring and modelling for the WQIP implementation should include assessment of the adoption of improved management practices, and ecosystem health and changes in water quality from improved practice adoption. Techniques including control sites, nested catchments, statistical techniques etc should be considered to help account for annual variability. Future research should include evaluation and modelling of change in land use practices and water quality, validation of the relationships between management practices, water quality and ecosystem health, and the biological effects of pollutants on ecosystem health to ensure that targets developed in the WQIP are appropriate. Issues for consideration during the implementation phase include more extensive monitoring of current practices, and therefore the ability to determine the magnitude of practice changes, particularly given the investment by government for accelerating improved practice adoption. The end of catchment versus subcatchment monitoring to determine changes in water quality should also be considered. The latter is a difficult task given incomplete data, lags through catchments, variability in catchment loads and alternative methodologies. Space, time and funding constraints may limit future monitoring of water quality and monitoring of adoption of practice changes. Changes over time for water quality in agricultural catchments where subsidies have been implemented for improved practices for over two decades have been shown, for example, to be detectable where initial concentrations in streams were high, but reductions were small compared with variation between catchments (Bechmann and Stålnacke 2005). Attempts to help quantify aspects of variability, e.g. associated with loads and practices, could include Bayesian network approaches. Regardless, such approaches have their limitations and advantages which must be considered by catchment managers.

The development of WQOs and targets for the Mackay Whitsunday region and complementary implementation strategies has enabled the region to make the most of government investment in water quality improvement. One of the most challenging components has been the stakeholder and community consultation. Balancing the many different and sometimes conflicting uses and interest in aquatic resources has made the derivation of agreed and useful targets an arduous process. However, this has also been the most rewarding component, as agreement of targets has enabled the region funding for implementing broad-scale practice changes in a practical attempt to improve water quality.

In conclusion, the Mackay Whitsunday WQIP aims to provide water quality suitable for human uses and ecosystem protection through development of water quality objectives and ecological health objectives. Modelling combined with a three-year event-based and an ambient water quality monitoring program have been important in this project for determining diffuse sources, loads and event-based WQOs.

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