20th International Congress on Modelling and Simulation, Adelaide, Australia, 1–6 December 2013
www.mssanz.org.au/modsim2013

Great Barrier Reef Paddock to Reef Monitoring & Modelling Program

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Abstract: Great Barrier Reef (GBR) catchments have been extensively modified over the past 150 years for agricultural production, leading to a decline in water quality entering the GBR lagoon. A joint Queensland and Australian government initiative produced the Reef Water Quality Protection Plan (Reef Plan) in 2003 in response to the decline in water quality, updating the plan in 2009 and most recently in 2013. The Reef Plan outlines a clear set of water quality and management practice targets for sediment, nutrients and pesticides. Improvement in water quality is achieved through government and landholder investment into improved agricultural management practices.

A Paddock to Reef Integrated Monitoring and Modelling, Reporting program (Paddock to Reef) has been established to measure and report progress towards meeting Reef Plan goals and targets, and to assess the benefits of improved land management practices on water quality discharged to the reef lagoon. The program integrates five lines of evidence including: monitoring of practice effectiveness, prevalence of adoption of improved practices and catchment indicators through time, paddock and catchment modelling, and catchment and marine monitoring and remote sensing.

Paddock to Reef is an innovative program where paddock and catchment modelling is an essential component used to report on progress towards meeting reef water quality targets. An important innovation is the linking from paddock through to catchment scale models to assess the impact of changes in management practices on end of system loads

***Keywords**:* *Source Catchment modelling, water quality targets, management practice*

1. INTRODUCTION

Great Barrier Reef (GBR) catchments have been extensively modified for agricultural production and urban settlement since European settlement, leading to a decline in water quality entering the GBR lagoon. A Reef Science Consensus Statement recently reinforced *'the decline of marine water quality associated with terrestrial runoff from the adjacent catchment is a major cause of the current poor state of many of the key marine ecosystems of the Great Barrier Reef'* (Brodie et al. 2013a).

Marine monitoring shows coral cover has halved between 1985 and 2013 in the central and southern parts of the GBR. Whereas, in the northern GBR, where there is less agricultural development, there is no such decline in coral cover (De'ath et al. 2012). Sediment and nutrient laden runoff predominantly affects coastal and inshore reefs, with evidence linking excess nutrient inputs with increased frequency of crown-of-thorns starfish outbreaks, which have the largest impact on the GBR. Coral disease and loss of seagrass are also linked to degraded water quality. The management of water quality improves ecosystem resilience to these and other pressures including those associated with a changing climate (Schaffelke et al. 2013).

In response to these water quality concerns the Reef Water Quality Protection Plan (Reef Plan) 2003 was initiated, updated in 2009 and once again in 2013 through a joint Queensland and Australian Government initiative (Reef Plan –Department of Premiers and Cabinet, 2013a).

To measure and report on the progress towards goals and targets set in Reef Plan 2013 a modelling and monitoring framework was established in 2009; the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (Paddock to Reef Program) (Carroll et al. 2012). The program is jointly funded by the Australian and Queensland Governments and delivers collaboratively between 20 organisations including governments, agricultural industry organisation (sugarcane, grazing, grains, and horticulture), research organisations, and Natural Resource Management (NRM) regional groups adjacent to the GBR.

The Reef Plan and the supporting Paddock to Reef program are unique in the sense that they seek to both influence and change on-farm management practices through incentives and policy, and report progress towards meeting specific goals and targets (Reef Plan –Department of Premiers and Cabinet, 2013b). The hypothesis is that improvements in management practice will result in improvements in water quality at the end of catchments discharging to the GBR lagoon and ultimately more healthy and resilient marine ecosystems. It also provides a modelling framework that normalises for seasonal climatic variability, and assesses progress against water quality and management action targets. Under Reef Plan and the Australian Government's Reef Rescue program, significant government and private investment is provided to improve on-farm management practices and achieve and report on targets.

In the Paddock to Reef program five lines of evidence are used to evaluate progress towards Reef Plan goals and targets:

(1) Effectiveness of management practices to improve water quality,
(2) Prevalence of adoption management practices, and change in catchment indicators,
(3) Long-term catchment water quality monitoring,
(4) Paddock and catchment modelling, and
(5) Marine monitoring of GBR water quality and reef ecosystem health.

Over a period of more than thirty years there has been a series of empirical and catchment modelling approaches to estimate constituent loads from GBR catchments (Belperio, 1979; McKergow et al., 2005; Brodie's et al., 2003; Kroon et al., 2012). These estimates can differ greatly due to the different methods, assumptions, modelling methods and monitoring periods covered, and types of data used. In the Paddock to Reef program a consistent modelling approach and a 23 year representative climate period (1986-09) is used to generate pre-development, total loads and subsequent anthropogenic baseline loads for the 35 reef catchments, which comprise the six NRM regions (Waters et al. 2013).

The eWater CRC Source Catchments modelling framework is used to generate sediment, nutrient and pesticide loads entering the GBR lagoon, with SedNet/ANNEX modelling functionality incorporated. In addition, improved spatial and temporal resolution of remotely sensed ground cover, riparian areas, soils information, and water quality data are included.

In this paper the Paddock to Reef program is outlined, with particular emphasis on the paddock and catchment modelling line of evidence that is used to provide a relative assessment of progress towards meeting Reef Plan water quality targets.

2. STUDY AREA

The Paddock to Reef Program considers 35 basins in the GBR region, based on the Division 1 Drainage Basins (Fig. 1). The catchments drain an area of 423,000 km^2 of coastal Queensland, and cover approximately 2100 km from the Cape York region in the north down to and including the Burnett Mary region in the south, which is on the southern boundary of the GBR Marine Park. The Queensland Land Use Mapping Project (QLUMP) shows the predominant land use in the GBR catchments is grazing (81%), Rain-fed summer and winter cropping and irrigated cotton, mainly found in inland areas of the Fitzroy region (2.7%), Sugar cane (1.3%). Smaller areas of horticulture crops are grown in the high rainfall and coastal irrigation areas.

The Australian Government initially committed $200 million between 2008 and 2013 through the Caring for our Country – Reef Rescue program, and has recently committed a further $200 million over the next five years to make continued progress towards water quality and land management practice targets (Reef Rescue, 2013). Likewise, the Queensland Government has recommitted to a further $35 million per year to ensure on-going progress. Reef Rescue funding is allocated to the six Natural Resource Management (NRM) groups in the GBR catchment (Cape York, Wet Tropics, Burdekin Dry Tropics, Mackay Whitsunday, Fitzroy, and Burnett Mary) (Fig. 1), and also industry groups, to support on-ground management actions to address GBR water quality and management targets.

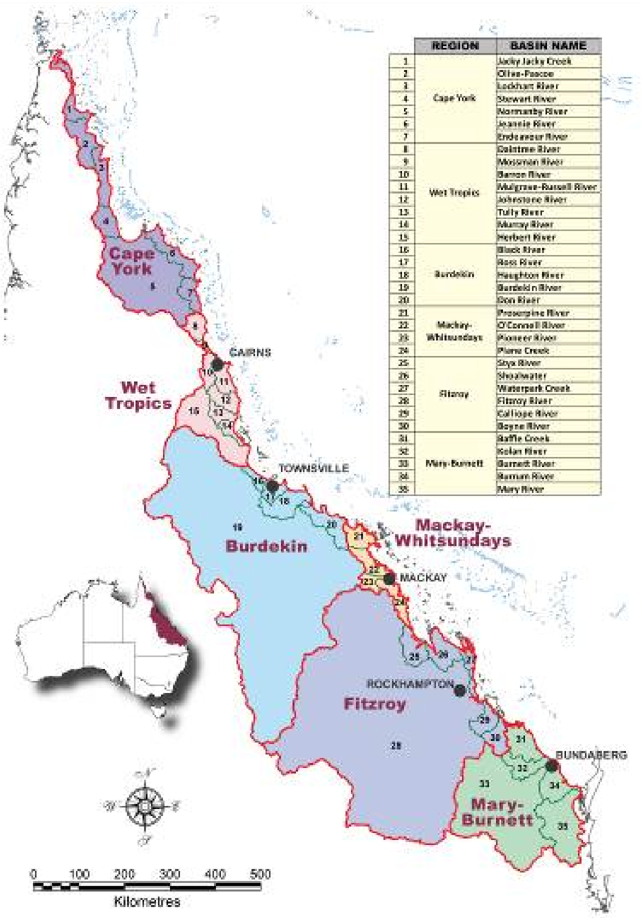

Figure 1. Thirty five Great Barrier Reef catchments and 6 Natural Resource Management regions.

3. WATER QUALITY TARGETS

Through a continuous improvement process Reef Plan water quality and management practice targets have been updated. Outcomes from the first phase of the Paddock to Reef program, including paddock and catchment modelling, were used to refine Reef Plan 2013 goals and targets. The specific water quality targets in Reef Plan (2013) are that by 2018 there is at least:

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

The land and catchment management targets are that by 2018:

- 90% of sugarcane, horticulture, cropping and grazing lands are managed using best management practice systems (soil, nutrient and pesticide) in priority areas,
- there is a minimum of 70% late dry season groundcover on grazing lands,
- the extent of riparian vegetation is increased,
- there is no net loss of the extent of natural wetlands, and there is an improvement in the ecological processes and environmental values of these wetlands.

4. PADDOCK & CATCHMENT MODELLING LINE OF EVIDENCE

The Paddock to Reef Program framework requires the ability to link paddock, catchment and marine monitoring and modelling outputs from a local scale to sub catchment and basin scale, to assess and report on the impact of improved land management practices on water quality targets. The paddock and catchment modelling component requires three of the other lines of evidence to model progress towards water quality targets.

4.1 Effectiveness of management practices to improve water quality

The Paddock to Reef Program has established a series of plot/paddock scale and rainfall simulation runoff and water quality experimental sites on different soils in cane, grazing, grain cropping and horticulture, to ensure that there is good evidence of the effectiveness of improved land management practices. Data produced from these experimental sites, include water quality of runoff and/or leachate from various farming management practices. Experimental studies, both historical and within the Paddock to Reef Program, provide data to parameterise paddock scale models and extrapolate results across locations and over an extended time sequence, which incorporates a range of improved management practices and climate zones across GBR catchments (Carroll et al. 2012).

4.2 Prevalence of adoption management practices, and change in catchment indicators.

An ABCD management systems framework is used to describe and categorise farming practices according to recognised water quality improvements at a paddock scale (Reef Plan –Department of Premiers and Cabinet, 2013b). Farm management practices are classed as:

A – cutting-edge or innovative practices, achievable with more precise technology and farming techniques,
B – best management practice, generally recommended by industry,
C – code of practice or common practices,
D – unacceptable practices that normally have both production and environmental inefficiencies.

For each industry (cane, grazing, cropping and horticulture) there are a suite of specific management principles and systems defined under the ABCD framework relevant to soil, nutrient and herbicide management. These definitions may vary between industries and regions due to difference in climate, soils, or land types. A variety of sources of information are collected on the baseline year of 2008/2009 and the adoption of improved management practices from Reef Rescue incentive funding to regional bodies.

Ground cover presence and persistence on dry tropical grazing lands and the extent and connectivity of intact riparian areas are important catchment attributes that play a role in the quality of water leaving paddocks and properties and entering streams and the GBR lagoon. Landsat Thematic Mapper and Enhanced Thematic Mapper+ (TM and ETM+) are used to report on vegetative ground cover in grassland or open woodlands (Trevithick et al. 2013). Groundcover is used to relate changes in grazing management systems through an adjustment in the C-Factor in the Revised USLE (RUSLE) (Renard et al. 1997; Shaw et al. 2013) for the catchment modelling. Currently, total ground cover is monitored annually, with an annual C-Factor used in the catchment modelling. In future it is likely more frequent temporal cover will be used, with total cover separated into dry vegetation and green cover and bare ground (Trevithick et al. 2013).

4.3 Long-term catchment water quality monitoring.

In 2005 a water quality monitoring program was implemented in the GBR catchment (Turner et al. 2013). The water quality monitoring activities of the original program focussed at the end of the freshwater system of ten priority rivers; Normanby, Barron, Johnstone, Tully, Herbert, Burdekin, O'Connell, Pioneer, Fitzroy, Burnett and 13 major sub-basins. A risk profile was used to prioritise reef catchments, including biophysical, capacity to change, development pressure, and risk to the marine environment. In response to the updated Reef Plan of 2009, and following regional workshops, some sites were reprioritised with the main alteration being the cessation of monitoring in the O'Connell and commencement in the Haughton and Plane catchments.

Initially, data collected at monitoring locations included nutrients and suspended sediments during flood events as these are responsible for transporting the majority of pollutants to the GBR. In 2009/2010 photosystem II (PSII) inhibiting herbicides were included as part of the catchment monitoring program sampling in 8 catchments and 3 sub-catchments. Analysis is conducted on the five priority PSII pesticides that are commonly detected from GBR catchments: diuron, atrazine, hexazinone, ametryn and tebuthiuron, In addition, organochlorine and organophosphate insecticides (e.g. endosulfan, chlorpyriphos) as well as other pesticides such as fungicides are opportunistically sampled (Turner et al. 2013).

The catchment water quality monitoring program is designed to collect data that will support the development and verification of Source Catchment modelling (Dougall et al 2013). These models will in turn be used to assess change over time in concentrations and loads of land-sourced pollutants that potentially impact on the health of the GBR.

4.4 Paddock and catchment modelling

Observing changes in water quality at a paddock and through to a catchment scale requires a long monitoring timescale. In the Paddock to Reef program paddock and catchment models are tools used to interpret experimental observations, and extrapolate results across spatial locations and over a longer timeframe to report on water quality targets. In addition modelling can guide prioritisation of on-ground management activities and identify knowledge gaps in contaminant generation and transport, and prioritise either where further monitoring is required or needs to change (Brodie et al. 2013b).

Paddock monitoring of different A,B,C,D class management practices provides a direct measurement of the changes to water quality over time at the paddock scale. This data provides the key data sets used to calibrate the paddock scale models. To quantify the reduction in loads due to the adoption of improved land management practices three agricultural system paddock scale models are used to generate sediment, nutrient, pesticide loads, since no single paddock model was available that can be used with confidence for all land uses and all constituents (Shaw et al. 2013). The APSIM (**A**gricultural **P**roduction Systems **Sim**ulator) was chosen for modelling sugar cane, particularly for dissolved inorganic nitrogen in runoff and drainage. Howleaky? with some enhancements was chosen to model pesticides and phosphorus in cane and for all constituents for cropping lands. Finally, the GRASP (**GRAS**s **P**roduction) model was chosen for grazing given it has been extensively parameterised for northern Australian grazing systems. The paddock model outputs from changed management are then linked to catchment models to produce relative changes in catchment loads (Shaw et al. 2013).

The 'Source Catchments' modelling framework (eWater CRC 2010) was selected in order to provide a fine resolution time step that will in the future facilitate the linkage between catchment and receiving water models. The commercial Source Catchments model, which uses event mean and dry weather concentrations, has been modified (Ellis and Searle 2013) to incorporate hillslope, gully and streambank erosion and floodplain deposition processes based on the SedNet/ANNEX approach (Wilkinson et al. 2004). These features were incorporated to better represent the erosion processes driven by the summer dominant rainfall in northern Australia.

Similar to many water management models the river system in Source Catchments is based on a node-link structure. A sub-catchment is the basic spatial unit, which is then divided into functional units or landuse categories.

A fixed climate period is used (1986 – 2009) for all model runs to account for climate variability. Catchment monitoring data is used to calibrate and or verify the catchment modelling outputs.
Three criteria were used to determine the hydrological modelling period. First, the rainfall and hydrology period reflects the long-term climatic variability across reef catchments; second, the period reflects current land use conditions, and third, it aligns with the remote sensing record of ground cover that is used to model sediment loads. The impact on current on-ground investments for 2010 to 2018 is assessed against the baseline year of 2009.

Two approaches are used to represent and model changes in land management practices in Source Catchments depending on the landuse of interest. Firstly for cane and cropping, the constituent time-series (e.g. load per day per unit area) for the given landuse in the Source Catchments model is replaced with an output time-series from a paddock model. Unique combinations of climate, soil type and management class (A,B,C,D) within each land-use are identified. For grains cropping (HowLeaky?), these unique combinations each represent one model scenario, while for cane modelling (APSIM) there are several model scenarios run for each region and these are matched to the climate/soil combinations. Each of the climate/soil combinations is also modelled to represent a level of land management practice (A, B, C or D).

In the second approach for grazing, a scaling approach, RUSLE model has been written into Source Catchments as a plug in (Ellis and Searle 2013) to model hillslope soil erosion in grazing lands, where the C-factor is generated from the remote sensed ground cover. The paddock scale model, GRASP outputs are used to give the scaling factors for adjusting RUSLE C-factors where management practices change from, for example, D to C, C to B, or B to A is required.

The primary role of Source Catchments modelling in the Paddock to Reef program is to report on end-of-catchment water quality targets. An additional benefit is that Source Catchment can predict the load of constituents at any location in the basin at varying temporal and spatial scales. This level of detail can assist policy makers in risk assessment (Brodie et al. 2013b), in prioritising future funding, and in helping NRM Groups prioritise on-ground management investments. Fentie et al. (2013) provide examples of how this information can be used at regional and whole-of-GBR scales. The Paddock to Reef program has a continuous improvement process that provides for periods of reflection to evaluate and update components of the program. Waters at al. (2013) used Source Catchments to explore target setting, and Zhang et al. (2013) considered alternative hydrology models within Source Catchment to enhance and improve the catchment modelling within the Paddock to Reef program.

5. CONCLUSIONS

The purpose of the Paddock to Reef Program is to measure and report on the progress towards Reef Plan goals and targets. The overall program involves monitoring and modelling a range of attributes including management practices, catchment indicators, and water quality at the paddock, sub catchment, catchment and marine scales. Reef Plan provides the policy instrument to influence changes in on-farm management practices, through incentives and policy. The Paddock to Reef program seeks to improve our ability to quantify the impact of the adoption of land management practices undertaken on agricultural lands and provide an assessment of associated reef health. Ultimately, the paddock and catchment monitoring and modelling outputs will link with the Marine Monitoring Program, and be used as inputs to an estuary receiving water model to link end of catchment loads to GBR ecosystem health.

The outputs of the Paddock to Reef program will continue to inform Reef Plan policy and program design and should significantly improve the efficiency and effectiveness of investments made in improving GBR water quality and ecosystem health.

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