

Simulating the response of Keppel Bay coastal waters to potential changes in sediment and nutrient loads

Final Report to the Fitzroy Basin Association
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EXECUTIVE SUMMARY

This report presents the final results of a study commissioned by the Fitzroy Basin Association. The study used the Fitzroy Receiving Waters Model developed through the Cooperative Research Centre for Coastal Zone, Estuary & Waterway Management to predict the effects on the Fitzroy Estuary / Keppel Bay system and material fluxes from Keppel Bay to the Great Barrier Reef Lagoon of reduced (or increased) sediment and nutrient loads from the Fitzroy Basin arising from potential land use and management changes.

The results suggest that (a) the estuary and immediate coastal zone tend to accumulate material during flood events but exports more sediment, nitrogen and phosphorus than is delivered from the catchment in non-flood conditions; (b) the estuary tends to dampen the impact of changes in land use in the short term, but this may not be so in the longer term; and (c) despite this dampening effect, reductions in sediment and nutrient loads to Fitzroy Estuary are predicted to have an immediate beneficial effect on water quality in the estuary and coastal zone, and will result in an immediate reduction in sediment and nutrient exports to the Great Barrier Reef Lagoon.

When simulated concentrations are compared with defined trigger values for each of four regions, some water quality variables show greater sensitivity to changes in loads than others. Of the variables considered, total suspended solids concentrations in the estuary and Secchi depths in the coastal zone showed the greatest response to changes in loads. Simulated chlorophyll *a* concentrations were insensitive to load, however the model is known to perform poorly in prediction of chlorophyll concentrations.

The report also discusses the visualisation tools that have been provided to the FBA to facilitate exploration of model results, the degree of uncertainty inherent in the model results, and current and possible future work which may further improve our capacity to predict the response of the Fitzroy Estuary / Keppel Bay system to variations in loads and flows.

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1. INTRODUCTION

Two State and Federal government initiatives, The National Action Plan for Salinity and Water Quality (NAPSWQ, now superseded by Caring for Country), and the Reef Water Quality Protection Plan (RWQPP) have had a common objective to halt and reverse the decline in water quality entering streams, coastal and inner reef lagoons. The Coastal Catchments Initiative (CCI) aims to achieve targeted reductions in pollution discharges to coastal waters of high conservation value that are threatened by pollution. Under these three initiatives, the Fitzroy Basin Association (FBA) is committed to the development of water quality targets for the Fitzroy Basin, identification of hotspot areas and prioritisation of management actions.

The Fitzroy Estuary (Qld), receives highly episodic flows and is the largest estuary feeding into the Great Barrier Reef Lagoon. To understand the impact of management actions, we need to know not only how much sediment and nutrient material is generated within the catchment, but also how this material is affected by physical and biochemical processes in the river and estuary before it reaches the sea.

To facilitate these goals, the FBA has supported two modelling exercises. The SedNet refinement project aims to improve estimates of current sediment and nutrient loads from the catchment, to identify hotspots, and to improve predictions of load reductions that could be achieved by implementing on-ground management actions in the Fitzroy Basin over the next ten years. This project (“Modelling FBA management actions in Keppel Bay for WQ target setting”) aims to simulate the implications of these catchment changes for water quality in Keppel Bay and delivery of sediments and nutrients to Fitzroy Estuary (FE), Keppel Bay (KB) and the inner Great Barrier Reef Lagoon (GBRL)

The Fitzroy Agricultural Contaminants Project of the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal Zone CRC) constructed and ran a sophisticated hydrodynamic and biogeochemical model for the FE and KB. This model, hereafter referred to as the Fitzroy Receiving Waters Model, simulates the transport and fate of sediments and nutrients as they travel through the system. The present project was designed to support target-setting for GBR environmental assets by:

- Improving the ability of the Fitzroy Receiving Waters Model to link with the current SedNet catchment model.
- Estimating exports of total suspended solids (TSS) and nutrients to FE, KB and GBRL for current conditions and management implementation scenarios.
- Providing spatial maps and time-series of simulated TSS, nutrient and chlorophyll concentrations under different flow conditions to facilitate quantification of risks to indicator species in these scenarios.

2. MODEL DESCRIPTION

A three-dimensional coupled hydrodynamic, sediment dynamic and biogeochemical model has been developed previously for the Fitzroy Estuary and Keppel Bay, through the Fitzroy Agricultural Contaminants Project of the Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management. The suite of modelling software used to implement the Fitzroy Receiving Waters Model is collectively known as EMS (Environmental Modelling Suite). The hydrodynamic component of EMS (SHOC) is described in detail by Herzfeld (2005) and its application to the FE/KB system is described by Herzfeld et al. (2006). The sediment model is described by Margvelashvili et al. (2006), and the biogeochemical model, by Robson et al. (2008;2006). A summary of findings from the Fitzroy Agricultural Contaminants Project is presented by Webster et al. (2006).

The same model has been used for the present project, with minor modifications to improve estimates of sediment and nutrient loads from the Fitzroy River and to improve the seaward boundary conditions used in the model.

2.1. Simulation periods

Flows to the Fitzroy Estuary are highly episodic, with strong interannual variability and strong seasonal patterns (higher rainfall and subsequently higher flows during the wet season and low flows during the rest of the year). Total annual discharge from one year to the next may differ by a factor of more than 100 (2006). In order to capture some of this variability, two simulation periods were chosen. The period from December 2003 to September 2004 was selected as a period representing “typical” flow conditions. Total annual flow for 2003-2004 was around the median for the past decade. This period had the added advantage that it was the focus period for biogeochemical sampling and model development (Robson et al. 2006).

Episodes of high rainfall and the resultant flood events are often associated with cyclones passing nearby. As there had not been a major flood event in the Fitzroy Estuary since 1991, the original project plan was to attempt to reconstruct past conditions using historical records and satellite data in order to simulate a major historical flood event. In January-February 2008, however, a major flood event occurred, delivering an estimated 11 megalitres of water to the estuary over a two-month period. This compares with a total flow of less than 7 megalitres over the entire period from the start of 2003 to the end of 2007. It was agreed to make the 2008 flood event the focus period for the “flood” flow condition scenarios, with these simulations covering a 170-day period from December 2007 through to April 2008.

To maximise the number of scenario runs that could be conducted within the timeframe of the project, simulations were limited to these two flow periods.

2.2. Load scenarios

Catchment modelling through the SedNet improvement project (Dougall et al. 2008) suggests that through land use changes and remediation measures, annual average sediment loads from the Fitzroy Basin could be reduced by up to 44% by 2030. With this in mind, the Fitzroy Receiving Waters Model was run for a range of scenarios in which sediment and nutrient loads varied from 50% of current loads to 100% of current loads, in increments of 10% (i.e. 50%, 60%, 70%, 80%, 90% and 100%). To cover the possibility of an unexpected decline in land condition or an upwards revision of estimated current loads, two additional scenarios were also included (i.e. 125% and 150% of current loads).

To allow results from the Receiving Waters Model to be matched up directly with SedNet scenario results, the visualisation tool provided allows a user to specify any load between 50% and 150% of estimated current loads, and to interpolate between the results of the scenarios for which the Receiving Waters Model was run. Given that the model output showed no major discontinuities or non-linearities in this range of scenarios, this interpolation procedure probably provides a good estimate of the results that would be obtained by running the model with the load specified.

2.3. Processes and variables simulated

In brief, the model simulates sediment and nutrient concentrations and the major physical, chemical and biological processes that affect these concentrations. Variables simulated include concentrations of coarse and fine sediments, chlorophyll *a*, dissolved oxygen and nutrients, as well as physical variables such as water velocity, salinity and temperature and several other components required to represent the system. Nitrogen is simulated as total nitrogen (TN), ammonium (NH₄), nitrate (NO₃), particulate organic nitrogen (PN, divided into three pools of varying characteristics) and dissolved organic nitrogen (DON). Phosphorus is simulated as total phosphorus (TP), dissolved inorganic phosphorus (DIP, analogous to filterable reactive phosphorus), particulate inorganic phosphorus and particulate organic phosphorus (collectively, PP), and dissolved organic phosphorus (DOP).

The hydrodynamic model simulates the physical movement of water and the dissolved and particulate substances in that water. It includes simulation of tidal propagation, heat fluxes, density currents, and the effects of wind stress and river inflows.

The sediment dynamics model simulates settling and resuspension of sediments of three size classes as well as particulate nutrients, and processes such as aggregation and flocculation that affect these sediments.

The biogeochemical model simulates chemical and biological processes that affect nutrient concentrations and chlorophyll *a* in the water and in the underlying sediments. Processes simulated include remineralisation of dissolved and particulate organic material, uptake and subsequent release of nutrients by phytoplankton and benthic microalgae, transfer and release of nutrients through zooplankton grazing and mortality, phosphorus adsorption and desorption to suspended sediment surfaces, denitrification, burial in the sediments, and transfer of oxygen across the air-water interface. The model employs well-understood relationships for these key ecosystem processes and incorporates established literature values for parameters such as maximum growth rates, grazing efficiencies and sinking rates (Murray and Parslow 1997).

A key feature of the biogeochemical model is its representation of nutrient cycling processes in the sediments. Processes such as benthic organic matter degradation and the return of nutrients to the water column from sediments are particularly important in shallow, energetic systems such as the Fitzroy Estuary and Keppel Bay.

For more details of the hydrodynamic, sediment dynamic, and biogeochemical models, comparison against *in situ* observations from FE and KB, refer to Herzfeld et al (2006), Margvelashvili et al (2006) and Robson et al. (2006), respectively.

2.4. Model domain

The Fitzroy Receiving Waters Model covers the FE downstream of the barrage at Rockhampton, and inner KB, extending as far north as Keppel Sands and as far east along the southern boundary as the Narrows (Figure 1). Although it is desirable to extend the model seawards to cover more of the key environmental assets of the region, the model is very computer-time intensive and it was necessary to limit the model's spatial domain so that the model could be run repeatedly to cover a range of management scenarios.

Current work being conducted through a separate project (the "Fitzroy Flood Modelling and Analysis Project" funded by CSIRO Water for a Healthy Country Flagship) is likely to result in a model with an expanded domain, however this model was not available in time to be used for the present project.

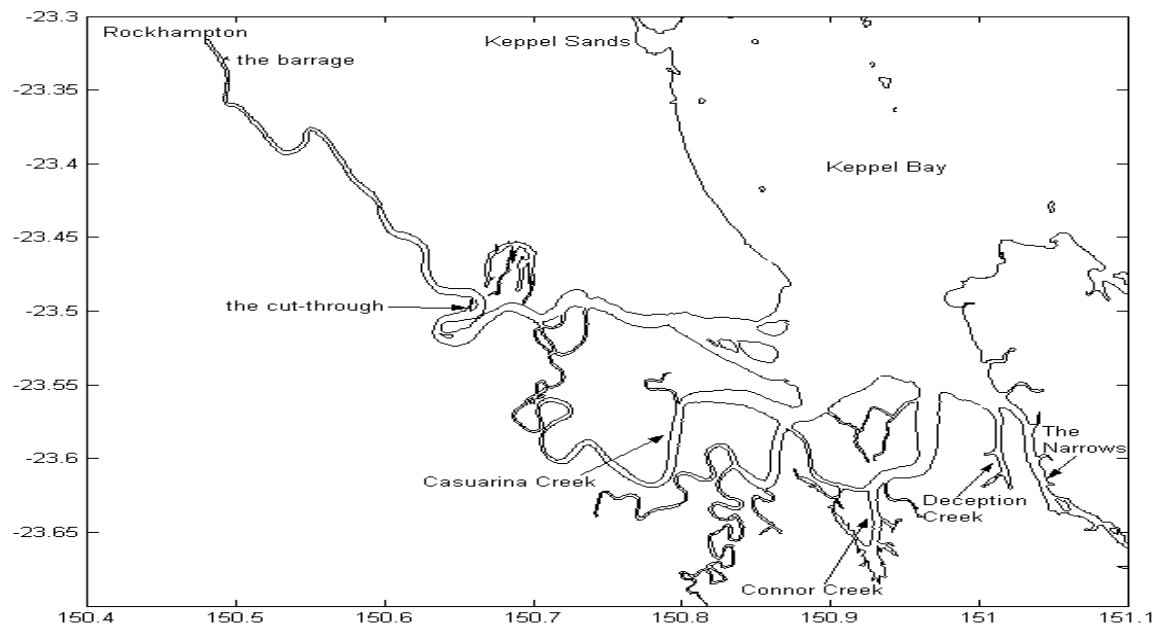


Figure 1 The model domain.

2.5. Input data

2.5.1. Initialisation

The model was initialised with salinity and temperature from the global ocean model product, SynTS. All other variables were initialised with model output from a previous model run, described by Robson et al. (2006). This earlier model was in turn initialised with estimated nutrient and sediment concentrations derived from field measurements of water quality and sediment characteristics made during September 2003 (Radke et al. 2006).

2.5.2. Flows

The model was forced with daily flows observed at the Gap, with $0.3 \text{ m}^3\text{s}^{-1}$ added to allow for inputs downstream of the observation point. These inputs include outflows from the sewage treatment plant. Flows were provided by Robert Packett at the NRM (Qld.)

2.5.3. Sediment and nutrient loads

Daily sediment and nutrient concentrations in river water for the period from September 2003 through to May 2008 were estimated by Robert Packett at the NRM, and were used as input to the model for the “100% of current loads” (i.e. current conditions) scenario. For all other load scenarios, these inflow concentrations were multiplied by a fixed proportion (i.e. 50%, 60%, 70%, 80%, 90%, 125% or 150%): in other words, it was assumed that, although sediment and nutrient concentrations and loads varied with flow, concentrations were reduced (or increased) by the same relative proportion during low flows as during high flow events.

2.5.4. Meteorology

Herzfeld et al. (2006) describe the procedure used to specify meteorological conditions for the model for the 2003-2004 model runs. The same approach was taken for the flood event scenarios, using data obtained from the Bureau of Meteorology (BoM). Observed three-hourly wind velocities and air pressure from nearby sites were interpolated to provide a time-varying wind and pressure field over the whole model domain. The monitoring sites included in this interpolation were “Yeppoon - The Esplanade”, “Lady Elliot Island”, “Rockhampton Airport”, “Sandy Cape Lighthouse”, “Heron Island Research Station”, “Gladstone Radar”, “Bundaberg Airport”, “Seventeen Seventy”, and “Rundle Island”.

Rainfall, air temperature and humidity (required to calculate heat fluxes in the model) were specified from BoM records at Yeppoon. Cloud cover (also used in this calculation, but not available from the Yeppoon site) was specified from records at Rockhampton Aeroport).

2.5.5. Outer boundary conditions – global and regional models

To obtain salinity, temperature and surface elevation at the outer boundary, the model was nested within a regional-scale model, in turn nested within a global ocean model. The regional model, r1, has been described by Herzfeld et al. (2006). The global model used to define 2007-2008 temperature and salinity at the outer border of the regional model is SynTS. Note that this model does not incorporate river flows, which limits the accuracy of these boundary conditions when the flood plume reaches its maximum extent, which approximately corresponds to the domain of the local model.

For the non-flood or “typical flow” year scenarios, outer boundary conditions for salinity and temperature for the regional model were defined using an older global model, OFAM (see Herzfeld, 2006).

Surface elevation for the outer boundary of the regional model was obtained overlaying the calculated effect of variations in air pressure on astronomical tides calculated from previously determined (Herzfeld, 2006) tidal harmonics for the region.

2.5.6. Outer boundary conditions – satellite observations

Estimates of total suspended solids (TSS) and chlorophyll a derived from satellite observations (Brando et al. 2006) are used to set the outer boundary concentrations for fine sediments (Brando et al. 2007) and small phytoplankton respectively, for the non-flood (2003-2004) or “typical flow” scenario. During the flood year, satellite observations were found to be extremely patchy due to a high level of cloud cover, so fixed concentrations were used for TSS and chlorophyll at the outer boundary for the flood scenarios (as used by Robson et al., 2006).

2.5.7. Outer boundary conditions – other

Concentrations of nitrogen, phosphorus, large phytoplankton and zooplankton at the outer boundary were set, in the absence of better data, to constant values corresponding to the values observed in outer Keppel Bay during the September 2003 and August 2004 field campaigns of the Fitzroy Contaminants project of the Coastal Zone CRC (Radke, 2006). Details of values used are given by Robson et al. (2006).

3. OUTPUTS AND RESULTS

The model results given in the sections that follow represent a summary of the more noteworthy predictions. Results of individual model runs for individual water quality variables can be explored with the visualisation tools provided, and are not reproduced in detail here.

3.1. Visualisation Tools

A graphical user interface, **fitz_scenarios** (Figure 2), has been provided as an attached DVD, to facilitate exploration of model output.

To install **fitz_scenarios**, first copy the installation package “**Installer for fitz_scenarios**” to your hard disk. Double-click on this file to run the installation package. This may take several minutes. When installation is complete, the installation file (**fitz_scenarios_pkg_full.exe**) can be deleted.

To run the visualisation tool, double-click **fitz_scenarios** (which will have been created during installation).

Alternatively, a smaller version of the tool, which does not allow plotting of results at a user-specified location, may be installed.

This visualisation tool can be used to display time-series of mean, minimum and/or maximum values of water quality variables at the surface in each of four defined regions or at any

specified (latitude, longitude) location. It can also be used to display time-series of TSS, TN and TP loads flowing through the barrage and calculated exports of TSS, TN and TP from the estuary to the enclosed coastal zone, enclosed coastal zone to coastal zone, and coastal zone to Great Barrier Reef Lagoon. Water quality variables can be compared with trigger values for each zone, and the results exported to Excel. Results for two or more load scenarios can be plotted together, and regional values can be interpolated to obtain a result for any specified load between 50% and 150% of current loads.

Concentrations and temperatures are plotted as daily averages to reduce the effect of tidal aliasing, nonetheless the effect of spring-neap tides is clearly evident in the oscillations that can be seen on a timescale of approximately two weeks.

The graphical user interface (GUI) can also be used to generate animations of changes in salinity, temperature and nutrient concentrations over time, over the whole model domain as well as tables summarising the percentage of each wet or dry season for which trigger values are exceeded, and the overall mean values (i.e. the temporal means of the spatial means) of any variable for each region.

The GUI also displays two maps in the lower left corner of the main screen. The map on the left illustrates the locations of the defined waterbodies, while the user can choose between three options for the map on the right: 1) a subjective estimate of uncertainty for the selected water quality variable; 2) a contour map showing how the temporal mean of the selected variable varies spatially; 3) a normalised contour map to illustrate where the highest concentrations are within each region. If option 3 is selected, the colour scale will show values ranging from 0 to 1 within each region, where a value of 1 indicates the maximum concentration within a region and 0 indicates the minimum. Typically, a value of 1 in the inshore region will indicate a much lower concentration than a value of 1 in the estuary: to see how concentrations vary in absolute terms, select option 2.

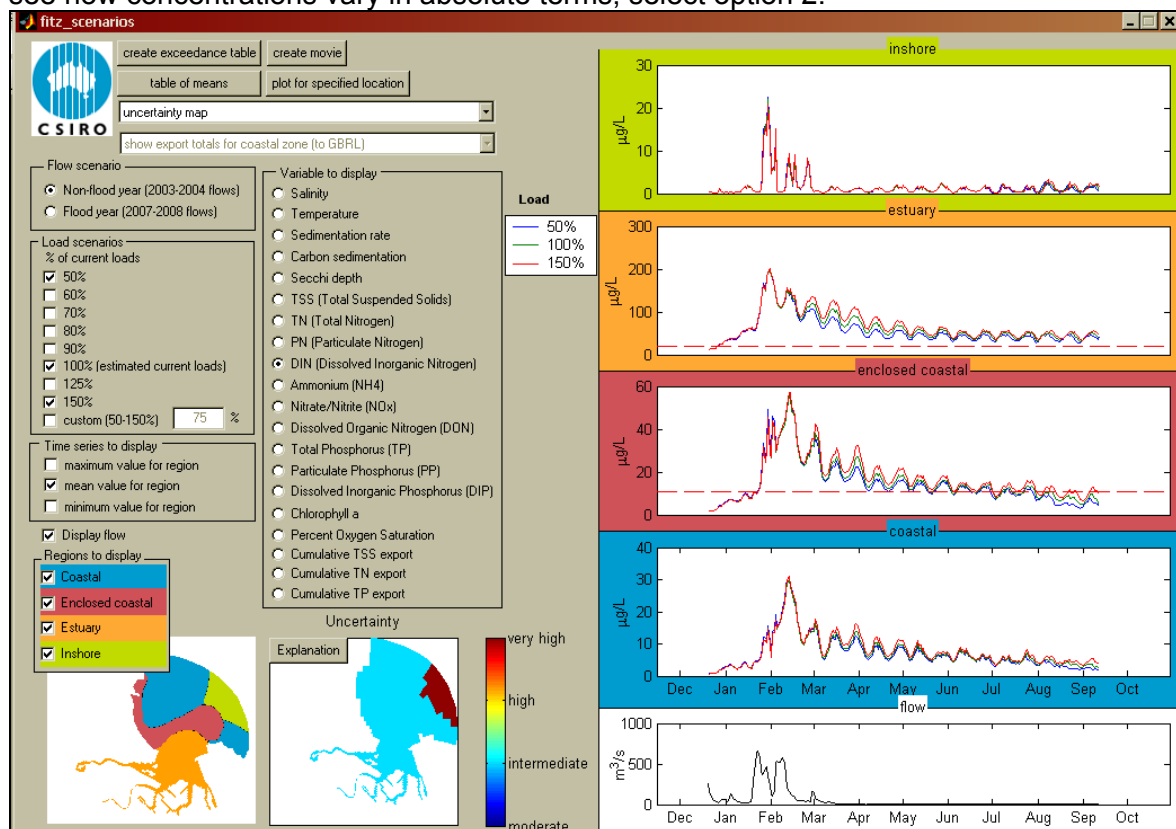


Figure 2 A screenshot from the graphical user interface, fitz_scenarios.

A second tool, DIVE (copyright CSIRO Marine and Atmospheric Research) is provided to allow three-dimensional exploration of outputs from individual scenarios. DIVE can be used to show horizontal maps of any variable in any vertical layer of the model, vertical profiles and time-series of any variable at any given point in the model domain, and vertical "slices"

of any variable (as illustrated in Figure 3). Model output is provided with a daily timestep for the surface layer, and with a weekly timestep for the whole three-dimensional domain.

Full documentation of DIVE is provided separately.

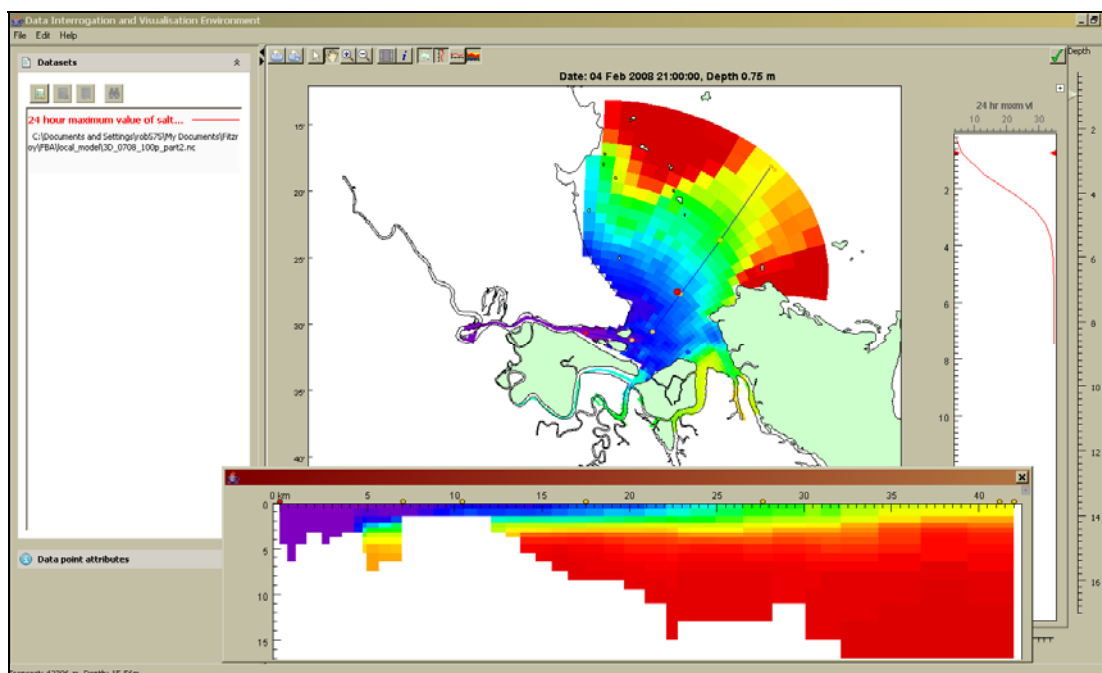


Figure 3 A screenshot from DIVE showing (inset) a vertical cross-section of simulated salinity during the 2008 flood event.

3.2. Trigger values

Trigger values – values at which water quality is likely to be of concern for management of key environmental assets – have been provided by the FBA. Trigger values for the estuary zone and enclosed coastal zone were derived from Queensland Water Quality Guidelines, while trigger values for the coastal and inshore zones, where available, were taken from the Great Barrier Reef Marine Park Authority draft water quality guidelines. The values used in this study are given in Table 1. These values refer to annual average values and are not necessarily appropriate to conditions during flow events. Where seasonal adjustments for summer are available, these have been applied in calculating exceedances for January to March.

Table 1 Water quality trigger values for comparison with modelled water quality.

Parameter	Waterbody			
	Estuary	Enclosed coastal	Coastal	Inshore
Ammonium, NH₄ (µg/L)	10	8	6	6
Nitrates, NO_x (µg/L)	10	3	3	3
Total organic nitrogen, TON (µg/L)	260	180	130	130
Particulate nitrogen, PN (µg/L) (use values 20% higher for summer)	n/a	n/a	20	20
Total nitrogen, TN (µg/L)	300	200	140	140
Filterable reactive phosphorus, FRP (DIP) (µg/L)	8	6	6	6
Particulate phosphorus, PP (µg/L) (use values 20% higher for summer)	n/a	n/a	2.8	2.5
Total Phosphorus, TP (µg/L)	25	20	20	20
Chlorophyll a, Chl a (µg/L) (use values 40% higher for summer)	4.0	2.0	0.45	0.4

Dissolved oxygen, DO (% saturation) (lower - upper)	85 – 100	90 – 100	n/a	n/a
Secchi depth (m) (reduced by 20% from default values due to high tidal range)	0.8	1.2	8	8.8
Total suspended solids, TSS (mg/L) (use values 20% higher for summer)	20	15	2.0	1.7
Sedimentation (mg/cm²/d, maximum mean annual)	n/a	n/a	3	3

As no trigger values were provided for dissolved inorganic nitrogen (DIN) or dissolved organic nitrogen (DON), DON was compared with the trigger for total organic nitrogen, while a trigger for DIN was derived by summing the concentrations provided for ammonium and NO_x in the table above.

Temperature triggers for coral bleaching (also provided by the FBA, and reproduced in Table 2) were also included, as the temperature is one of the variables simulated. In these simulations – using observed meteorological forcing for late 2003-2004 and late 2007-2008 – simulated temperature never exceeded the 1-day trigger for bleaching, and rarely exceeded the 24-day exposure value (never for more than a few days, and that only in the estuary zone where no coral assets exist). These scenarios did not consider the likely effects of climate change and climate variability.

Table 2 Temperature triggers for coral assets

Effect	Length of Exposure	Temp
Bleaching	24 days	28.6 ⁰ C
	8 days	29.4 ⁰ C
	1 day	29.7 ⁰ C
Mortality (50% of population)	66 days	29.4 ⁰ C
	51 days	29.7 ⁰ C
	1 day	30.4 ⁰ C

3.3. Effects of changes in sediment and nutrient loads on material exports to the Great Barrier Reef Lagoon

The model suggests Fitzroy Estuary/Keppel Bay system (FEKB) tends to buffer changes in sediment loads in the short term. If loads are reduced, the model predicts that a higher proportion of the total load will be exported to the GBRL (as sediment stores in FEKB are run down), while if loads are increased, the model predicts that a lower proportion of the total load will be exported, with increased retention of material and increased sedimentation in FEKB (Figure 5). Nonetheless, reducing sediment loads is predicted to have a clear benefit in terms of reduced exports to the GBRL (Figure 4).

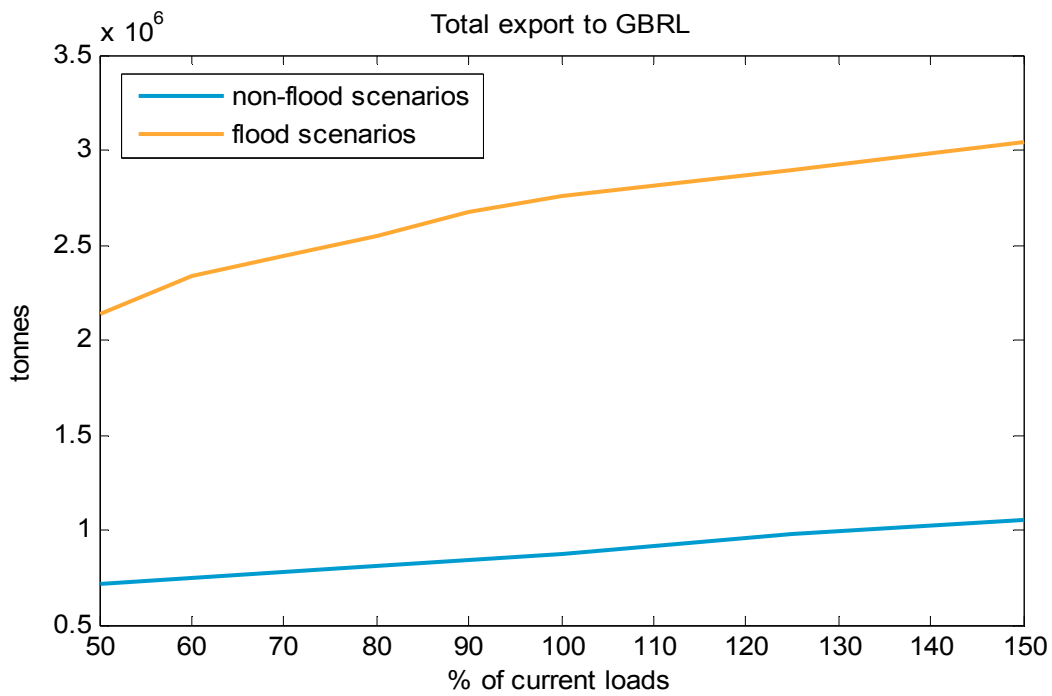


Figure 4 Simulated total sediment export to the Great Barrier Reef Lagoon over the duration of the simulation under different sediment and nutrient load scenarios.

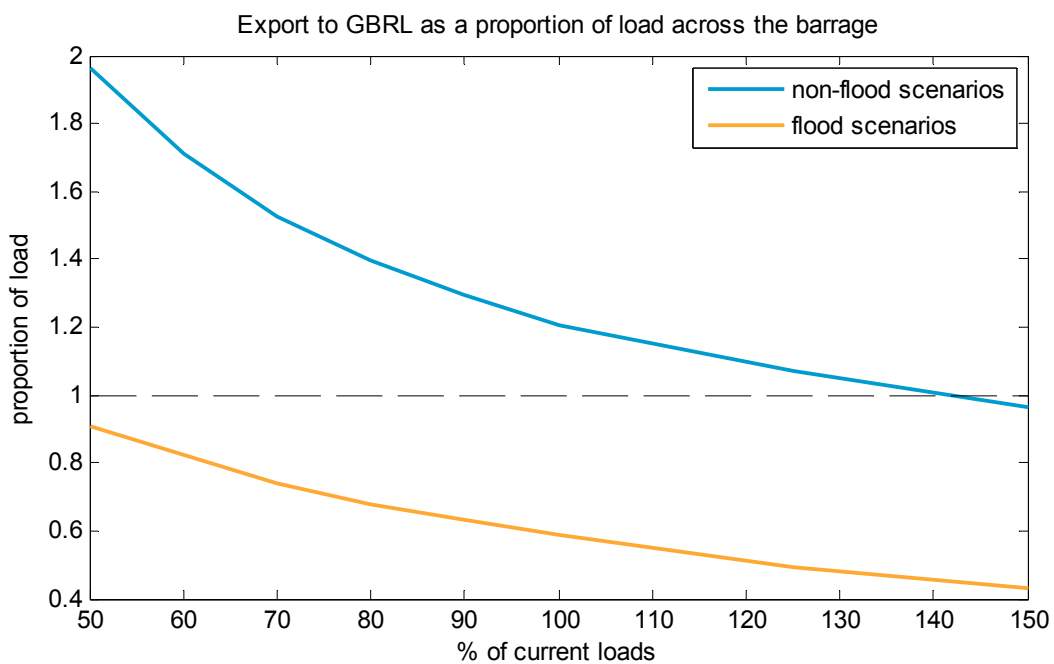


Figure 5 Simulated total sediment export to the Great Barrier Reef Lagoon over the duration of the simulation as a proportion of total sediment load from the barrage. Values less than one indicate a net increase in sediment stores in Fitzroy Estuary and Keppel Bay while values greater than one indicate a net loss of sediments from FE/KB.

Results for export of nitrogen (Figure 6 and Figure 8) and phosphorus (Figure 7 and Figure 9) are similar. In the non-flood scenarios (i.e. given the flows of a “typical” year without a major storm event), the model suggests that there is a net depletion of sediments and nutrients in the system: that is, more material is exported to the GBRL than is introduced to the system from the Fitzroy River.

During a major flood event, sediment and sediment phosphorus stores are replenished. The simulations do not show a substantial replenishment of nitrogen stores during the simulated flood event. There are a few possible explanations for this: nitrogen may be replenished primary from oceanic sources, by nitrogen fixation, or during even larger flood events. One

possibility that bears further investigation, however, is that the model overestimates breakdown of fresh organic nitrogen into dissolved forms which are more readily exported. Data from the recent flood event should help to fine-tune the nitrogen breakdown rate for the next version of the model. This information, unfortunately, was not available in time to be incorporated into these simulations.

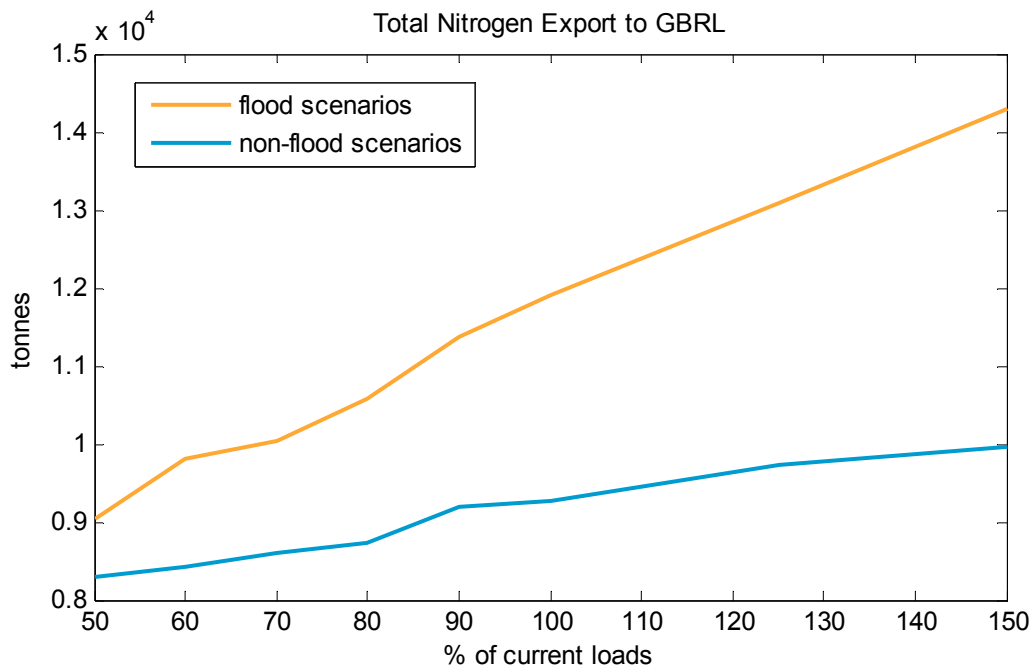


Figure 6 Simulated Total Nitrogen export to the Great Barrier Reef Lagoon over the duration of the simulation under different sediment and nutrient load scenarios.

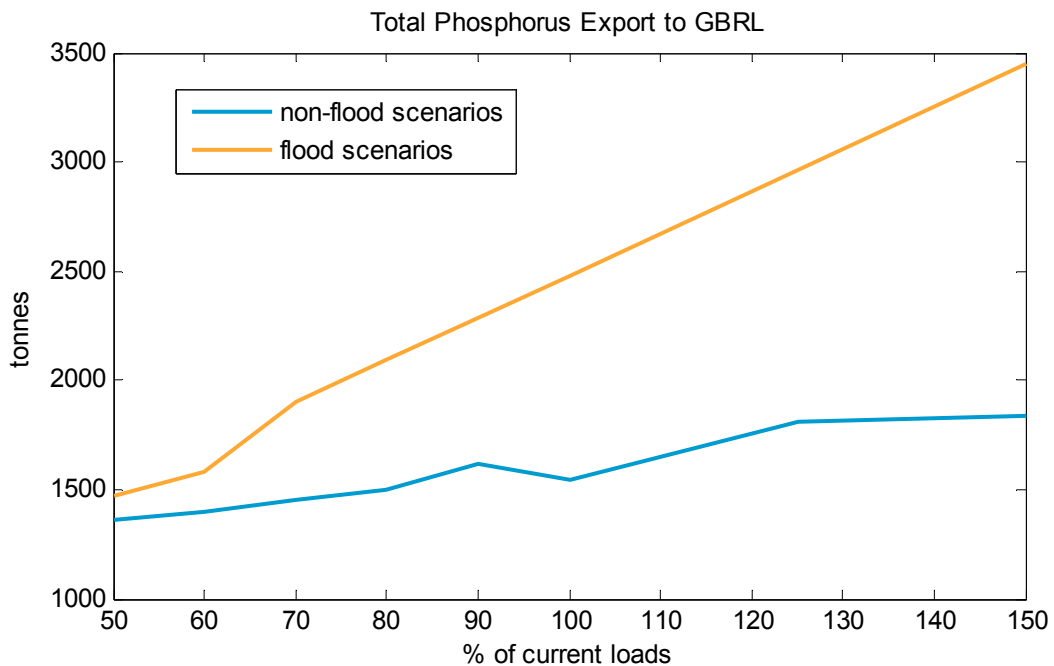


Figure 7 Simulated Total Phosphorus export to the Great Barrier Reef Lagoon over the duration of the simulation under different sediment and nutrient load scenarios.

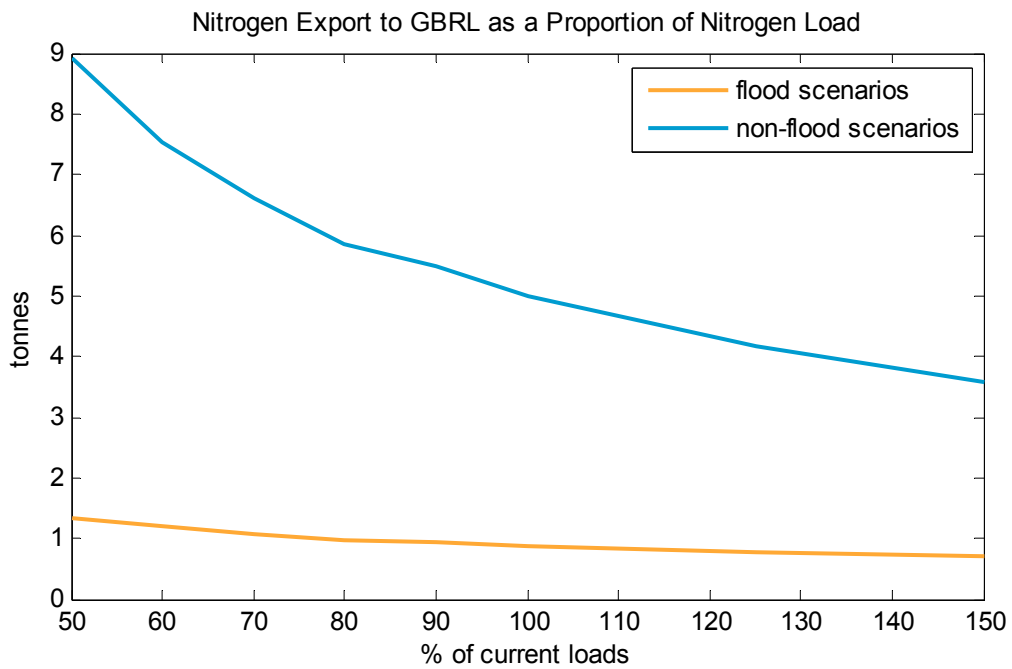


Figure 8 Simulated Total Nitrogen export to the Great Barrier Reef Lagoon over the duration of the simulation as a proportion of total nitrogen load from the barrage. Values less than one indicate a net increase in sediment nitrogen stores in Fitzroy Estuary and Keppel Bay while values greater than one indicate a net loss of sediments from FE/KB.

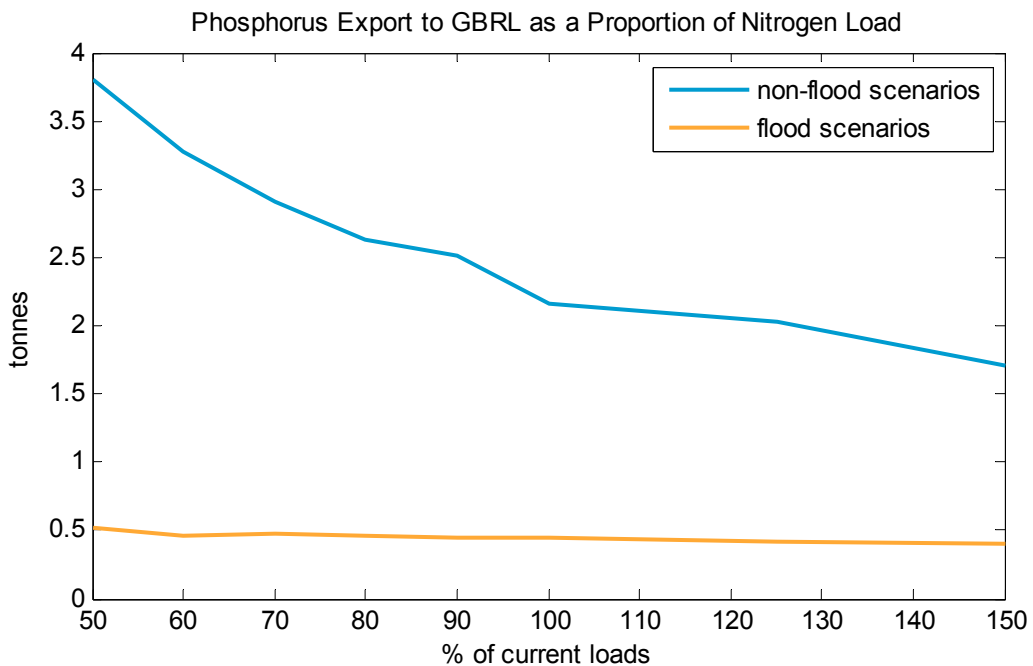


Figure 9 Simulated Total Phosphorus export to the Great Barrier Reef Lagoon over the duration of the simulation as a proportion of total phosphorus load from the barrage.

These results indicate the potential immediate effects of a reduction (or increase) in sediment loads. In the long term, sediment stores may reach a new equilibrium, so reductions in sediment loads will have a greater effect on exports than the immediate reduction shown here. Although time constraints prohibited conducting an extended simulation for each scenario, to demonstrate the likely longer-term impacts of reduced loads, one of the scenarios (a 50% reduction in sediment loads in a non-flood year) was continued for a second year. The results suggest that sediment stores under reduced load conditions may drop relatively rapidly in the first two low-flow months, but thereafter decline more slowly (Figure 10). The simulated total sediment export in the second year was approximately half that in the first year, suggesting that over the long term, exports to the GBRL might scale

linearly with loads to FE/KB: i.e. although 50% reduction in loads does not produce an immediate 50% reduction in exports, it is likely to produce a 50% reduction in exports in the long term.

The decline in sediment export over the second year of simulation shown in Figure 10 could be attributed not only to reduced sediment loads from catchments but also in part to adjustment of the sediment fields to new hydrodynamic conditions: running the model with 100% TSS loads might also result in a reduced second year export when we compare it with the first year results. This has not yet been tested.

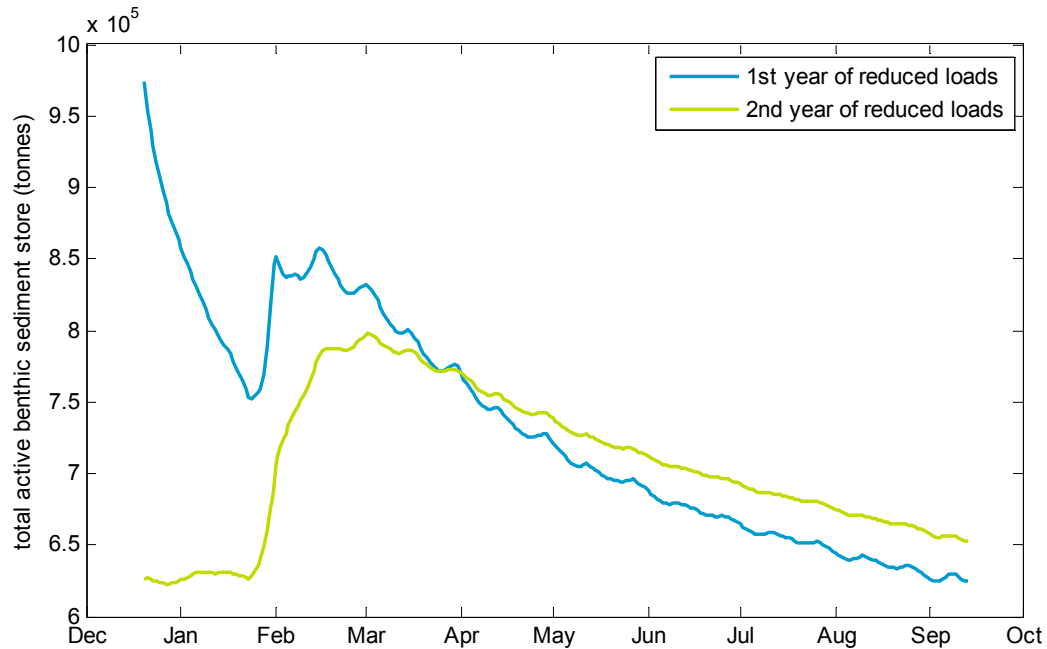


Figure 10 Time series of total sediment store in the Fitzroy Estuary and Keppel Bay over the duration of two sequential simulations of a non-flood year (i.e. 2003-2004 flows and meteorological conditions) with a 50% reduction in sediment loads. The blue line shows the immediate effect of reduced sediment loads, while the green line shows the effect when the simulation is continued for a second year with the same inputs (i.e. the blue line shows a simulation using 50% of the estimated current sediment and nutrient loads, while the green line shows an otherwise identical simulation initialised with output from the end of the simulation represented by the blue line).

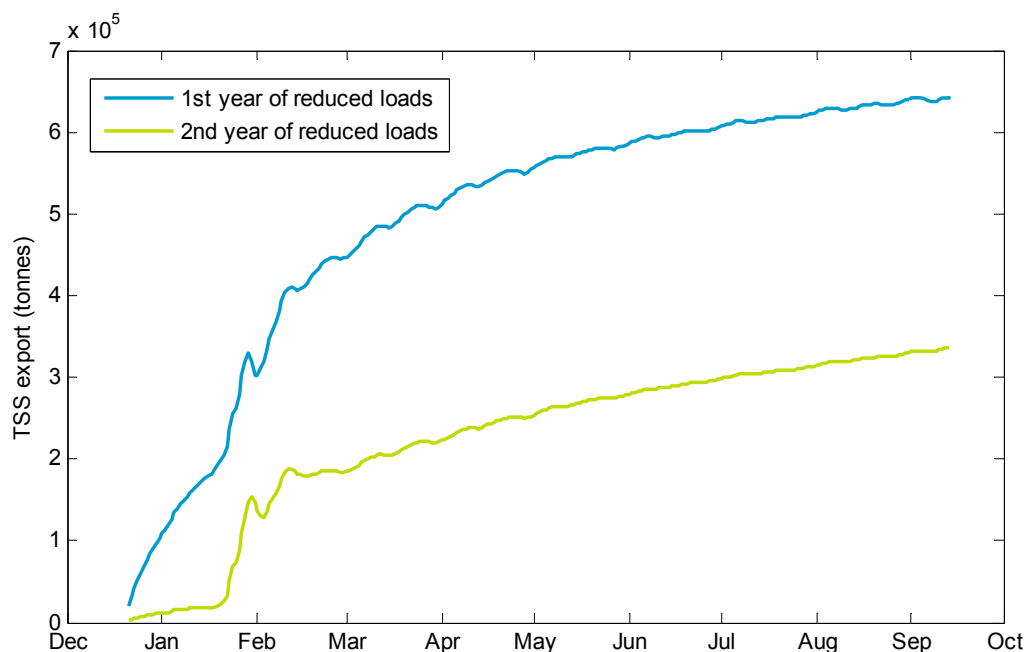


Figure 11 Time-series of total sediment exports to the GBRL over the duration of two sequential simulations of a non-flood year (i.e. 2003-2004 flows and meteorological conditions) with a 50% reduction in sediment loads. The blue line shows the immediate effect of reduced sediment loads, while the green line shows the effect when the simulation is continued for a second year with the same inputs.

3.4. Effects of changed loads on water quality trigger exceedance frequency

3.4.1. Total suspended sediments

Simulated TSS frequently exceeded defined trigger values, even in the non-flood scenarios at 50% of current loads (Table 3). This may call into question whether the defined triggers for the coastal and estuary zones are appropriate to this naturally turbid system.

TSS trigger exceedance for the estuary zone was particularly responsive to changes in catchment loads, with a 50% reduction in loads resulting in a 100% reduction in simulated dry-season trigger exceedance events for the non-flood scenarios.

This result is very sensitive to the trigger value, as water-column suspended solids concentrations in these simulations hovered around the defined estuary trigger value of 0.02 g/L (Table 4).

During the flood event scenarios, TSS concentrations (along with concentrations of nitrogen and phosphorus) were, not surprisingly, elevated in all regions for much of the period simulated (Table 5), and this was relatively insensitive to the simulated reduction or increase in total load.

Table 3 Percent of time for which trigger values for TSS were exceeded in surface water during typical (non-flood) flow scenarios. These values show simulated results for the first year following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

	dry season				wet season			
	coastal	enclosed coastal	estuary	inshore	coastal	enclosed coastal	estuary	inshore
50% of current loads	31	0	0	0	100	1	67	14
60% of current loads	37	0	4	0	100	1	73	14
70% of current loads	41	0	9	0	100	2	78	14
80% of current loads	43	0	14	1	100	2	78	14
90% of current loads	41	0	16	0	100	2	78	13
100% of current loads	42	0	23	0	100	2	78	13
125% of current loads	44	0	39	0	100	2	80	14
150% of current loads	53	0	62	1	100	2	81	14

Table 4 Mean TSS concentrations (mg/L) during typical (non-flood) flow scenarios. These values show simulated results for the first year following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

	dry season				wet season			
	coastal	enclosed coastal	estuary	inshore	coastal	enclosed coastal	estuary	inshore
50% of current loads	1.9	3.8	11.4	0.6	4.6	9.8	28.3	1.1
60% of current loads	1.9	4.1	12.7	0.6	4.7	10.0	30.1	1.1
70% of current loads	2.0	4.3	14.0	0.6	4.7	10.2	31.7	1.1
80% of current loads	2.1	4.5	15.1	0.7	4.8	10.4	33.0	1.1
90% of current loads	2.0	4.4	16.0	0.6	4.7	10.2	34.9	1.1
100% of current loads	2.1	4.6	17.2	0.7	4.7	10.3	36.1	1.1
125% of current loads	2.2	4.9	19.0	0.7	4.8	10.5	38.9	1.1
150% of current loads	2.3	5.4	21.4	0.7	4.9	10.6	41.4	1.2

Table 5 Percent of time for which trigger values for TSS were exceeded in surface water during flood flow scenarios. These values show simulated results for the first year following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

	dry season				wet season			
	coastal	enclosed coastal	estuary	inshore	coastal	enclosed coastal	estuary	inshore
50% of current loads	92	14	14	8	78	63	78	28
60% of current loads	92	14	14	8	78	74	78	28
70% of current loads	92	14	18	8	78	74	78	28
80% of current loads	92	14	18	8	78	74	78	28
90% of current loads	92	14	20	8	78	74	79	28
100% of current loads	92	14	20	8	78	74	80	28
125% of current loads	92	14	22	8	79	74	82	28
150% of current loads	92	14	26	8	79	74	82	28

3.4.2. Nitrogen

Simulated dissolved inorganic nitrogen (DIN, i.e. ammonium and nitrate) usually exceeded the defined trigger values for the estuary and enclosed coastal zones in all scenarios, though particulate nitrogen (and hence total nitrogen, TN) rarely exceeded the triggers. The accuracy of this prediction should be verified against recorded nitrogen species concentrations in the estuary.

Dissolved organic nitrogen (DON) by contrast, was rarely above the defined trigger values (Table 7), and never for scenarios in which simulated nitrogen loads were reduced to 80% of current loads or less.

Table 6 Percent of time for which trigger values for DIN were exceeded in surface water during typical (i.e. non-flood) flow scenarios. These values show simulated results for the first year following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

	dry season				wet season			
	coastal	enclosed coastal	estuary	inshore	coastal	enclosed coastal	estuary	inshore
50% of current loads	N/A	46	96	N/A	N/A	75	100	N/A
60% of current loads	N/A	50	96	N/A	N/A	75	100	N/A
70% of current loads	N/A	51	96	N/A	N/A	75	100	N/A
80% of current loads	N/A	54	96	N/A	N/A	75	100	N/A
90% of current loads	N/A	51	96	N/A	N/A	75	100	N/A
100% of current loads	N/A	54	96	N/A	N/A	75	100	N/A
125% of current loads	N/A	58	96	N/A	N/A	75	100	N/A
150% of current loads	N/A	73	96	N/A	N/A	75	100	N/A

Table 7 Percent of time for which trigger values for DON were exceeded in surface water during typical (i.e. non-flood) flow scenarios. These values show simulated results for the first year following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

	dry season				wet season			
	coastal	enclosed coastal	estuary	inshore	coastal	enclosed coastal	estuary	inshore
50% of current loads	N/A	0	0	N/A	N/A	0	0	N/A
60% of current loads	N/A	0	0	N/A	N/A	0	0	N/A
70% of current loads	N/A	0	0	N/A	N/A	0	0	N/A
80% of current loads	N/A	0	0	N/A	N/A	0	0	N/A
90% of current loads	N/A	0	0	N/A	N/A	0	9	N/A
100% of current loads	N/A	0	0	N/A	N/A	0	16	N/A
125% of current loads	N/A	0	1	N/A	N/A	0	29	N/A
150% of current loads	N/A	0	2	N/A	N/A	0	41	N/A

Fresh particulate nitrogen brought into the system during flood events is believed to be much more reactive than ‘worked-over’ particulate nitrogen in the Keppel Bay sediment stores, and in the model, this results in a large release of DIN as material in the flood plume breaks down. If the breakdown rate for fresh particulate organic material in the model is close to accurate, algal productivity (and hence secondary productivity) in the wake of flood events is likely to be particularly sensitive to changes in nutrient loads from the catchment. While a reduction in sediment and nitrogen loads should result in an increase in water clarity and a general improvement in water quality, it may also result in a diminished “boom” in fisheries following flood events.

3.4.3. Phosphorus

Dissolved inorganic phosphorus exceeded the trigger values less often than DIN, but was still frequently in excess of these values in the estuary zone (Table 8). DIP reacted less strongly changes in loads than did DIN, in part due to adsorption of DIP onto sediment particles, removing excess DIP from the water column.

Total Phosphorus (TP) rarely exceeded the defined trigger values in any of the scenarios, except during wet-season flow events (Table 9).

Table 8 Percent of time for which trigger values for DIP were exceeded in surface water during typical (i.e. non-flood) flow scenarios. These values show simulated results for the first year

following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

	dry season				wet season			
	coastal	enclosed coastal	estuary	inshore	coastal	enclosed coastal	estuary	inshore
50% of current loads	0	0	52	0	0	31	100	0
60% of current loads	0	0	52	0	0	32	100	0
70% of current loads	0	0	52	0	0	31	100	0
80% of current loads	0	0	52	0	0	32	100	1
90% of current loads	0	0	54	0	0	31	100	0
100% of current loads	0	0	54	0	0	30	100	0
125% of current loads	0	0	54	0	0	31	100	0
150% of current loads	0	0	55	0	0	31	100	0

Table 9 Percent of time for which trigger values for TP were exceeded in surface water during typical (i.e. non-flood) flow scenarios. These values show simulated results for the first year following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

	dry season				wet season			
	coastal	enclosed coastal	estuary	inshore	coastal	enclosed coastal	estuary	inshore
50% of current loads	0	0	0	0	0	0	63	0
60% of current loads	0	0	0	0	0	0	64	0
70% of current loads	0	0	0	0	0	0	64	0
80% of current loads	0	0	0	0	0	0	66	0
90% of current loads	0	0	1	0	0	0	77	0
100% of current loads	0	0	1	0	0	0	77	0
125% of current loads	0	0	1	0	0	0	81	0
150% of current loads	0	0	4	0	0	0	82	0

3.4.4. Secchi depth

Secchi depth estimates are subject to a high degree of uncertainty. The model suggests that Secchi depths are not likely to be worse than defined trigger values during non-flood conditions with any of the load scenarios, except in the coastal zone. In this zone, mean simulated Secchi depth during non-flood conditions was less than the defined trigger of 8m approximately 4% of the time during the dry season (regardless of load) and 20-25% of the time during the wet season (again regardless of load).

For the flood scenario, Secchi depths were (not surprisingly) lower in the wet season, with optical conditions not meeting the trigger target consistently in any of the four defined regions, but especially in the coastal zone. In the coastal zone, Secchi depth proved particularly sensitive to load during the flood event (Figure 12). Interestingly, the maximum rate of trigger value exceedance for Secchi depth in the coastal zone occurred at 60-70% of current nutrient loads (Figure 12), due to the balance between algal and non-algal contributions to turbidity (chlorophyll *a* concentrations were marginally higher in this area in the 60-70% of current load scenarios).

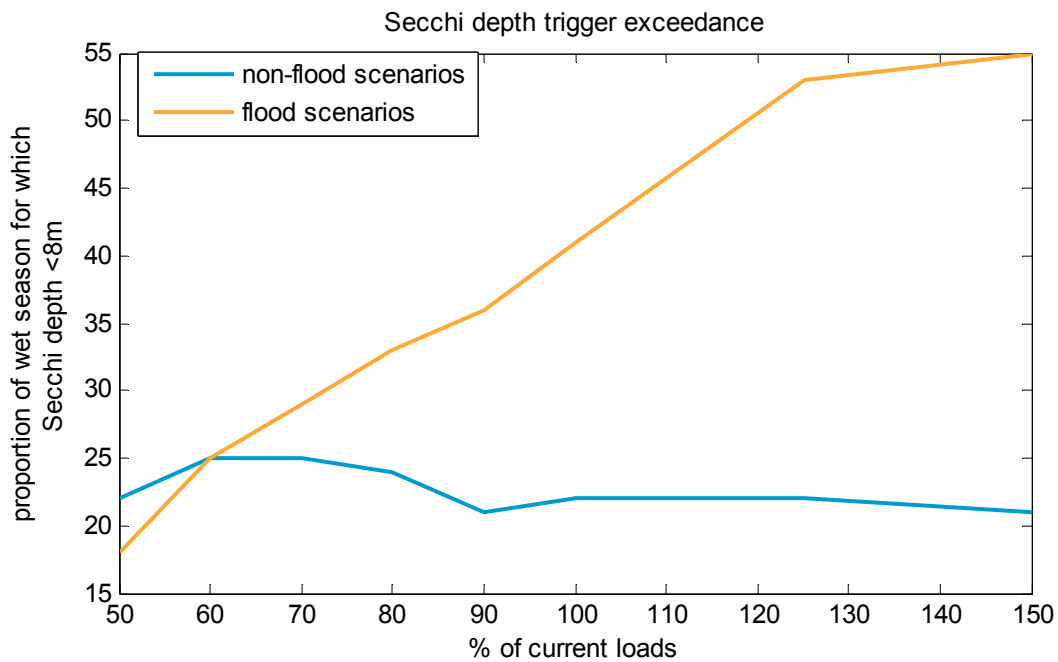


Figure 12 Effect of sediment and nutrient loads on wet-season trigger exceedance for Secchi depth in the coastal zone. These values show simulated results for the first year following a change in loads. Long-term impacts are expected to be greater as the system adjusts.

3.4.5. Sedimentation

Sedimentation rates vary in time, but the model suggests that total sedimentation is unlikely to exceed daily or mean annual trigger values for any of the four defined regions (although it may do so in very localised subregions).

3.4.6. Chlorophyll a

Simulated chlorophyll a did not respond to changes in sediment and nutrient loads. Previous results (Robson 2006) indicate that the model probably underestimates the degree of variability of chlorophyll a in the system, and it is likely that the sensitivity of chlorophyll a to changes in loads is also underestimated. When the model was originally calibrated, very limited observational data for chlorophyll a concentrations were available. More recently, satellite estimates of chlorophyll a have begun to show a clearer picture. Future work (beyond the scope of the present project) will focus on improving simulation of chlorophyll a in the system.

3.5. Effects of reaching load reduction targets on mean concentrations and sedimentation rates in Keppel Bay

The Fitzroy Basin Association is currently considering management actions that are expected to reduce sediment loads reaching Keppel Bay by between 11% and 44% in the medium term (i.e. to 2030). The following tables, based on scenario results for current conditions and for 11% and 44% load reductions, are included to provide information to support this decision. For this purpose, the “wet season” is taken as the months from December to February, and the “dry season” results are for the months between March to September (in the case of the “typical flow” simulations) or March to May (for the shorter, “flood year flow” simulations).

Table 10 Mean simulated sedimentation rates and surface water concentrations for each water body defined within Keppel Bay given current sediment and nutrient loads from the catchment and typical (2003-2004) flows.

	Dry season				Wet season					
	coastal	coastal	enclosed	estuary	inshore	coastal	coastal	enclosed	estuary	inshore
sedimentation rate (mg/cm ² /d)	-0.2	-0.1	-0.2	-0.2	-0.4	-0.2	1.2	-0.6		
carbon sedimentation (mg C/cm ² /d)	0.5	0.4	0.5	0.1	1.3	0.8	0.4	1.1		
Secchi depth (m)	10	7	5	13	9	5	3	12		
TSS (mg/L)	2.1	4.6	17.2	0.7	4.7	10.3	36.1	1.1		
TN (mg/L)	100	127	206	87	112	155	318	90		
PN (mg/L)	10	29	34	3	9	29	38	3		
DIN (mg/L)	5	11	46	1	11	24	95	2		
NH ₄ (mg/L)	4	6	17	1	4	8	25	1		
NO _x (mg/L)	2	6	33	1	8	17	76	2		
DON (mg/L)	89	95	135	85	96	111	201	87		
TP (mg/L)	4	7	16	3	6	11	31	4		
PP (mg/L)	0.3	0.8	1.5	0.1	0.4	1.2	2.9	0.1		
DIP (mg/L)	0.8	1.8	8.4	0.2	2.2	4.8	19.1	0.6		
Chl a (mg/L)	0.05	0.11	0.14	0.01	0.03	0.05	0.13	0.00		
% O ₂ saturation	99	99	100	98	100	100	100	100		

Table 11 Mean simulated sedimentation rates and surface water concentrations for each water body defined within Keppel Bay in the first year following an 11% reduction in sediment and nutrient loads from the catchment and typical (2003-2004) flows. Reductions in subsequent years are likely to be greater.

	Dry season				Wet season					
	coastal	coastal	enclosed	estuary	inshore	coastal	coastal	enclosed	estuary	inshore
sedimentation rate (mg/cm ² /d)	-0.2	-0.1	-0.2	-0.2	-0.4	-0.2	1.0	-0.6		
carbon sedimentation (mg C/cm ² /d)	0.5	0.3	0.4	0.1	1.3	0.8	0.4	1.0		
Secchi depth (m)	10	7	5	13	9	5	3	12		
TSS (mg/L)	2.0	4.4	15.9	0.6	4.7	10.2	34.7	1.1		
TN (mg/L)	100	126	202	87	112	153	309	90		
PN (mg/L)	10	29	34	3	9	29	38	3		
DIN (mg/L)	5	11	45	1	11	24	94	3		
NH ₄ (mg/L)	3	6	16	1	4	8	23	1		
NO _x (mg/L)	2	6	32	1	8	17	76	2		
DON (mg/L)	89	95	132	85	95	110	193	87		
TP (mg/L)	4	6	15	3	6	11	30	4		
PP (mg/L)	0.3	0.8	1.5	0.1	0.4	1.2	2.8	0.1		
DIP (mg/L)	0.8	1.8	8.4	0.2	2.2	4.8	19.1	0.6		
Chl a (mg/L)	0.06	0.13	0.15	0.01	0.03	0.05	0.13	0.00		
% O ₂ saturation	99	99	100	98	100	100	100	100		

Table 12 Mean simulated sedimentation rates and surface water concentrations for each water body defined within Keppel Bay in the first year following a 44% reduction in sediment and nutrient loads from the catchment and typical (2003-2004) flows. Reductions in subsequent years are likely to be greater.

	Dry season					Wet season				
	coastal	coastal	enclosed	estuary	inshore	coastal	coastal	enclosed	estuary	inshore
sedimentation rate (mg/cm ² /d)	-0.2	-0.1	-0.2	-0.2	-0.2	-0.4	-0.2	0.5	-0.6	-0.6
carbon sedimentation (mg C/cm ² /d)	0.5	0.3	0.4	0.0	0.0	1.3	0.8	0.4	1.1	1.1
Secchi depth (m)	10	8	5	13	13	9	5	3	12	12
TSS (mg/L)	1.9	4.0	12.2	0.6	0.6	4.6	9.9	29.4	1.1	1.1
TN (mg/L)	99	125	189	87	87	111	150	282	90	90
PN (mg/L)	10	30	34	3	3	9	29	36	3	3
DIN (mg/L)	5	10	41	1	1	11	24	89	3	3
NH ₄ (mg/L)	3	5	13	1	1	4	7	18	1	1
NO _x (mg/L)	2	6	31	1	1	8	18	76	2	2
DON (mg/L)	88	93	122	85	85	94	107	168	87	87
TP (mg/L)	4	7	15	3	3	6	11	28	4	4
PP (mg/L)	0.3	0.9	1.5	0.1	0.1	0.4	1.2	2.6	0.2	0.2
DIP (mg/L)	0.8	1.8	8.2	0.2	0.2	2.3	5.0	18.8	0.6	0.6
Chl a (mg/L)	0.08	0.18	0.19	0.01	0.01	0.03	0.05	0.13	0.01	0.01
% O ₂ saturation	99	99	100	98	98	100	100	100	100	100

Table 13 Mean simulated sedimentation rates and surface water concentrations for each water body defined within Keppel Bay given current sediment and nutrient loads from the catchment during a major flood event (2008 flows).

	Dry season					Wet season				
	coastal	coastal	enclosed	estuary	inshore	coastal	coastal	enclosed	estuary	inshore
sedimentation rate (mg/cm ² /d)	-0.7	-0.5	-1.0	-0.9	-0.9	-0.1	0.2	8.1	-0.3	-0.3
carbon sedimentation (mg C/cm ² /d)	1.1	0.3	-0.3	0.3	0.3	2.3	1.5	0.8	1.4	1.4
Secchi depth (m)	8	5	3	12	12	9	5	3	11	11
TSS (mg/L)	5.8	12.9	23.0	1.3	1.3	10.3	30.1	67.8	3.0	3.0
TN (mg/L)	124	181	320	93	93	176	339	618	117	117
PN (mg/L)	11	31	33	6	6	7	18	40	5	5
DIN (mg/L)	8	18	57	1	1	23	64	129	8	8
NH ₄ (mg/L)	8	17	43	1	1	15	40	85	4	4
NO _x (mg/L)	2	4	20	0	0	9	24	45	4	4
DON (mg/L)	112	144	247	91	91	152	265	471	106	106
TP (mg/L)	7	14	31	4	4	21	52	90	10	10
PP (mg/L)	0.3	1.2	1.4	0.1	0.1	0.7	1.8	2.7	0.5	0.5
DIP (mg/L)	1.4	3.4	12.2	0.3	0.3	11.8	31.4	52.4	5.4	5.4
Chl a (mg/L)	0.08	0.15	0.26	0.02	0.02	0.07	0.18	0.36	0.04	0.04
% O ₂ saturation	100	100	100	100	100	100	100	99	100	100

Table 14 Mean simulated sedimentation rates and surface water concentrations for each water body defined within Keppel Bay in the first year following an 11% reduction in sediment and nutrient loads from the catchment during a major flood event (2008 flows). Reductions in subsequent years are likely to be greater.

	Dry season					Wet season				
	coastal	coastal	enclosed	estuary	inshore	coastal	coastal	enclosed	estuary	inshore
sedimentation rate (mg/cm ² /d)	-0.7	-0.5	-0.9	-0.9	-0.9	-0.1	0.2	6.7	-0.3	-0.3
carbon sedimentation (mg C/cm ² /d)	1.1	0.3	-0.3	0.3	0.3	2.3	1.5	0.8	1.4	1.4
Secchi depth (m)	8	5	3	12	12	9	5	3	11	11
TSS (mg/L)	5.7	12.7	22.4	1.3	1.3	10.0	29.4	64.9	3.0	3.0
TN (mg/L)	122	176	303	93	93	169	318	569	115	115
PN (mg/L)	11	31	32	6	6	7	18	38	5	5
DIN (mg/L)	7	17	53	1	1	22	60	120	8	8
NH ₄ (mg/L)	7	16	39	1	1	13	36	77	4	4
NO _x (mg/L)	1	4	20	0	0	9	24	45	4	4
DON (mg/L)	110	139	233	91	91	146	247	430	104	104
TP (mg/L)	7	13	30	4	4	20	50	86	10	10
PP (mg/L)	0.3	1.3	1.4	0.1	0.1	0.7	1.8	2.6	0.5	0.5
DIP (mg/L)	1.4	3.4	12.2	0.3	0.3	11.8	31.3	52.2	5.4	5.4
Chl a (mg/L)	0.08	0.15	0.27	0.02	0.02	0.07	0.18	0.36	0.04	0.04
% O ₂ saturation	100	100	100	100	100	100	100	99	100	100

Table 15 Mean simulated sedimentation rates and surface water concentrations for each water body defined within Keppel Bay in the first year following a 44% reduction in sediment and nutrient loads from the catchment during a major flood event (2008 flows). Reductions in subsequent years are likely to be greater.

	Dry season					Wet season				
	coastal	coastal	enclosed	estuary	inshore	coastal	coastal	enclosed	estuary	inshore
sedimentation rate (mg/cm ² /d)	-0.7	-0.5	-0.9	-0.9	-0.9	-0.1	0.2	6.7	-0.3	-0.3
carbon sedimentation (mg C/cm ² /d)	1.1	0.3	-0.3	0.3	0.3	2.3	1.5	0.8	1.4	1.4
Secchi depth (m)	8	5	3	12	12	9	5	3	11	11
TSS (mg/L)	5.3	11.3	19.2	1.2	1.2	8.6	24.9	51.5	2.9	2.9
TN (mg/L)	122	176	303	93	93	169	318	569	115	115
PN (mg/L)	11	31	32	6	6	7	18	38	5	5
DIN (mg/L)	7	17	53	1	1	22	60	120	8	8
NH ₄ (mg/L)	7	16	39	1	1	13	36	77	4	4
NO _x (mg/L)	1	4	20	0	0	9	24	45	4	4
DON (mg/L)	110	139	233	91	91	146	247	430	104	104
TP (mg/L)	7	13	30	4	4	20	50	86	10	10
PP (mg/L)	0.3	1.3	1.4	0.1	0.1	0.7	1.8	2.6	0.5	0.5
DIP (mg/L)	1.4	3.4	12.2	0.3	0.3	11.8	31.3	52.2	5.4	5.4
Chl a (mg/L)	0.08	0.15	0.27	0.02	0.02	0.07	0.18	0.36	0.04	0.04
% O ₂ saturation	100	100	100	100	100	100	100	99	100	100

4. UNCERTAINTY AND MODEL LIMITATIONS

4.1. Accuracy of model predictions under current conditions

The accuracy of the Fitzroy Receiving Waters model under current conditions has been discussed previously by Robson et al. (2008), and the accuracy of the sediment and hydrodynamic components of the model is discussed in more detail by Margvelashvili (2006) and Herzfeld (2006). In short, while we have a reasonable degree of confidence in the model's ability to simulate the well-understood physical processes affecting currents, salinity and temperature, the model is somewhat less accurate in simulating suspended particulate materials. Along the coast in the enclosed coastal zone, suspended sediment and particulate nutrient concentrations are probably over-estimated. Chemical and biological processes add another layer of complexity and additional potential sources of error. The model, as applied during the Coastal Zone CRC, performed reasonably well in reproducing observed concentrations of dissolved inorganic nutrients (DIN and DIP) and dissolved organic nitrogen, but less well for particulate nutrients and dissolved oxygen, and poorly for chlorophyll *a* (see Robson et al., 2008 for details of metrics used). Overall, model performance in predicting dry-season dissolved and total nutrient concentrations was considered satisfactory (Robson et al., 2006), but performance for wet-season conditions was not as strong.

The model results will be most reliable when used to indicate the direction and magnitude of change expected under the scenarios considered.

4.2. Applicability of the model to flood conditions

The Fitzroy Receiving Waters Model was developed and validated for non-flood conditions (Herzfeld, 2006; Margvelashvili, 2006; Robson 2006) and has not yet been validated against observational data for flood conditions. A parallel project being conducted through the CSIRO Water for a Healthy Country Flagship (the "Fitzroy Flood Modelling and Analysis" project) aims to perform this comparison using satellite data and *in situ* measurements made during the 2008 flood event. Early indications are that the model performs well in simulating the plume extent and direction (Figure 16), and that simulated suspended sediment (Figure 13) and total nitrogen (Figure 14) and dissolved organic nitrogen (Figure 15) concentrations correlate well with *in situ* measurements, although suspended sediment concentrations are consistently over-estimated by the model, suggesting perhaps that some of the sediment material in the flood was deposited on the floodplain before reaching Keppel Bay. Simulated NH_4 and chlorophyll *a* were not correlated with observations made during the flood, and these aspects of the model need to be refined. The Fitzroy Flood Modelling and Analysis project is due for completion in June 2010, and results will be communicated to the FBA.

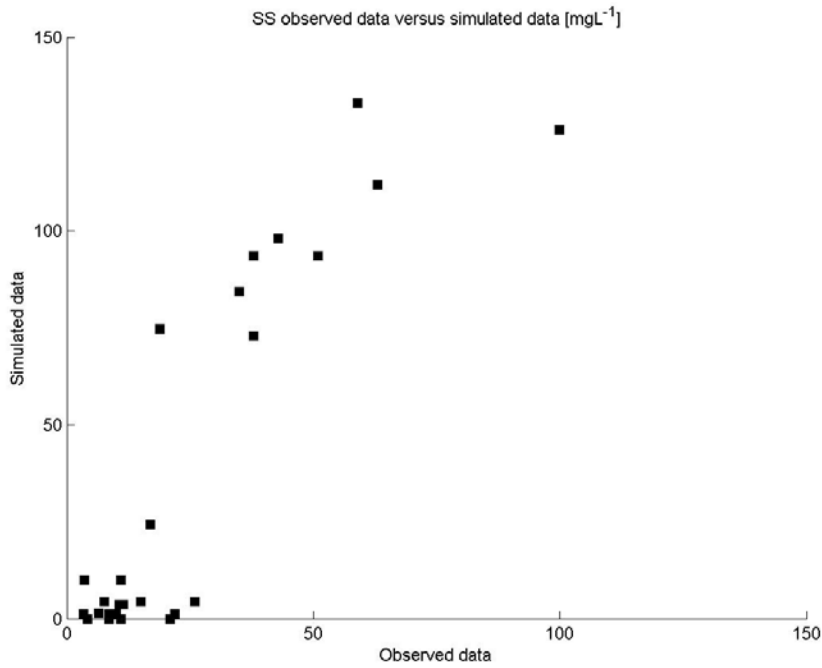


Figure 13 Total suspended solids measured in surface water samples taken from Keppel Bay, 31 January to 9 February, versus simulated total suspended sediment concentrations.

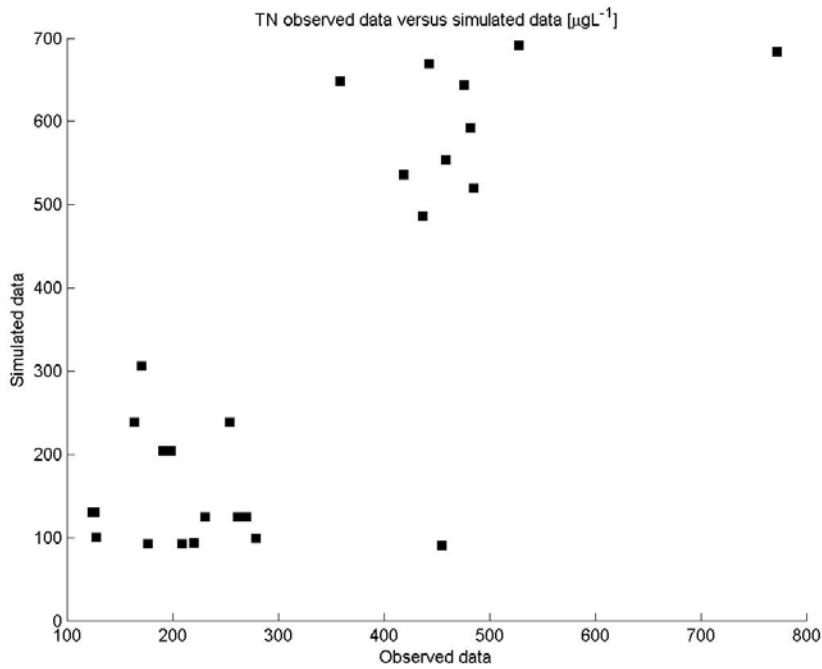


Figure 14 Total nitrogen measured in surface water samples taken from Keppel Bay, 31 January to 9 February, versus simulated total nitrogen concentrations. *In situ* measurements are from data collected by CSIRO, GBRMPA, JCU and AIMS.

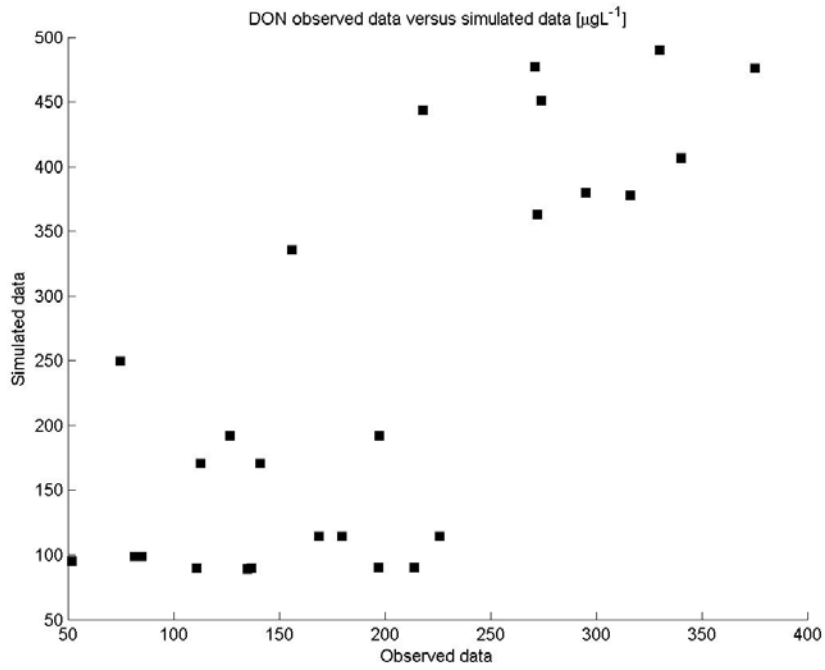


Figure 15 Total suspended solids measured in surface water samples taken from Keppel Bay, 31 January to 9 February, versus simulated dissolved organic nitrogen concentrations. *In situ* measurements are from data collected by CSIRO, GBRMPA, JCU and AIMS.

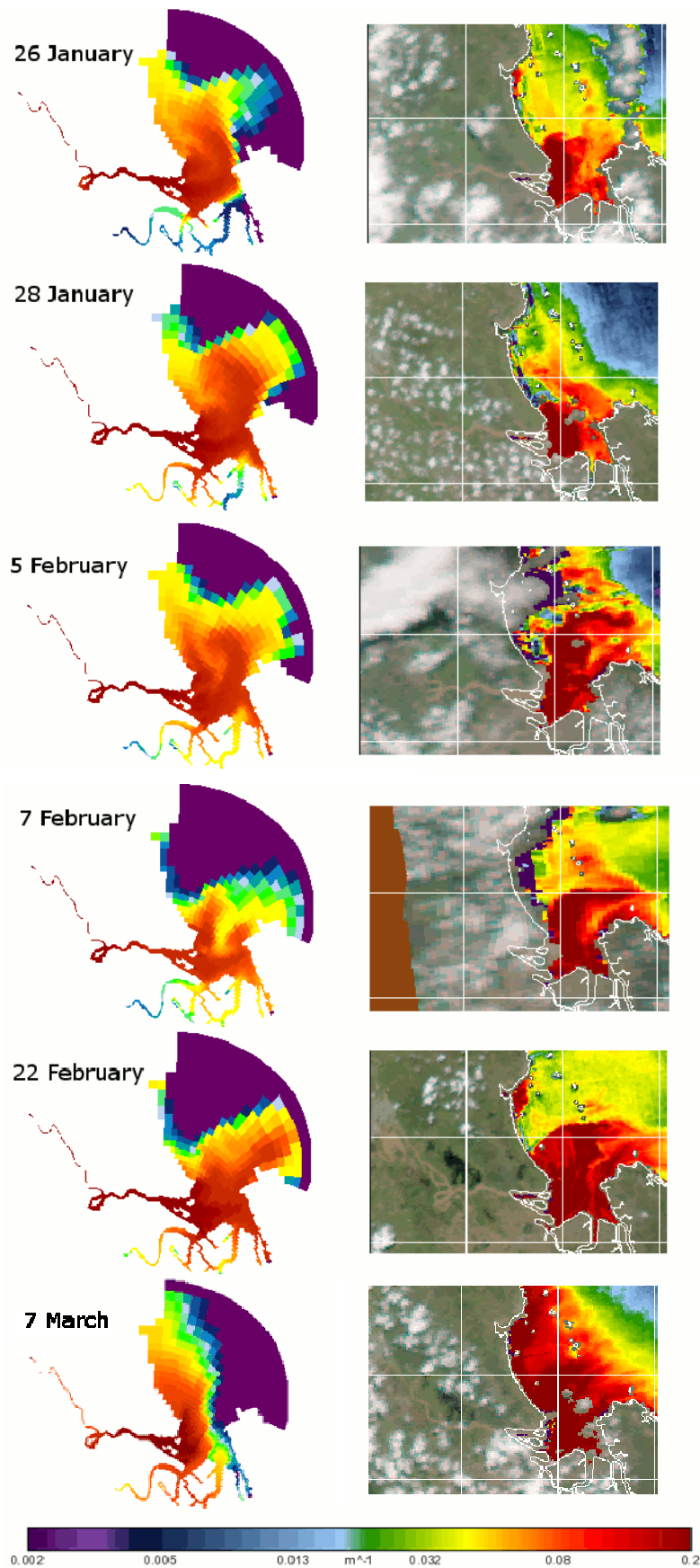


Figure 16 Left: Simulated total suspended solids (kg m^{-3} , left) and satellite observed total backscatter at 550 nm (m^{-1} , right). These measures are not directly comparable, but serve to allow a qualitative comparison of the simulated and observed extent and location of the flood plume on days for which cloud-cover was sufficiently low to allow a clear satellite image. Satellite images are from MODIS-Aqua products provided by the Naval Research Laboratory, Stennis Space Centre, MS.

4.3. Validity of scenario assumptions

SedNet simulations predict changes in annual average sediment loads and (with SedNet-ANNEX) average annual total nitrogen and phosphorus loads. The Fitzroy Receiving Waters Model requires as input daily sediment and speciated nutrient loads. For the scenario simulations, the relative reduction (or increase) in sediment and nutrient loads was assumed to apply uniformly over the entire scenario period: in other words, each daily load estimate for current conditions was multiplied by a fixed value. In reality, it is likely that land use changes would influence exports at high flows and low flows to different degrees, and might also influence loads on the rising and falling flood differently. The effect of this on scenario results is difficult to predict, however if it was primarily loads associated with high flows that were affected by the land use and management changes associated with the scenarios, it is likely that dry-season conditions under all scenarios would be closer to current conditions than the model results suggest.

A second factor to consider is the pace of change. The scenarios here represent the effect of a sudden change to the load indicated. With a more gradual, long-term change, sediment stores in Keppel Bay would be likely to change over time. Water quality in Keppel Bay and sediment and nutrient exports to the GBRL are influenced not only by current inflow conditions, but also by sediment stores. Previous modelling work suggests, for instance, that water quality and material fluxes following a major flood event are likely to be influenced by that event for several years afterwards (Margevelashvili 2006, Robson et al., 2006).

Finally, changes in nutrient and sediment loads due to changes in land use and management are themselves uncertain (Dougall et al., 2008) and are likely to be complicated by climate variability and, over the medium term, by climate change. If major storm events become more frequent, for instance, or baseline rainfall declines, that will directly influence both sediment and nutrient loads to FE and rates of chemical and biological processes in the receiving waters.

5. FUTURE WORK

The Fitzroy Flood Modelling and Analysis project, mentioned previously in section 4.1, aims to:

- Verify the applicability of the Fitzroy Receiving Waters Model under flood conditions by comparing model predictions with *in situ* and satellite observations;
- Improve the performance of the model under flood conditions; and
- Use the model and observational data to explore the function of the FE/KB system during and after a flood, and consider likely implications for ecological function.

This project is due for completion in June 2010, subject to renewal of funding in July 2009.

Other ongoing work aims to improve the performance of the model's simulation of primary production by incorporating a more physically realistic model for light propagation (Cherukuru et al.).

There is potential to build further on this work and improve the results through a number of avenues, not currently fully scoped. These might include:

- Expansion of the model domain further into Keppel Bay, and onto the flood-plain;
 - Linking the model with a GBRL-scale biogeochemical model, the development of which has been proposed and scoped recently (Webster et al. 2007);
 - Application of the models to climate change scenarios;
 - Linking the model more directly to ecological outcomes, for instance by simulating the dispersal of coral propagules and conditions to which fish recruits might be exposed;
- or

- Expanding the model to incorporate pesticides and other pollutants.

Nonetheless, we believe that the model in its present form will provide information of direct relevance to water quality management and management of ecological assets in this system.

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