Climate Change Impacts on the Sediment Load for the Nogoa Catchment of the Fitzroy Basin

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Keywords: *Nogoa, E2, Sediment load, Climate change, Land use change*

EXTENDED ABSTRACT

The likelihood of changes to mean annual total suspended solids (TSS) was assessed for the Nogoa catchment (Figure 1) by perturbing input data to the E2 Model according to quantified ranges of climate change for 2030. These ranges incorporate the range of global warming according to the IPCC Third Assessment Report and regional changes in temperature, rainfall and potential evaporation encompassing the results from nine different climate models. The wettest, driest and average climate scenarios for the region were used in hydrological models to assess changes in water flow for the Nogoa catchment of the Fitzroy Basin (Nogoa River and Theresa Creek). Changes in land use (cropping, grazing) were applied to the models and sediment loads in the waterways were simulated under existing and climate change conditions. Changes in climate, water flow and sediment loads were measured against a base period from 1961-1990.

The dry scenario for 2030 was associated with a mean temperature increase of 1.4^{o}C, 9% lower annual rainfall, 10% higher evaporation and 10-13% lower annual flow. The wet scenario for 2030 was associated with a mean temperature increase of 0.9^{o}C, 2% higher annual rainfall, 2% higher evaporation and 10-13% higher annual flow.

The range of change in TSS from the driest and wettest extremes of regional climate change indicate a wide range of change in mean annual TSS ranging from approximately -11% to +12% for Craigmore (southern part of catchment) and -33% to +38% for Theresa Creek (northern part of catchment) by 2030. These changes in TSS were influenced by land use. Doubling cropping land use at the expense of grazing was associated with higher sediment loads and decreasing cropping in favour of grazing with lower sediment loads.

The combined sediment loads for Craigmore (0.541 Mt/year) and Theresa Creek (0.477 Mt/year) was 1.02 Mt/year for the base scenario which corresponds with an independent study at Duck Ponds (at the end of the Nogoa catchment), where a mean annual sediment load of 1.23 Mt/year was estimated.

Increased sediment (and nutrient) load in the watercourses of the Nogoa catchment may increase the amount of sediment deposition onto coral reefs and the ocean floor, increase turbidity and water temperature and restrict aquatic animal and plant processes. The removal of topsoil may also reduce the production of terrestrial animals and plants.

The use of agricultural land by the cropping and grazing sectors influences runoff, flows and sediment deposition into watercourses. A wet climate change scenario in 2030 may create more cropping, whereas a dry scenario is likely to create more grazing, probably at the expense of cropping. Managing these systems to maintain good groundcover slows runoff and reduces sediment loads. The use of sustainable agricultural management practices will help reduce the risk of damage to terrestrial and aquatic resources and help maintain agricultural productivity.

Figure 1. The Fitzroy River Basin showing major catchments.

1. INTRODUCTION

The Fitzroy Basin covers an area of approximately 142,500 km^2. It contains about 10% of Queensland's agricultural land and 95% of the catchment is under agricultural land use, comprising about 80% grazing and 6% dryland cropping, while irrigated agriculture is economically significant but less than 1% of land use. Forestry accounts for around 900 000 hectares of land across Central Queensland, and remnant vegetation covers approximately 1.8 million hectares. Primary producers are increasingly becoming involved in agroforestry as an alternative/supplement to cropping and grazing, indicating an increase in private forestry in addition to that controlled by the State. Approximately 6% of the region's land is under conservation management.

The Fitzroy Basin includes the catchment of the Fitzroy River and its major tributaries: the Dawson, Comet, Nogoa, Mackenzie, Isaac and Connors Rivers (Figure 1). The Fitzroy is the largest river basin on the east coast of Australia, and drains to the southern end of the Great Barrier Reef, just south-east of Rockhampton.

Although dryland cropping is an important industry for the Fitzroy Basin, it is located at the northern margin of the wheat cropping region of Australia. Prior to the 1970s, the Emerald region was primarily used for grazing beef cattle despite the potential for higher gross margins in cropping. Subsequently in the next 30 years cropping developed in importance and it's possible that the relative suitability of cropping versus grazing is an artefact of recent climate (Howden *et al.* 2001). If the increase in cropping was due to long-term climate variability (the variation of climate from a mean on decadal or longer timescales, which is cyclic in nature) then cropping is likely to decline in the region as conditions return to those experienced earlier in the record. If the increase in cropping was related to climate change (a persistent upward or downward trend in climate) then cropping in the region is likely to persist. These changes in land use influence the natural resources and one possible impact is the sediment loads in rivers and their eventual deposition onto the water around the southern part of the Great Barrier Reef.

This study involves the Nogoa catchment where various land uses are currently practised (Figure 2) and which has undergone a significant change from grazing to cropping since 1970. On a basin scale this change represents about 6% of land use. This study compares the sediment load currently produced by grazing and cropping systems to that produced if the cropping area doubles at the expense of grazing at 2030 (i.e. 6 to 12% is the same rate of land use change as that experienced between 1970 and 2000) and if the current cropping area is replaced by grazing at 2030.

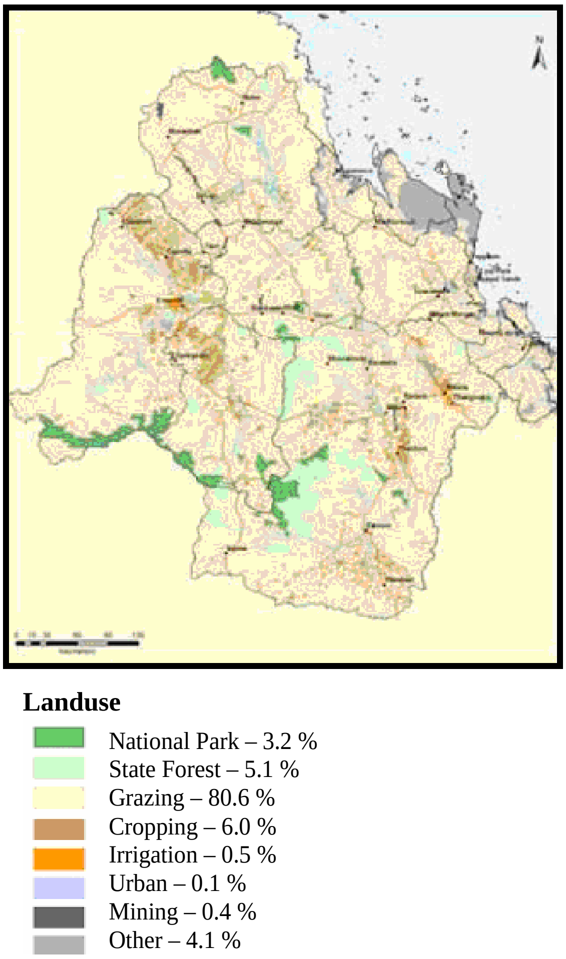

Figure 2. Land use in the Fitzroy Basin showing grazing and cropping areas.

2. METHOD

2.1. General circulation models

The overall approach was to perturb historical records of climate variables required to run various models using a series of climate change scenarios for 2030. The aim of this study was to represent the range of uncertainty displayed by a number of climate models rather than attempt to develop precise scenarios from individual models.

The projections of percent changes in regional climate variables were extracted from CSIRO's OzClim database and from the CSIRO Consultancy Report on climate change in

Queensland (Cai *et al.* 2003). The OzClim database includes different emission scenarios and global circulation models. The projections from a range of international General Circulation Models (GCM's), and regional climate models (RCMs) were used (Table 1). This set of nine models includes some of the models that were used by CSIRO in its recent studies in the Burnett and Fitzroy region (Durack *et al.* 2005) and represent a broad range of climate change scenarios.

The multiple series of climate variables for 2030 climate were run through the E2 model to produce output that was conditioned on 2030 climate.

Table 1. Climate model simulations analysed in this report. Note that DARL125 and CC50 are regional climate models

Centre	Model	Emissions Scenarios	Years	Horizontal resolution (km)
CSIRO, Aust	CC50	SRES A2	1961-2100	50
CSIRO, Aust	Mark2	IS92a	1881–2100	~400
CSRIO, Aust	Mark 3	SRES A2	1961-2100	~200
CSIRO, Aust	DARL125	IS92a	1961–2100	125
Canadian CC	CCCM1	IS92a	1961–2100	~400
DKRZ Germany	ECHAM4	IS92a	1990–2100	~300
Hadley Centre, UK	HadCM3	IS92a	1861–2099	~400
NCAR	NCAR	IS92a	1960-2099	~500
Hadley Centre, UK	HadCM3	SRES A1T	1950–2099	~400

2.2. Perturbing historical data

The locations of climate stations within the Nogoa catchment of the Fitzroy Basin (Figure 1) close to the Nogoa River and Theresa Creek were chosen for the extraction of climate change factors using Ozclim. The stations that were chosen included Anakie, Bogantungan, Capella, Clermont, Emerald, Glentana, Gordon Downs, Mantuan Downs, Peakvale and Telemon.

These stations covered a large area of the catchment and represented a range of climate change factors over this region. Ozclim was used to obtain climate change maps for rainfall and evaporation, for each of the models and scenarios listed in Table 1, for all months. Each OzClim map was imported into ArcGIS and the points of the climate stations were overlayed. The climate change factors for rainfall and evaporation for each location and month were recorded and imported into a spreadsheet. This process was carried out for all the models and scenarios listed in Table 1.

The average monthly climate change factors for rainfall and evaporation across the Nogoa catchment were calculated by taking the average across all stations for each month, for each climate model and scenario. These factors were graphed for each model and scenario to help choose the three models for the wet, median and dry scenarios of climate change.

The wet scenario was represented by the ECHAM4 model with IS92a emissions warming at high climate sensitivity and the dry scenario by the CC50 model with SRES A2 emissions warming at high climate sensitivity. The average scenario was chosen to be the average of the factors for all of the climate models and scenarios in Table 1. The average of the factors of all of the climate models produced climate change factors that were midway between the wet and dry scenarios in most cases.

2.3. Model configuration

E2 is a software product for whole-of-catchment modelling (Argent *et al.* 2006). Models created using E2 will predict the flow and load of constituents, such as sediment and nutrients, at any point in a river network over time, operating at daily (or sub-daily) time steps and reporting on a variety of time scales.

DEM data (from Natural Resources & Water) was used to configure the hydrological network in the Nogoa catchment. Corrected DEM data (after pit-filling with ArcGIS software) was entered into E2 and 142 sub-catchments were defined, the hydrological network comprising all major streams and rivers.

The functional units were grouped into five land use categories, which were forest, water, grazing, cropping and urban. An arc-ascii grid file of land use data for the Nogoa catchment (from NRW) was used and matched with the appropriate land use codes in E2. For each functional unit a constituent model of EMC/DWC applied a fixed concentration of sediment (in mg/L) for each land use type. The concentration of sediment was calculated using expert knowledge (monitoring data, published papers and experience) of soil erosion data for different land uses.

In the configuration the 'straight through' link model was used to route flows which carried sediments through to the end of system. Filter and node models were not used in this study.

2.4. Model calibration

The flows and TSS models were calibrated using recorded data at Craigmore and Theresa Creek (at the junction of Retreat Creek). Craigmore is upstream of Fairbairn Dam on the Nogoa River and covers an area of 14140 km^2 in the southern part of the Nogoa catchment. Theresa Creek represents northern parts of the catchment and covers an area of 8415 km^2.

The rainfall and evaporation data used has been described for Craigmore and Theresa Creek (Mahmutovic 1998a, Mahmutovic 1998b). Observed flow and TSS data at these locations was obtained from the Watershed website of NRW (www.nrw.qld.gov.au/watershed).

Flows were calibrated using Simhyd in the rainfall runoff library (RRL) (Podger 2004) to utilise the automated calibration, optimisers and objective functions, features that were not available for the version of Simhyd in E2. The calibrated parameters generated in Simhyd (RRL) were then used in Simhyd (E2) to generate water flows. We used a combination of correlation and matching probability of exceedance (POE) curves to determine 'best-fit' parameterisation. For example, correlation coefficients between observed and modelled values were compromised to provide distributions of observed and simulated flows that were similar, across the whole range of the POE curve. The linear correlation between observed and simulated flows at Craigmore was R=0.691 and R=0.647 at Theresa Creek.

TSS was calibrated using observed TSS data at Craigmore and Theresa Creek. At Craigmore the association between observed and simulated TSS was R=0.77 (n=48) and the POE curves matched relatively well, although there was some discrepancy in the very high range (>100kg/s). Using the same parameter values the linear correlation between observed and simulated TSS at Theresa Creek was R=0.81 (n=58), although the model tended to overestimate TSS in the low range (0-4 kg/s). This maybe associated with a difference in the frequency of observed no flows between Theresa Creek and Craigmore.

The higher apparent correlations between observed and simulated TSS compared to flows maybe due to 1) differences in the number of data points and 2) R values being compromised to 'best fit' the observed and simulated POE distribution curves. For example, the correlation of TSS data was apparently higher at Theresa Creek than Craigmore, however the POE curves for simulated TSS did not match observed TSS at Theresa Creek as well as they did for Craigmore.

2.5. Application of climate change factors

Base data was comprised of 30 years of daily data from 1961 to 1990 for two rainfall stations and one evaporation station applied across the upper and lower regions of the catchment. Percentage changes derived from OzClim for precipitation and evaporation for each month of 2030 were multiplied with the base data. The climate change factors that were used to modify the base data for precipitation and evaporation are shown in Appendix A. E2 was run calculating the streamflow and TSS for base conditions (1961-1990) and rerun using the modified climate files to obtain the flows and TSS for the wet, average and dry climate change scenarios.

3. RESULTS

Mean changes in temperature, rainfall and evaporation for the dry, average and wet climate change scenarios for 2030 are shown in Table 2.

3.1. Craigmore flow changes

The results show that based on the set of scenarios, either increases or decreases in stream flow are possible for the Nogoa catchment. The change in mean annual flow for Craigmore ranges from approximately -12.7% to +13.4% by 2030. Table 2 shows the change in mean annual flow for each of the climate change scenarios. The wet/dry scenarios were associated with higher/lower flows than the base scenario, the differences being more evident at high flows.

Table 2. Mean changes in temperature, rainfall, evaporation and annual stream flow for Craigmore and Theresa Creek for the dry, average and wet climate change scenarios for 2030

Scenario	Dry	Average	Wet
Global warming scenario	SRESA2	Average of All	IS92a
GCM	CC50	Average of All	ECHAM4
Global mean warming (°C)	0.92	Average of All	0.78
Change in annual rainfall (%)	-8.6	-2.36	1.5
Change in annual potential evaporation (%)	10.2	4.2	2.1
Change in streamflow at Craigmore (%)	-12.7	-0.5	13.4
Change in streamflow at Theresa Creek (%)	-10.2	0.3	10.4

3.2. Theresa Creek flow changes

The change in mean annual flow for Theresa Creek ranged from approximately -10.2% to +10.4% by 2030. Table 2 shows the change in mean annual flow for each of the climate change scenarios. The wet/dry scenarios were associated with higher/lower flows than the base scenario.

3.3. Craigmore TSS changes

Based on the set of scenarios, either increases or decreases in total suspended solids (TSS) are possible for the Nogoa catchment at Craigmore by 2030. The mean change in annual TSS for Craigmore for existing land use ranged from -0.048 Mt/Year (-8.8%) to 0.047 Mt/Year (+8.7%) for the dry and wet scenarios respectively. Table 3 shows the change in mean annual TSS for each of the climate change and land use scenarios. Under base climate conditions reverting from cropping to grazing land use was associated with a small reduction (3%) in annual TSS loads, and doubled cropping with a small increase (3%) in TSS at Craigmore.

A combination of the wet scenario and doubled cropping land use was associated with a 12% increase in annual TSS, and the dry scenario together with reverting from cropping to grazing land use with an 11% decrease, compared to the base scenario with existing land use. The average scenario was associated with a 3% decrease in annual TSS when cropping reverted to grazing, and a 3% increase in TSS if cropping land use was doubled.

Table 3. Mean change in annual TSS from the base scenario with existing land use at Craigmore across different climate change and land use scenarios

LAND USE	WET	AVERAGE	DRY
EXISTING	0.047 Mt/Year (8.68%)	-0.0005 Mt/Year (-0.09%)	-0.048 Mt/Year (-8.82%)
CROPPING TO GRAZING	0.030 Mt/Year (5.59%)	-0.017 Mt/Year (-3.08%)	-0.062 Mt/Year (-11.41%)
CROPPING UP 6%	0.064 Mt/Year (11.78%)	0.015 Mt/Year (2.75%)	-0.034 Mt/Year (-6.22%)

The wet/dry climate change scenarios were associated with higher/lower TSS than the base scenario, the difference being more evident at high TSS loads. Probability of exceedance curves showed that TSS was consistently higher at the same probabilities for the doubled cropping land use than existing land use, and lower for the cropping to grazing land use.

3.4. Theresa Creek TSS changes

Based on the set of scenarios, either increases or decreases in TSS are possible for the Nogoa catchment at Theresa Creek by 2030. The mean change in annual TSS for Theresa Creek for existing land use ranged from -0.049 Mt/Year (-10%) to 0.051 Mt/Year (+11%) for the dry and wet climate change scenarios respectively. Table 4 shows the change in mean annual TSS for each of the climate change and land use scenarios. Under base climate conditions reverting from cropping to grazing land use was associated with a large reduction (25%) in annual TSS loads, and doubled cropping with a large increase (25%) in TSS.

A combination of the wet climate change scenario and doubled cropping land use was associated with a 38% increase in annual TSS, and the dry climate change scenario together with reverting from cropping to grazing land use with a 33% decrease, compared to the base scenario with existing land use. The average scenario was associated with a 25% decrease in annual TSS when cropping reverted to grazing, and a 26% increase in TSS if cropping land use was doubled.

Table 4. Mean change in annual TSS from the base scenario with existing land use at Theresa Creek across different climate change and land use scenarios

LAND USE	WET	AVERAGE	DRY
EXISTING	0.051 Mt/Year (10.58%)	0.002 Mt/Year (0.32%)	-0.049 Mt/Year (-10.16%)
CROPPING TO GRAZING	-0.084 Mt/Year (-17.56%)	-0.120 Mt/Year (-25.07%)	-0.157 Mt/Year (-32.90%)
CROPPING UP 6%	0.182 Mt/Year (38.17%)	0.122 Mt/Year (25.58%)	0.059 Mt/Year (12.46%)

Probability of exceedance curves for each land use scenario showed that the wet/dry scenarios were associated with higher/lower TSS than the base scenario. They also showed that TSS was consistently higher at the same probabilities for the doubled cropping land use than the existing land use, and lower for the cropping to grazing land use.

4. DISCUSSION

The range of change in TSS from the driest and wettest extremes of regional climate change indicate a wide range of change in mean annual TSS ranging from approximately -11% to +12% for Craigmore and -33% to +38% for Theresa Creek by 2030. These changes in TSS were influenced by land use. Doubling the cropping land use at the expense of grazing was associated with higher sediment loads and removing cropping in favour of grazing with lower sediment loads. The wet/dry scenarios were associated with higher/lower TSS than the base scenario. The increase/decrease of TSS was larger in Theresa Creek than Craigmore as the proportion of existing cropping land was higher in the northern part of the catchment than the southern part of the catchment.

The mean annual TSS load for the base scenario at Craigmore (0.541 Mt/year) and Theresa Creek (0.477 Mt/year) combined (1.02 Mt/year) corresponds with an independent study downstream at Duck Ponds (Joo *et al.* 2005, 1.23 Mt/year) at the end of the Nogoa catchment.

Increased sediment (and nutrient) load in the watercourses of the Nogoa catchment may increase the amount of sediment deposition onto coral reefs and the ocean floor, increasing turbidity and water temperature and restricting aquatic animal and plant processes. The removal of topsoil may also reduce the production of terrestrial animals and plants.

The use of agricultural land by the cropping and grazing sectors influences runoff, flows and sediment deposition into watercourses. A wet climate change scenario in 2030 may create more cropping, whereas a dry scenario is likely to create more grazing, probably at the expense of cropping. Managing these systems to maintain good groundcover slows runoff and reduces sediment loads. The use of sustainable agricultural management practices will help reduce the risk of damage to the terrestrial and aquatic resources and help maintain agricultural productivity.

5. CONCLUSION

In this study we have assessed the likelihood of changes to mean annual TSS for the Nogoa catchment by perturbing input data to the E2 Model according to quantified ranges of climate change for 2030. These ranges incorporate the range of global warming according to the IPCC Third Assessment Report (IPCC, 2001), and regional changes in temperature, rainfall and potential evaporation encompassing the results from nine different climate models. The methods used are primarily designed to manage uncertainty and its impact on processes impacting on sediment load. Land use change influences sediment load onto important natural resources such as the Great Barrier Reef and climate change is a key driver of land use change. Identifying the likely impacts of climate change and implementing sustainable agricultural management practices will be important in adapting to climate change.

6. ACKNOWLEDGEMENTS

This work was funded by the Australian Greenhouse Office. Craig Clifton, Trica Gowdie and Michael Bent provided valuable support during the community consultation phases of the project. Roger Jones provided the scaling factors for the GCM’s and emissions scenarios. The Department of Primary Industries and Fisheries supported this project though most of its life before it was transferred to the Department of Natural Resources and Water.

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APPENDIX A - Climate change factors (% change from base scenario) for dry, average and wet scenarios for 2030 over the Nogoa catchment.

Variable	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Wet	6.0	8.8	-0.6	-0.5	4.7	-4.0	-1.0	12.0	-7.0	-9.6	3.7	5.3
Rainfall	**Average**	0.9	1.9	-1.7	-0.7	-1.6	-3.9	-0.1	-6.3	-6.9	-5.0	-3.5	-1.4
	Dry	-0.8	-9.1	1.7	-4.3	-11.9	-11.7	-13.7	-19.5	-9.9	-5.8	-11.3	-7.0
	Wet	0.7	0.6	1.3	2.4	2.5	2.6	2.5	2.4	2.7	3.5	3.1	1.2
Evaporation	**Average**	2.9	2.7	3.9	3.8	4.0	4.9	4.5	5.1	5.1	5.0	4.8	4.2
	Dry	3.1	6.9	6.2	4.2	7.6	11.3	13.2	17.8	17.0	12.9	12.2	10.5

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