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PRACTICAL ADAPTATION TO CLIMATE CHANGE IN REGIONAL NATURAL RESOURCE MANAGEMENT

Queensland Case Studies – Fitzroy Basin Report – Part B

Australian Greenhouse Office
Sinclair Knight Merz
Queensland Murray Darling Basin Committee
Desert Channels Queensland
Fitzroy Basin Association
South East Queensland Western Catchments

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AN INTEGRATED REGIONAL NATURAL RESOURCE MANAGEMENT PLAN FOR THE WESTERN CATCHMENTS OF SOUTH-EAST QUEENSLAND
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Australian Government
Department of the Environment and Heritage
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Queensland Government
Climate Change Centre of Excellence
Department of Natural Resources and Water

PRACTICAL ADAPTATION TO CLIMATE CHANGE IN REGIONAL NATURAL RESOURCE MANAGEMENT

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Qld Case Studies – Report for Fitzroy Basin Association Case Study – Climate Change Impacts on the Sediment Load for the Nogoa Catchment of the Fitzroy Basin.

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Cover: Fitzroy Basin – Cotton, Irrigation, River and Sorghum. Photos courtesy of Russ Boadle (top left, top right, bottom right) and Fitzroy Basin Association (bottom left).

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Executive Summary

A number of general circulation models (9) and greenhouse gas emission scenarios (3) were used to provide a range of projected temperature, evaporation and rainfall change to 2030. 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°C, reduced annual rainfall of 9% and higher evaporation of 10%. The wet scenario for 2030 was associated with a mean temperature increase of 0.9°C, higher annual rainfall of 2% and higher evaporation of 2%.**

Annual rainfall projections range from slightly wetter, to much drier than the historical climate. Seasonally, changes are uncertain in DJF and to a lesser extent in MAM but are dominated by decreases in JJA and SON. Changes in potential evaporation are much more certain.

Based on the set of scenarios in this study, either increases or decreases in stream flow are possible for the Nogoa catchment depending on which scenario is most closely associated with observed climate in the future. **The change in mean annual flow for Craigmore ranges from approximately -13% to +13% by 2030. The change in mean annual flow for Theresa Creek ranges from approximately -10% to +10% by 2030.** The wet/dry scenarios were associated with higher/lower flows than the base scenario, and the difference between scenarios at Craigmore was more evident at high flows.

Total suspended solids (TSS) were influenced by changes in land use. The total mean annual TSS load for the Nogoa catchment (Craigmore and Theresa Creek at Retreat Creek confluence) was 1.02 Mt/year (1Mt = 10^9 kg). Increased cropping land use at the expense of grazing was associated with higher sediment loads and decreased cropping in favour of grazing with lower sediment loads.

The mean annual TSS load for the base scenario at **Craigmore** was 0.541 Mt/year. By 2030, either increases or decreases in TSS are possible based on the set of scenarios used in this study. **The mean change in annual TSS with 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.** Under base climate conditions, fully reverting from cropping to grazing land use was associated with a small reduction (3%) in annual TSS loads, and doubling cropping with a small increase (3%) in TSS.

In the southern areas (i.e. Craigmore) where the proportion of existing cropping land is relatively small, 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 fully reverting from cropping to grazing land use was associated 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.

The mean annual TSS load for the base scenario for **Theresa Creek** (confluence with Retreat Creek) was 0.477 Mt/year. By 2030, either increases or decreases in TSS are possible based on the set of scenarios used in this study. **The mean change in annual TSS with existing land use ranged from -0.049 Mt/year (-10%) to 0.051 Mt/year (+11%) for the dry and wet scenarios respectively.** Under base climate conditions, fully reverting from cropping to grazing land use was associated with a large reduction (25%) in annual TSS loads, and doubling cropping with a large increase (25%) in TSS.

In the northern areas (i.e. Theresa Creek) where the proportion of existing cropping land is relatively large, a combination of the wet scenario and doubled cropping land use was associated with a 38% increase in annual TSS, and the dry scenario together with fully 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.

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, 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 the terrestrial and aquatic resources and help maintain agricultural productivity.

Further work is needed using finer resolution climate models and differential changes in daily rainfall and number of raindays to assess the impact of changes in rainfall intensity and timing. In addition more work is needed studying differential changes in summer temperatures and wind speed to assess the extreme evaporation period over summer.

1 Project overview

The project involved seven regional natural resource management (NRM) organisations - including the Fitzroy Basin Association (FBA), Queensland Murray-Darling Basin Committee (QMDC) – and the Queensland Department of Natural Resources and Water. It was coordinated by Sinclair Knight Merz.

The project has two main objectives, as follows:

1. improve understanding of the implications of climate change for regional NRM
2. develop tools and processes that help regional NRM organisations incorporate climate change impacts, adaptations and vulnerability into their planning processes.

The project was divided into three main stages:

Stage A. This stage identified components of participating region's natural resource system that were more vulnerable to climate change. The key steps were to develop the 'conceptual mapping' workshop process, conduct a literature review to document climate change projections, impacts and adaptive mechanisms for each participating region and then to run 'conceptual mapping' workshops in each of these regions.

Stage B. This stage completed a series of regional case studies which explored climate change impacts on one or a small number of components of the natural resource system that were more vulnerable to climate change. The case studies were designed to provide more objective information on climate change impacts and vulnerability and will be used to support analysis of how regional NRM processes can incorporate climate change considerations. Results of the case study for FBA are reported here and will be used by each of the participating NRM regions to complete Stage C.

Stage C. The final stage, in which lessons from the case study will be used to help develop tools and processes (e.g. thinking models, numerical models, workshop processes, modifications to risk assessment processes) that enable regional NRM organisations to incorporate climate change into their planning, priority setting and implementation. A series of workshops will be held in each state to receive feedback on the tools and processes developed or identified through the project.

2 Objectives of the case study

Earlier work in this project (Stage A) completed a review of literature and assessment of the likely impacts of climate change in the Fitzroy Basin (Miles *et al*. 2005), and is available from the Fitzroy Basin Association or Queensland Murray Darling Committee in Toowoomba. A meeting was held in Rockhampton (September 2005) to help the community better understand the drivers, pressures and impacts of climate change, and to plan the responses that maybe useful to prepare for climate change (Stage A). During this process a number of key issues were identified related to climate change (Clifton and Turner 2005). This report provides a scientific assessment (Stage B) of one key issue in the region, namely; under climate change conditions for 2030 identify changes in:

1. Regional rainfall, temperature and evaporation
2. Potential sediment load from three types of key agricultural land use including:
    - Existing land use (cropping 6%, grazing 81%);
    - Cropping back to grazing (no cropping, grazing 87%); and
    - Cropping area doubled (cropping 12%, grazing 75%).

3 Fitzroy Basin

The Fitzroy Basin covers an area of approximately 142,500 km^2 (Figure 1). 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 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. The Fitzroy Basin includes the catchment of the Fitzroy River and its major tributaries: the Dawson, Comet, Nogoa, Mackenzie, Isaac and Connors Rivers. The catchment area of the Nogoa River at Craigmore covers 14,140 km^2 and 16,320 km^2 at Fairbairn Dam. The catchment area of Theresa and Retreat Creeks covers 8,415 km^2.

The climate of the Fitzroy Basin is subtropical to tropical, ranging from humid near the coast to semi-arid inland. There is a wide range of diverse environments within the catchment, comprising higher rainfall areas of the Great Dividing Range near the coast with up to 1,200 mm of mean annual rainfall declining to about 500 mm inland. There is a pronounced wet season in the summer months which produces high seasonal flows and frequent flood events following monsoonal downpours and tropical cyclones. Flows are highly variable, with many of the rivers having very low flows, or drying altogether during the dry season.

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 was due to long-term climate variability 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 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 the rivers and their eventual deposition into the water around the southern part of the Great Barrier Reef.

This study involves the Nogoa catchment where cropping is 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. from 6 to 12% of basin) (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 1. The Fitzroy River Basin showing major catchments.

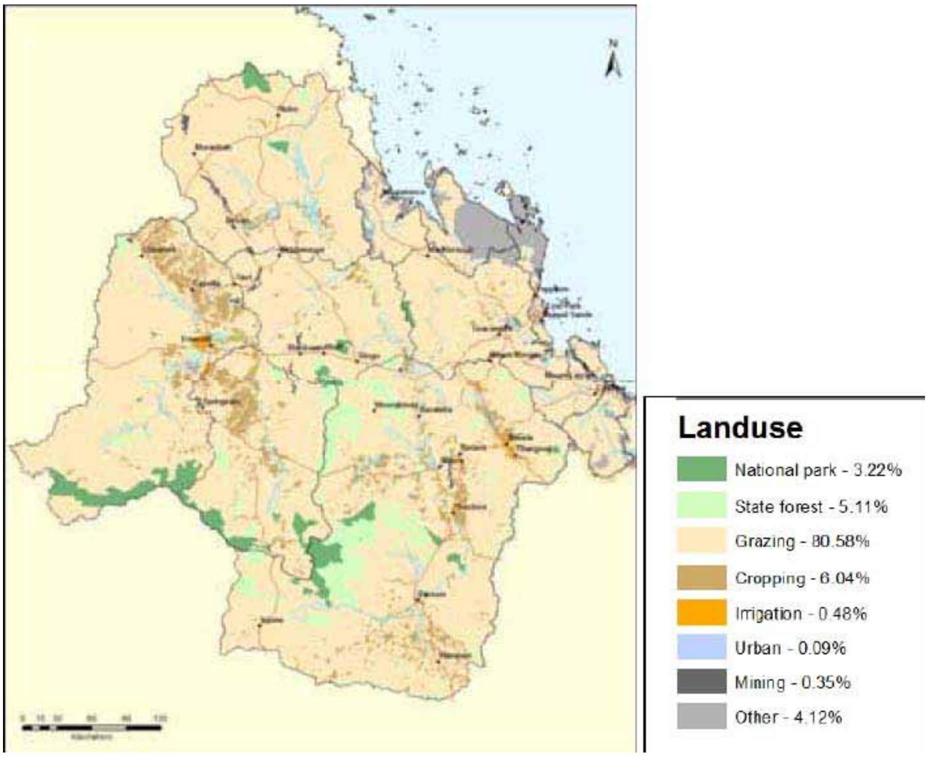

Figure 2a. Land use in the Fitzroy Basin showing grazing and cropping areas.

Figure 2b. Stream network, location of major nodes, topography and catchments of the Fitzroy River Basin.

4 The climate change scenarios

4.1 UNCERTAINITY IN CLIMATE CHANGE

Three major climate-related uncertainties were considered in this study. The first two are global uncertainties, which include the future emission rates of greenhouse gases and the sensitivity of the climate system's response to the radiative balance altered by these gases. Both uncertainties are shown in Figure 3, which shows the range in global warming to 2100, based on the Special Report on Emission Scenarios (SRES; Nakiçenovic *et al.*, 2000) and Intergovernmental Panel on Climate Change (IPCC 2001). The dark grey shading shows emission-related uncertainties, where all the SRES scenarios have been applied to models at constant 2.5°C climate sensitivity. The light grey envelope shows the uncertainty due to climate sensitivity ranging from 1.5–4.5°C (measured as the warming seen in an atmospheric climate model when pre-industrial CO_2 is doubled). These uncertainties contribute about equally to the range of warming in 2100.

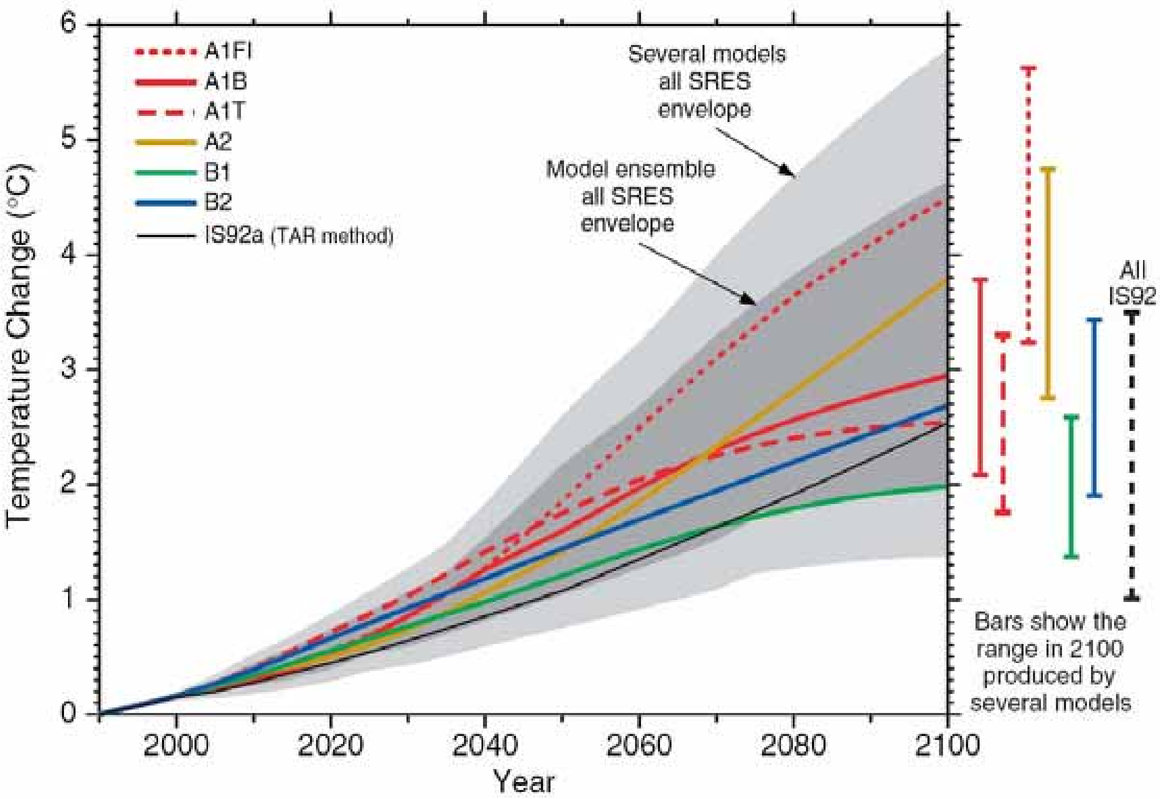

Figure 3. Global mean temperature projections for the six illustrative SRES scenarios using a simple climate model tuned to a number of complex models with a range of climate sensitivities. Also for comparison, following the same method, results are shown for IS92a. The darker shading represents the envelope of the full set of thirty-five SRES scenarios using the average of the models results. The lighter shading is the envelope based on all seven model projections (from IPCC, 2001).

The third major uncertainty is regional, described by changes to mean monthly rainfall and potential evaporation. To capture the ranges of these regional changes, we use projections from a range of international GCMs, as well as GCMs and Regional Climate Models (RCMs) developed by CSIRO.

Projections of regional climate change and model performance in simulating Queensland's climate have been described by Cai *et al.* (2003). Here, we have access to a similar suite of climate model results as summarised in Cai *et al.* (2003). They investigated the ability of the models to simulate sea level pressure, temperature and rainfall, discarding the four poorest-performing models from subsequent analysis. The models used for this study are summarised in Table 1.

Table 1. Climate model simulations analysed in this report. The non-CSIRO simulations may be found at the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/). Note that D125 and CC50 are regional climate models

Centre	Model	Emissions Scenarios post-1990 (historical forcing prior to 1990)	Years	Horizontal resolution (km)
CSIRIO, 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	DARLAM125	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

Note: The HadCM3, ECHAM4 and CC50 Models were run for both medium and high climate sensitivities, all other models were run with medium climate sensitivity.

In the region surrounding the Fitzroy River Basin, annual rainfall projections range from slightly wetter, to much drier than the historical climate. Seasonally, changes are uncertain in DJF and to a lesser extent in MAM but are dominated by decreases in JJA and SON. Over successive generations of climate model, estimates of rainfall change have become drier, but increases in the Fitzroy River region remain plausible.

Regional temperature increases inland at rates slightly greater than the global average, with the high-resolution models showing the steepest gradient away from the coast. Ranges of change are shown in Cai *et al.* (2003). Changes to potential evaporation increases in all cases, with increases greatest when coinciding with significant rainfall decreases.

4.2 CLIMATE CHANGE PATTERNS

Patterns of climate change calculated as percentage change per degree of global warming were created for monthly changes in rainfall and point potential evaporation from a range of models. In OzClim, these are linearly interpolated onto a 0.25° grid (the simplest form of downscaling). Changes are averaged for a specific area.

Area average changes for the Nogoa catchment are shown in Table 2. All the models show increases in potential point evaporation, however increasing rainfall results in lesser increases in potential evaporation, an outcome that is physically consistent with having generally cloudier conditions in situation where rainfall increases. This will produce a "double jeopardy" situation if mean rainfall decreases because this will be accompanied by relatively larger increases in potential evaporation.

Table 2. Changes in annual rainfall and point potential evaporation for the Nogoa catchment, simulated by the models in Table 1, expressed as a percentage change per degree of global warming

Model	Rainfall	Point Potential Evaporation
CCCM1	-2.55	5.84
DARLAM125	4.15	4.24
NCAR	2.10	3.70
MARK2	-5.21	5.26
ECHAM4	1.91	2.76
HADCM3 - IS92A	-5.46	8.21
HADCM3 - A1T	-5.42	8.14
CC50	-9.36	11.13
MARK3	-8.30	6.80

Seasonal changes are shown in Figure 4 where the mean monthly change for both rainfall and potential evaporation per degree of global warming is shown with the upper and lower extremes. Changes in potential evaporation are much more certain, always increasing and showing a slight inverse relationship with rainfall, with deviations of only few percent per degree of global warming between models.

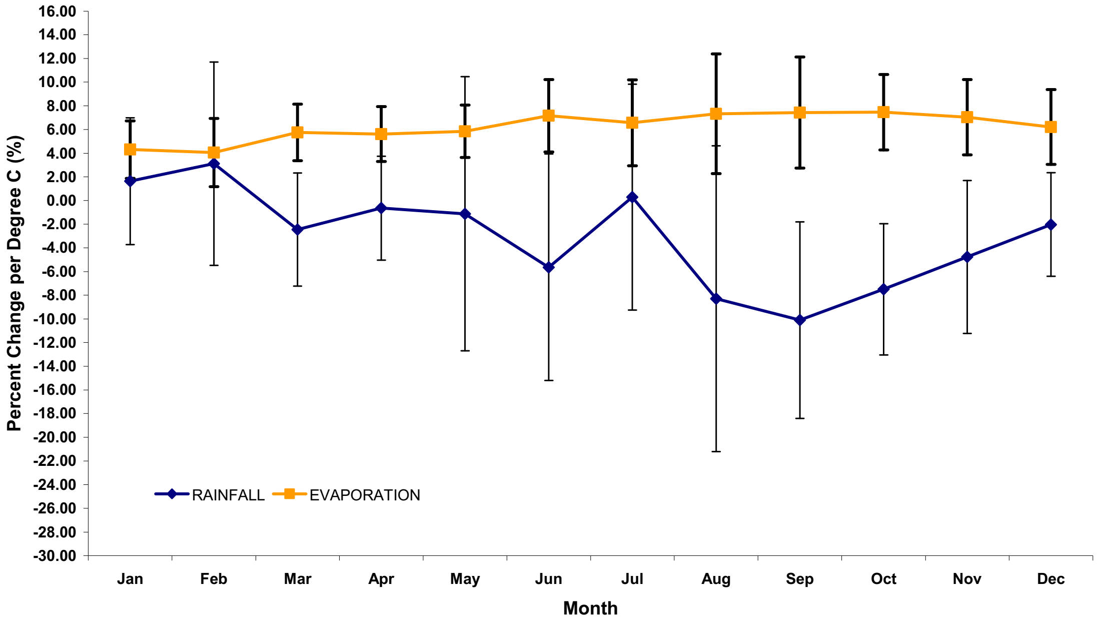

Figure 4. Average monthly percentage change in rainfall and potential evaporation for the Nogoa catchment (see Table 4 for the 10 locations) per degree of global warming using the nine climate models and emission scenarios with medium sensitivity shown in Table 1 with one standard deviation.

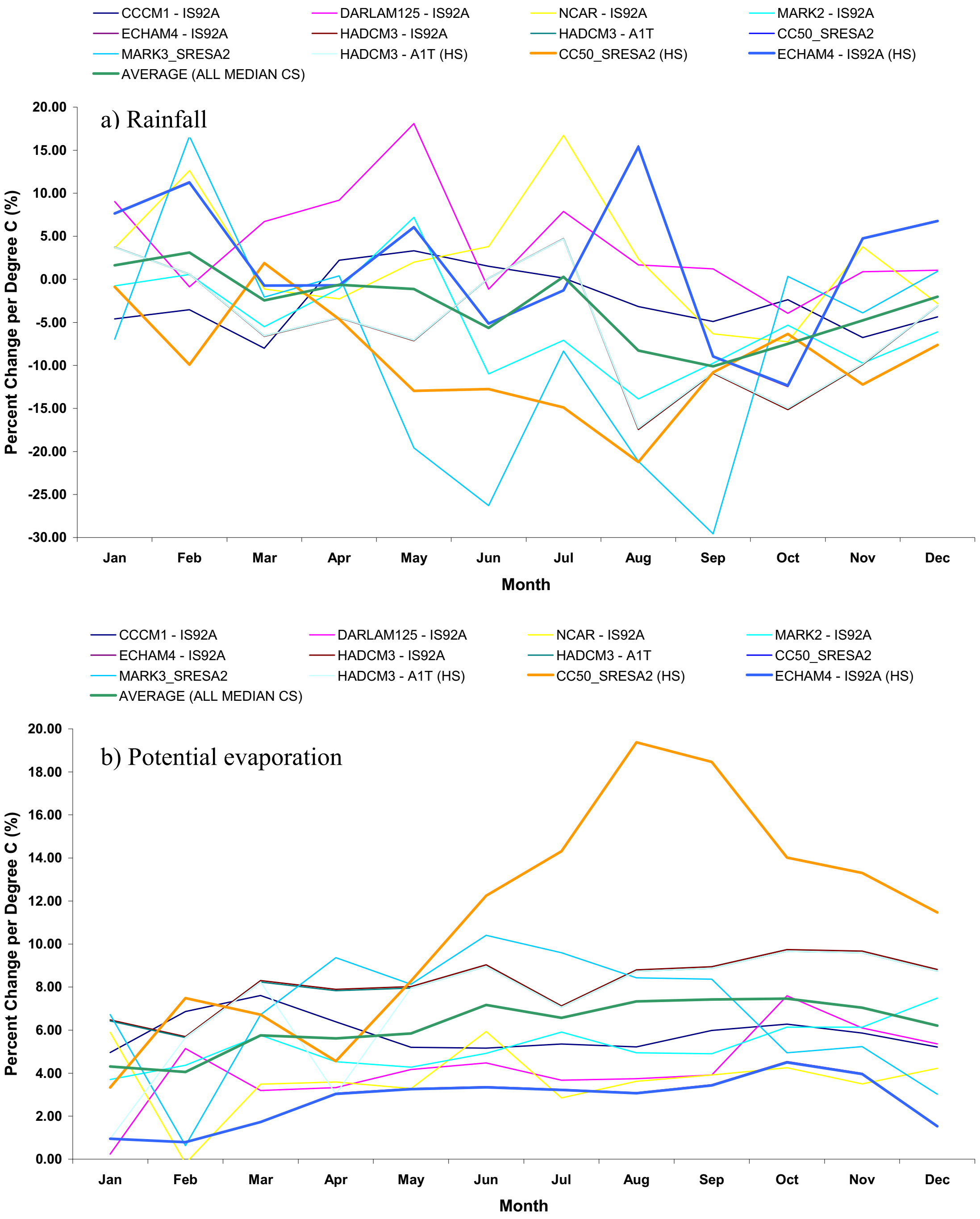

Figure 5. Average monthly percentage change in a) rainfall and b) potential evaporation for the Nogoa catchment (see Table 4 for the 10 locations) per degree of global warming for the nine climate models shown in Table 1 at medium (MS) and high sensitivity (HS).

4.3 CLIMATE CHANGE SCENARIOS

This report presents the range of possible changes provided by dry, wet and average scenarios for the Nogoa catchment in 2030. This range combines the range of global warming from IPCC (2001) and the climate change patterns in Table 2. These provide an initial set of estimates for possible hydrological change and set the scene for a risk analysis of possible changes to water resources in the catchment.

The three scenarios are:

- A dry climate change scenario where global warming follows the SRES A2 greenhouse gas scenario in 2030 forced by high climate sensitivity with regional rainfall and potential evaporation changes expressed by the CC50 GCM.
- An average climate change scenario where global warming follows the average of all the climate models used in this analysis.
- A wet climate change scenario where global warming follows the IS92a greenhouse gas scenario in 2030 forced by high climate sensitivity, with regional rainfall and potential evaporation changes expressed by the German ECHAM4 GCM.

These simulations represent most of the possible ranges of change in average climate over the Nogoa catchment by 2030. Note that the dry and wet climate scenarios are both forced by high climate sensitivity. This is because in locations where either increases or decreases in rainfall are possible, the more the globe warms, the larger these accompanying regional changes will become. Therefore, if we wish to look at the extremes of possible changes in catchment response to climate change, then both the wet and dry scenarios will utilise the higher extreme of plausible global warming. These scenarios are summarised in Table 3.

Table 3. Dry, average and wet climate change scenarios for 2030 for the Nogoa catchment

Scenario	**Dry**	**Average**	**Wet**
Global warming scenario	SRES A2	Average of All	IS92a
GCM	CC50	Average of All	ECHAM4
Global mean warming (°C)	0.92	Average of All	0.78
Regional minimum temperature change (°C)	1.20	Average of All	0.90
Regional maximum temperature change (°C)	1.60	Average of All	0.90
Regional mean temperature change (°C)	1.40	Average of All	0.90
Change in annual rainfall (%)	-8.61	-2.36	1.47
Change in annual potential evaporation (%)	10.24	4.22	2.13

5 Model construction and calibration

5.1 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 of 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.

5.2 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 are shown in Table 4.

Table 4. Climate stations together with their latitudes and longitudes for which climate change factors were obtained from OzClim

Name	Latitude	Longitude
Anakie	-23.57	147.75
Bogantungan P.O.	-23.65	147.29
Capella	-23.09	148.02
Clermont P.O.	-22.83	147.64
Emerald P.O.	-23.53	148.16
Glentana	-24.60	147.57
Gordon Downs	-23.23	148.33
Mantuan Downs	-24.41	147.24
Peakvale	-23.19	147.35
Telemon	-24.19	147.72

These stations covered a large area of the basin and represented a range of climate change factors over the 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 (Figure 5) to help choose the three models for the wet, average and dry scenarios of climate change. The models for these scenarios were chosen by graphing the monthly climate change factors for rainfall and evaporation divided by the change in global warming for each of the models and scenarios listed in Table 1. The overall factors for summer, the dry season, and the calendar year for each of the models and scenarios were used to select the wet, average and dry scenarios.

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, and especially for evaporation (see Figure 5 and Table 6).

5.3 MODEL DESCRIPTION

Water flows and total suspended solids for two sites in the Nogoa catchment were modelled using E2. Embedded in E2 are a number of models. The flows were modelled using a rainfall runoff model called Simhyd, and total suspended solids using a consistuent generation model called EMC/DWC (event mean concentration/dry weather concentration).

The first site, at Craigmore is upstream of the Fairbairn Dam on the Nogoa River and represents the southern parts of the catchment. The second site, was Theresa Creek at the junction of Retreat Creek that represents the northern parts of the catchment. A large proportion of the cropping land in the Fitzroy Basin is located in the northern part of the Nogoa catchment (see Figure 2).

5.3.1 E2 model

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 (Figure 6a).

The building blocks of an E2 model are sub-catchments, nodes and links:

- sub-catchments: The sub-catchment is the basic spatial unit in E2, although it can be divided into "functional units" based on a common response or behaviour (eg. based on land use). Within each functional unit, three models may be assigned - a rainfall-runoff model, a constituent generation model and a filter model.
- nodes: Nodes represent sub-catchment outlets, stream confluences, or other places of interest (eg. stream gauges, dam walls). Nodes are connected by links, forming a representation of the stream network.
- links: Links represent river reaches, dams, or floodplains. Within each link, three models may be assigned - a routing model, a source/sink model and a decay/enrichment model.

When applying each of the models mentioned above, the user is given a choice between multiple modelling options. Therefore, E2 provides a unique opportunity to create an overall integrated model that is highly tailored to the problem at hand.

E2 is designed for application in a range of catchment sizes, from backyards to many 100,000 km^2. It provides output at various temporal and spatial scales. E2 provides capacity to model such scenarios as:

- Changes in land use
- Changes in land management
- Modification of riparian zones
- Construction of wetlands, dams etc.
- Modification of flow regimes or water management
- Response to changing or variable climate.

E2 can simulate the effects of the above scenarios on outputs such as fluxes and yields of both water and constituents such as total suspended solids and total nitrogen.

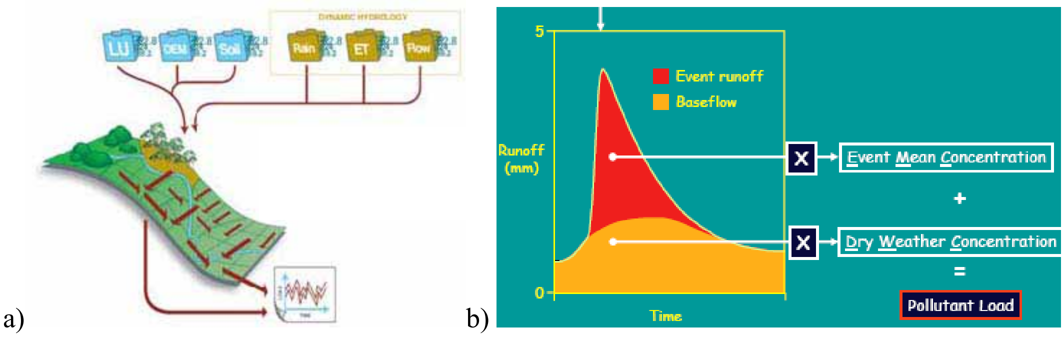

Figure 6. a) Temporal and spatial information used by E2 and b) the association between runoff, event mean concentration/dry weather concentration (EMC/DWC) and pollutant load (total suspended solids).

5.3.2 Simhyd model

Simhyd is a model that uses nine parameters to simulate the processes involved in calculating runoff from rainfall (Figure 7). In the Simhyd model rainfall first enters the system via the interception store, from which daily evaporation occurs. Rainfall in excess of this storage is infiltrated into the soil according to an infiltration function, which determines the infiltration capacity. The rainfall that exceeds the infiltration capacity becomes infiltration excess runoff. The remaining moisture is diverted to interflow, groundwater storage and soil moisture storage via a soil moisture function. Interflow is estimated as a linear function of soil wetness (soil moisture level divided by soil moisture capacity). The equation for interflow mimics both interflow and saturation excess runoff processes.

Groundwater recharge is then estimated as a linear function of soil wetness, where the remaining moisture is stored in the soil moisture store. Evapotranspiration from the soil moisture store is estimated as a linear function of the soil wetness, but cannot exceed the atmospherically controlled rate of areal potential evapotranspiration. The soil moisture store overflows into the groundwater store. Finally, baseflow is simulated as a linear recession from the groundwater store.

5.3.3 EMC/DWC model

The Event Mean Concentration (EMC)/Dry Weather Concentration (DWC) model applies a fixed concentration to a functional unit/land use. The EMC value represents the sediment generated by a surface (quick) flow and DWC applied to slow (base) flow (Figure 6b).

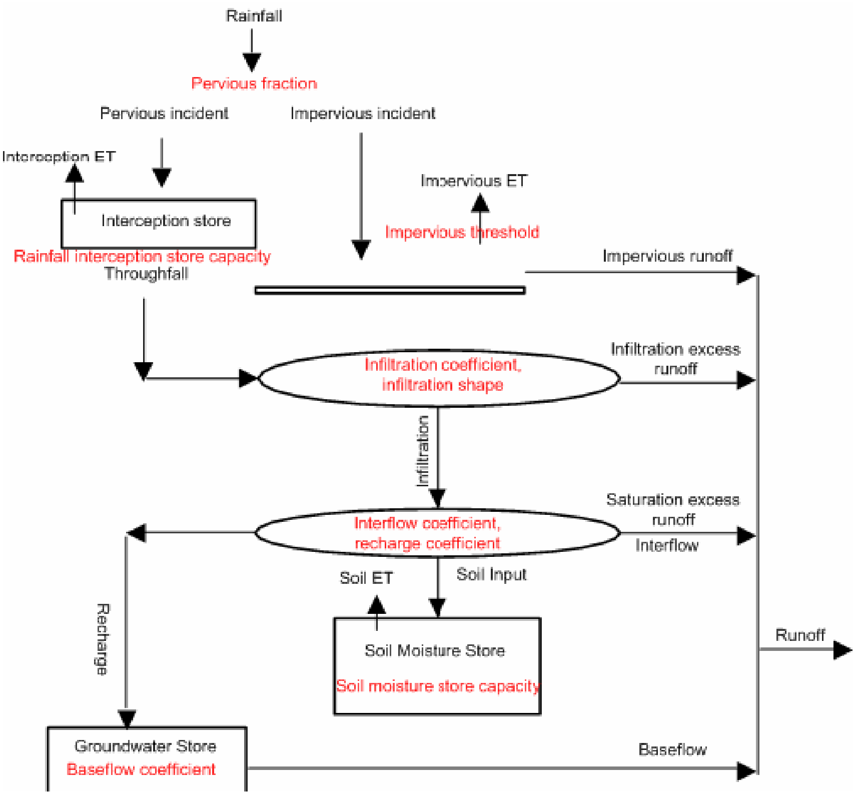

Figure 7. Structure of the Simhyd rainfall-runoff model. Model parameters are shown here in red.

5.4 MODEL CONFIGUATION

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

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 from soil erosion data for different land uses.

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

5.5 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 the Fairbairn Dam on the Nogoa River and covers an area of 14140 km^2 in the south 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 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 using the same parameters, R=0.647 at Theresa Creek.

TSS was calibrated using parameters that were calculated from expert knowledge of soil erosion from different land use. At Craigmore the association between observed and simulated TSS was R=0.77 (n=48) and the POE curves matched, although there was some discrepancy in the very high range. 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 scatterplots and POE curve plots showing the associations between observed and simulated flows and TSS at Craigmore and Theresa Creek are shown in Appendix 5.

5.6 APPLICATION OF THE CLIMATE CHANGE FACTORS

Base data was comprised of 30 years of daily data from 1961 to 1990 for 2 rainfall and 1 evaporation stations across the catchment. Percentage changes derived from OzClim for precipitation and evaporation for each month of 2030, were multiplied with the base data. The monthly changes for rainfall and potential evaporation in percentage change per degree of global warming from each of the climate models are shown in Figure 5. The climate change factors that were used to modify the base data for precipitation and evaporation are shown in Table 5.

Table 5. Climate change factors (% change from base scenario) for the 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
Rainfall	**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
	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
Evaporation	**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
	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

5.7 GENERATION OF MODIFIED FLOWS AND TSS

E2 was run calculating the streamflow and TSS for base conditions (1961-1990) and rerun using the modified climate files described in Section 4.4 to obtain the flows and TSS for the wet, average and dry scenarios.

6 Results of impact assessment

6.1 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 6 shows the change in mean annual flow for each of the scenarios. Figure 8 shows the mean annual flows at Craigmore for the base scenario and each of the climate change scenarios. Figure 9 shows the POE curves of the simulated annual flows for the base scenario and each of the climate change scenarios. The wet/dry scenarios were associated with higher/lower flows than the base scenario, and the difference was more evident at high flows.

Table 6. Mean changes in annual stream flow for Craigmore 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
Regional minimum temperature change (°C)	1.20	Average of All	0.90
Regional maximum temperature change (°C)	1.60	Average of All	0.90
Regional mean temperature change (°C)	1.40	Average of All	0.90
Change in annual rainfall (%)	-8.61	-2.36	1.47
Change in annual potential evaporation (%)	10.24	4.22	2.13
Change in annual streamflow at Craigmore (%)	-12.72	-0.52	13.43

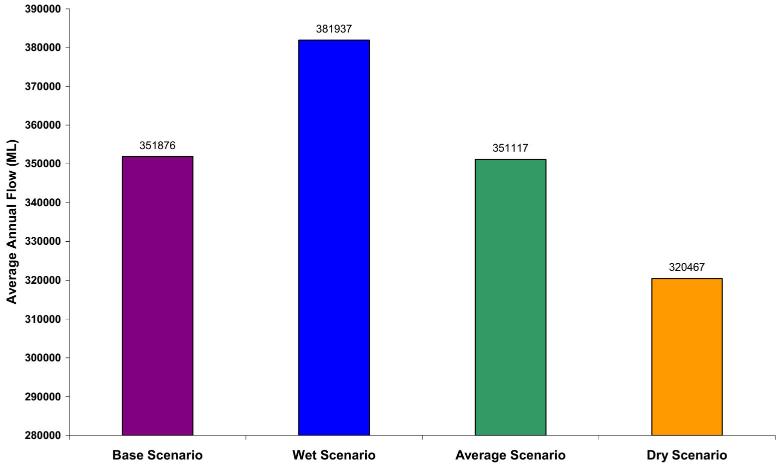

Figure 8. Mean annual streamflow for Craigmore for the base scenario and the dry, average and wet climate change scenarios for 2030. Note: mean gauging station flows between 1972 and 1996 were 388,678 ML/year.

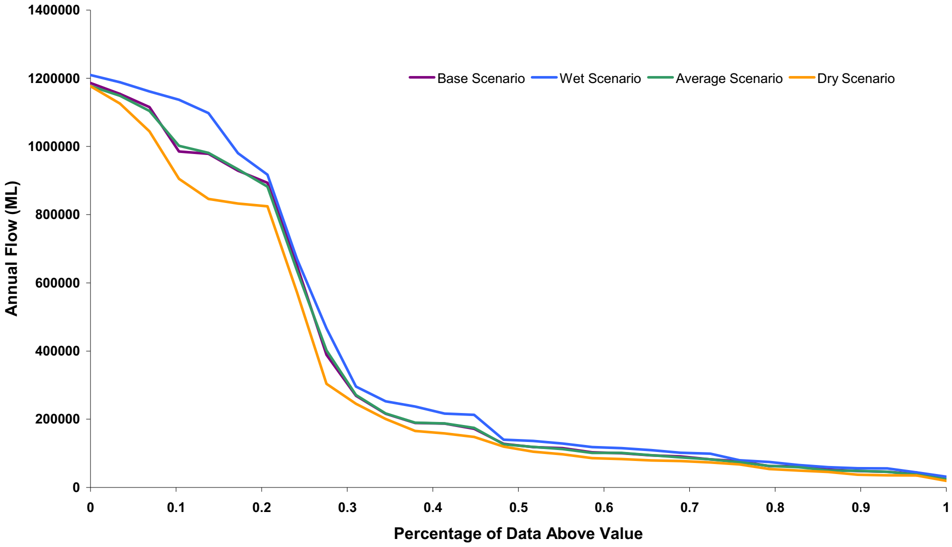

Figure 9. Annual flow exceedance curves for Craigmore for the base scenario and the dry, average and wet scenarios for 2030.

6.2 THERESA CREEK FLOW CHANGES

The change in mean annual flow for Theresa Creek ranges from approximately -10.2% to +10.4% by 2030. Table 7 shows the change in mean annual flow for each of the scenarios. Figure 10 shows the mean annual flows at Theresa Creek for the base scenario and each of the climate change scenarios. Figure 11 shows the POE curves of the simulated annual flows for the base scenario and each of the climate change scenarios. The wet/dry scenarios were associated with higher/lower flows than the base scenario.

Table 7. Mean changes in annual stream flow for 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
Regional minimum temperature change (°C)	1.20	Average of All	0.90
Regional maximum temperature change (°C)	1.60	Average of All	0.90
Regional mean temperature change (°C)	1.40	Average of All	0.90
Change in annual rainfall (%)	-8.61	-2.36	1.47
Change in annual potential evaporation (%)	10.24	4.22	2.13
Change in annual streamflow for Theresa Creek at the Retreat Creek confluence (%)	-10.16	0.32	10.38

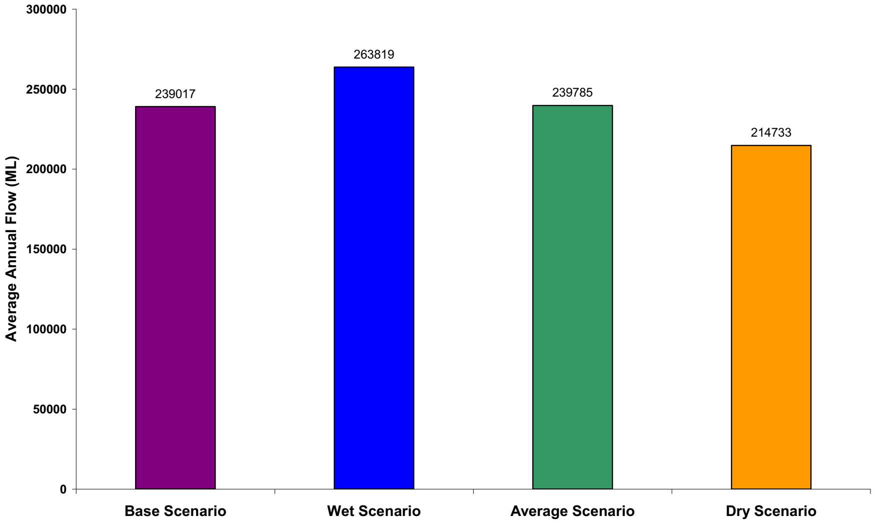

Figure 10. Mean annual streamflow for the base scenario and the dry, average and wet climate change scenarios for 2030. Note: mean gauging station flows between 1956 and 1996 were 210,526 ML/year.

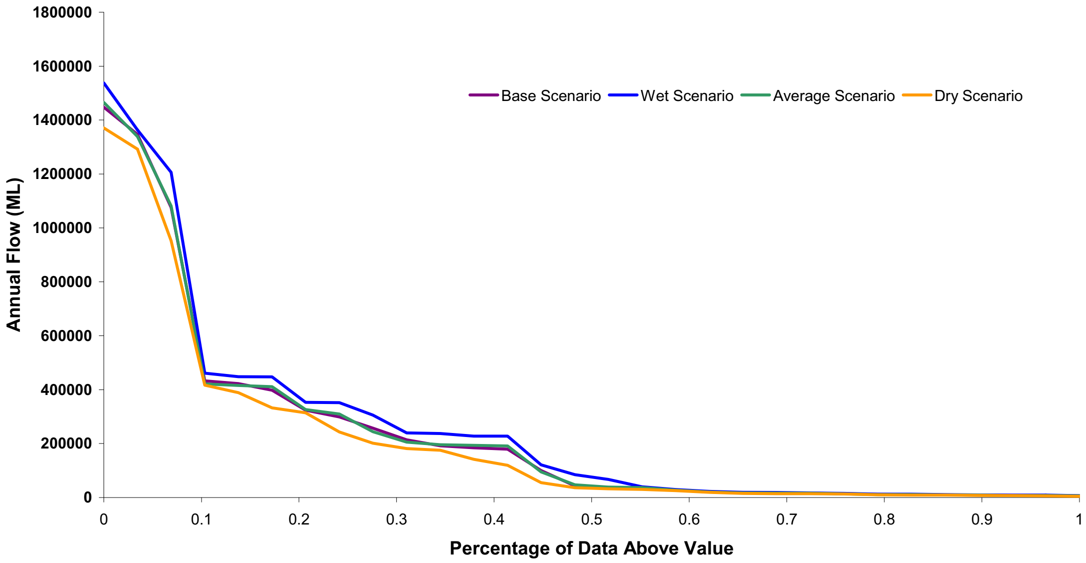

Figure 11. Annual flow exceedance curves for the base scenario and the dry, average and wet climate change scenarios for Theresa Creek in 2030.

6.3 CRAIGMORE TSS CHANGES

Based on the set of scenarios used in this study, either increases or decreases in total suspended solids (TSS) are possible for the Nogoa catchment at Craigmore by 2030. The mean annual TSS load for the base scenario at Craigmore was 0.541 Mt/year. The mean change in annual TSS 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. Under base scenario conditions, reverting from cropping to grazing land use was associated with a small reduction (3%) in annual TSS loads, and doubling cropping with a small increase (3%) in TSS. Table 8 shows the change in mean annual TSS for each of the climate change and land use scenarios.

Table 8. 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%)

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.

Figure 12 shows the annual TSS exceedance curve for existing land use (exceedance curves for the other land use scenarios are shown in Appendix 4). The wet/dry scenarios were associated with higher/lower TSS than the base scenario, and the difference was more evident at high TSS loads.

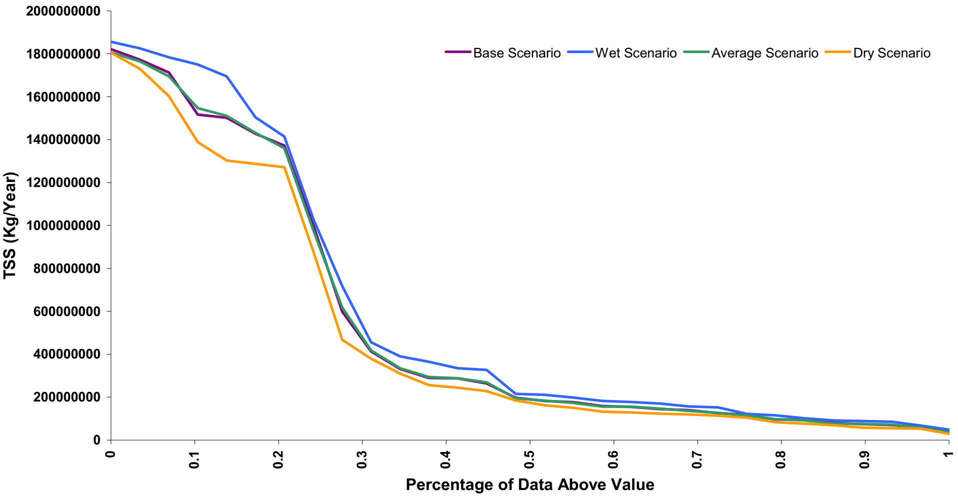

Figure 12. Annual exceedance curve for TSS at Craigmore for existing land use for the base scenario and the wet, average and dry climate change scenarios in 2030.

Other exceedance graphs in Appendix 4 show 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.

For each base and climate change scenario the average annual TSS was higher for doubled cropping than existing land use, and lower for the cropping to grazing land use compared to existing land use (Figure 13).

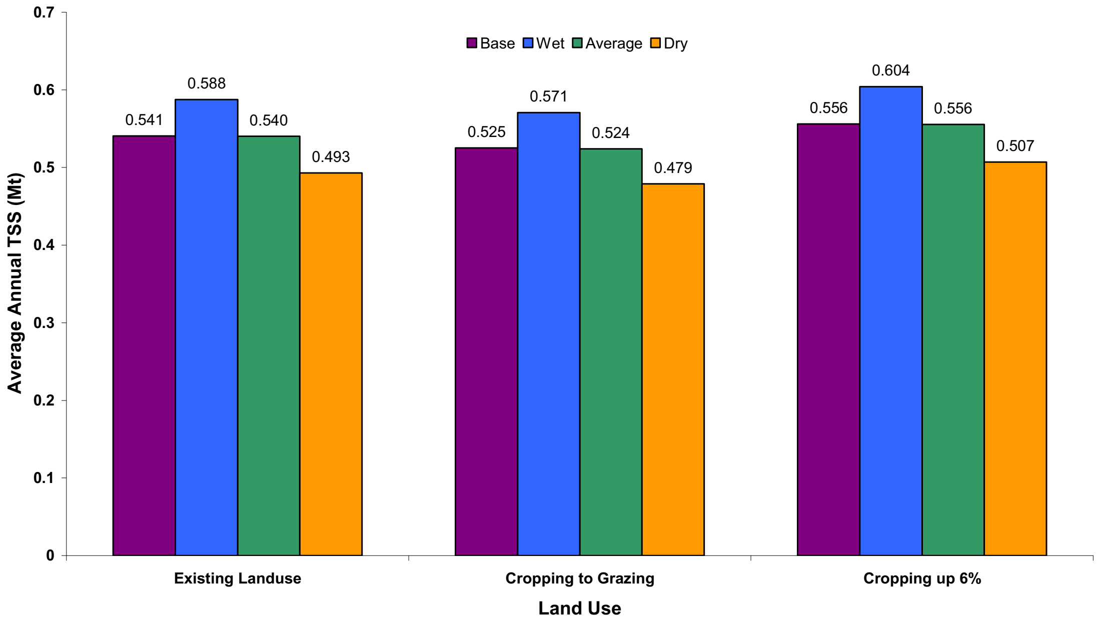

Figure 13. Mean annual TSS at Craigmore for different land use and climate change scenarios.

6.4 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 annual TSS load for the base scenario at Theresa Creek (confluence with Retreat Creek) was 0.477 Mt/year. The mean change in annual TSS for existing land use ranged from -0.049 Mt/Year (-10%) to 0.051 Mt/Year (+11%) for the dry and wet scenarios respectively. Under base scenario conditions, reverting from cropping to grazing land use was associated with a large reduction (25%) in annual TSS loads, and doubling cropping with a large increase (25%) in TSS. Table 9 shows the change in mean annual TSS for each of the climate change and land use scenarios.

Table 9. 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%)

A combination of the wet scenario and doubled cropping land use was associated with a 38% increase in annual TSS, and the dry 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.

Figure 14 shows the annual TSS exceedance curve for existing land use (exceedance curves for the other land use scenarios are shown in Appendix 4). The wet/dry scenarios were associated with higher/lower TSS than the base scenario.

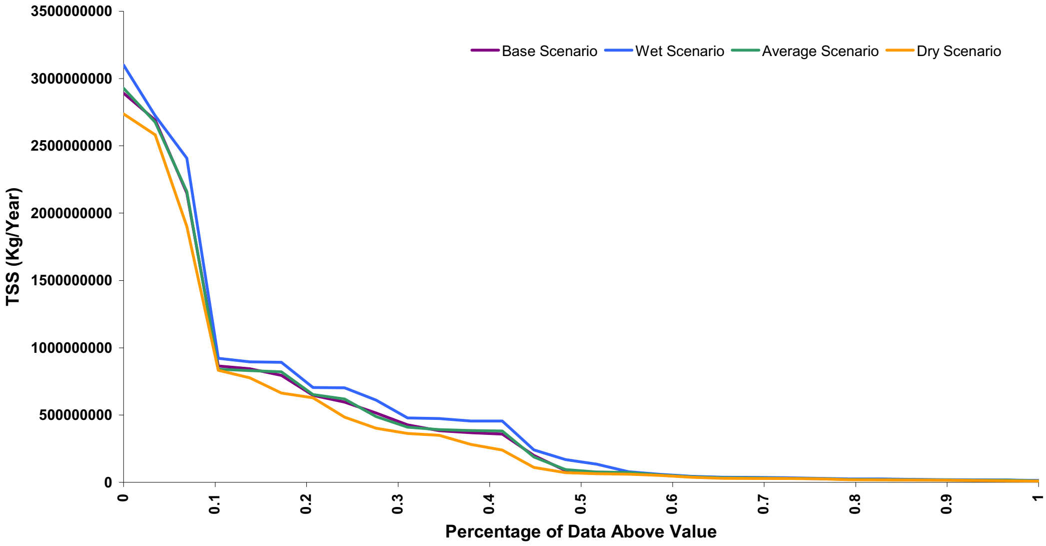

Figure 14. Annual exceedance curve for TSS at Theresa Creek for existing land use for the base scenario and the wet, average and dry climate change scenarios in 2030.

Other exceedance graphs in Appendix 4 show 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.

For each base and climate change scenario the average annual TSS was higher for doubled cropping than existing land use, and lower for the cropping to grazing land use compared to existing land use (Figure 15).

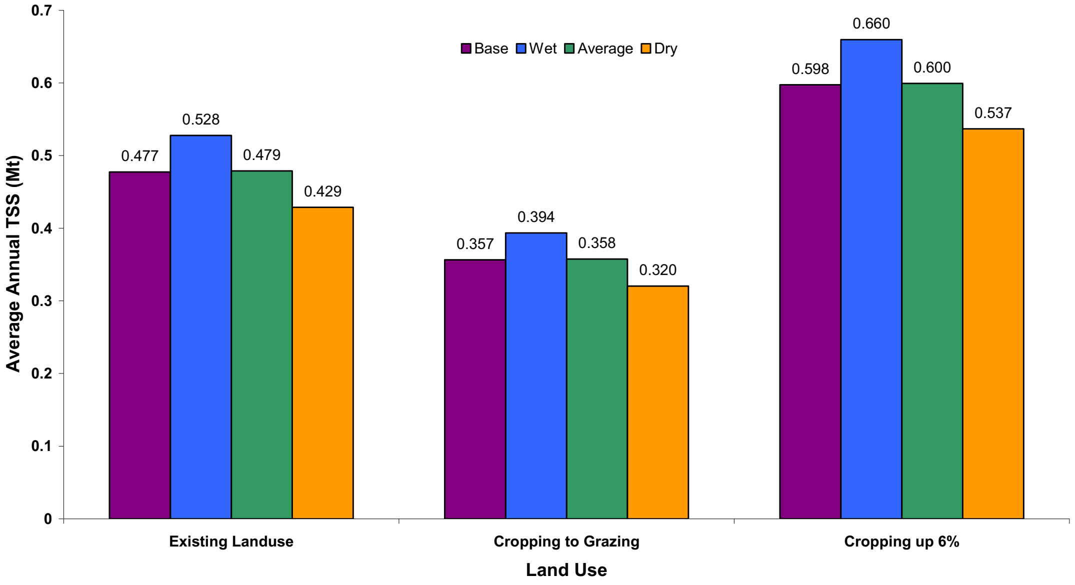

Figure 15. Mean annual TSS at Theresa Creek for different land use and climate change scenarios

7 Conclusions and recommendations

7.1 SUMMARY OF RISK ANALYSIS

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 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. Another aspect of uncertainty, which is land use change, has also been addressed.

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.

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 cropping land use at the expense of grazing was associated with higher sediment loads and zero cropping in favour of grazing with lower sediment loads. In the southern areas where the proportion of existing cropping land is relatively small, fully reverting from cropping to grazing under base climate conditions was associated with reduced annual TSS (3%) and doubled cropping (increase from 6 to 12% cropping across the basin) with an increased TSS load (3%), compared to existing land use. In the northern areas where the proportion of existing cropping land is higher than the south, 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.

The wet/dry scenarios were associated with higher/lower TSS than the base scenario. In the south, 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 fully 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.

In the north, a combination of the wet scenario and doubled cropping land use was associated with a 38% increase in annual TSS, and the dry scenario together with fully 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.

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.

7.2 LIMITATIONS OF THE ASSESSMENT

There are a number of limitations in this assessment that will affect the interpretation and application of its results. These limitations concern:

- uncertainty linked to the greenhouse effect;
- the limitations of climate modelling, which affect how subsequent output can be used,
- the method of scenario construction,
- the application of those scenarios to the impact model,
- the relationship between climate change and ongoing climate variability, and
- hydrological model uncertainties.

7.2.1 Greenhouse-related uncertainties

Climate change uncertainties can be divided into scientific uncertainties and socio-economic uncertainties. Many scientific and some socio-economic uncertainties can be reduced by improved knowledge that can be simulated within models. Some uncertainties are irreducible; for example, the chaotic behaviour of systems or future actions of people affecting rates of greenhouse gas emissions. Some uncertainties will be reduced through human agency; for example adaptation to reduce the impacts of climate change or the mitigation of climate change through greenhouse gas reductions.

In this report, the major greenhouse-related uncertainties we have accounted for are climate sensitivity (model sensitivity to atmospheric radiative forcing), regional climate change (managed by using a suite of climate models providing a range of regional changes) and a non-fossil fuel greenhouse gas scenario (the A1T SRES scenario).

7.2.2 Climate model limitations

The main limitations of climate models, apart from incomplete knowledge, which is addressed above, relates to scale. Much of the variability within the real climate is emergent from very fine-scaled processes that may not be well represented in climate models, particularly those models with coarser resolution. The two major limitations relate to changes in the interannual and daily variability of rainfall. A further limitation relates to the coarse resolution of topography, not thought to be a major contributor to regional uncertainty over most of Australia. Incomplete or partially known physical processes also limit climate models – the most significant of those being limited to the behaviour of clouds under climate change, which contributes to climate model sensitivity, mentioned in the previous section.

Interannual rainfall variability is subject to large scale teleconnections, and so requires fully coupled climate models of sufficient vertical and horizontal resolution to be adequately simulated. However there is as yet no real agreement between different models as to how important phenomena, such as the El Niño – Southern Oscillation phenomenon may behave under climate change. Each rain event is also limited in scale to the size of the grid spacing in the model. Essentially, each rain event occurs across a whole grid box, which tends to reduce its intensity because fine-scale convection processes cannot easily be produced. Therefore, although climate models indicate increases in daily rainfall intensity, these increases are generally under-estimated under all but the finest resolution regional models. Methods are currently being explored to combine both global and local influences in fine scale model simulations but as yet this data is not available for impact studies. However, a few specialised climate runs would also fail to properly address a range of uncertainties that a larger set of models can provide. This is one reason why we have not traditionally relied heavily on downscaled rainfall data.

7.2.3 Scenario construction methods

Climate scenario construction needs to strike a balance between representing a realistic set of changes and uncertainty using available resources. Rainfall is the main driver in simulating hydrological change and can potentially change across a range of temporal and spatial scales. Obviously, it is difficult to produce scenarios that represent all changes that a model can realistically simulate or to compensate for those changes where model simulations indicate a change but where the output cannot be used directly (as in downscaling).

In this project, we used the OzClim climate scenario generator which has climate change patterns from a number of different models installed: most importantly for this project, monthly patterns of change per degree of global warming for average rainfall and potential evapotranspiration. These patterns contain normalised representations of local change as a function of global warming that can be re-scaled using a wide range of average global warming to provide changes representing the outcomes for each climate model for any date from 1990 to 2100. This method is valid for the range of global warming provided by IPCC (2001). Therefore, by using a range of climate models we are representing as wide a range of local climate change that can reliably be quantified.

However, changes to climate variability have not been explicitly represented in these scenarios. This would require access to large volumes of high-resolution data and likely involve intensive downscaling methods for data from many models, which we do not have the resources to undertake.

7.2.4 Scenario application

The method of scenario application we have used is to multiply daily changes in rainfall and potential evaporation by a single monthly value of percentage change, the so-called uniform perturbation method. This assumes that all values within that month will change by the same amount e.g. -5%, without any changes in daily variability.

Studies of daily rainfall output from climate models indicate that extreme rainfall is likely to increase, except where decreases in the mean are large. The number of raindays appears likely to decrease, except for larger increases in rainfall. Even for situations where mean rainfall does not change, climate models indicate increases in extreme falls and a decrease in lighter falls and the number of rain days. As detailed in the previous section, we do not have the resources to test the impacts of such changes.

The application of changes in monthly mean to historical daily data means that changes in annual and seasonal mean rainfall are well represented, but not differential changes in daily rainfall or the number of raindays. Where such changes have been simulated from CSIRO Mark2 data, they produce increases of several percent (Chiew *et al.* 2003) but this rainfall output was not downscaled further, which would increase the simulated intensities of the heaviest falls.

The perturbation of historical data also means that interannual variability is largely preserved (it is altered somewhat by interseasonal changes), so the underlying assumption is that the pattern of dry and wet years will not be greatly altered under climate change. (There is no compelling reason from the investigation of climate model data to either confirm or deny this). This is one reason why long time series of historical data are preferred, so that a reasonable sample of climate variability can be assessed for potential change.

7.2.5 Climate change and variability

The method of scenario application used in this study does not incorporate longer-term changes in climate variability that have been known to occur in the past, beyond those contained in the baseline data. Abrupt changes in rainfall regime affecting both means and variability are known to occur several decades apart but the dynamics of these changes are not well understood and as yet are unpredictable.

7.2.6 Hydrological uncertainties

Impact assessments using different hydrological models indicate that the models themselves may have varying sensitivity to climate change (e.g. Boorman and Sefton 1987). Further work comparing the sensitivity of the rainfall-runoff model to other commonly used Australian rainfall-runoff models would help put the results provided here in a broader context. Further uncertainty is associated with the modelling process, including the short records of sediment and flow data, calibration techniques, temporal and spatial extrapolation and modelling assumptions.

7.3 SUMMARY AND RECOMMENDATIONS

The methods and results described and presented in this report show that the potential of risk analysis to reduce uncertainty about future streamflow and TSS change is considerable. Despite large uncertainties in the spread of possible results, uncertainties that explode the further into the future one looks, the most likely range is much more constrained. In terms of planning that takes account of those changes, it is possible to focus on the most likely outcomes, with a watching brief being held to ensure that climate change is not likely to shift outcomes beyond that range.

However, changes affecting water resources due to the greenhouse effect will not occur in isolation. Ongoing changes in climate variability over decadal scales, suggests a whole of climate approach needs to be taken. Non-climatic effects will also affect yield, for example: the development of farm dams, re-forestation and other forms of water harvesting.

Recommendations for further research include:

- Compare the capacity of various crop and grazing management practices at the paddock/farm scale to limit runoff and TSS loads.
- Identify important natural resource and agricultural thresholds in a changing climate and investigate the adaptive capacity of planning and management.
- Investigate modes of decadal rainfall variability for the region.
- Investigate how NRM planning responds to changes in climate that may be beyond the coping range of natural resource managers.
- Assess current water and land use strategies in light of possible changes.
- Identify differential changes in daily rainfall and number of raindays using finer resolution climate models to assess the impact of changes in rainfall intensity and timing.
- Identify differential changes in summer temperatures and wind speed using finer resolution climate models to assess the extreme evaporation period over summer.

8 Publications

An abstract has been submitted and accepted for the MODSIM 2007 Conference in New Zealand titled *Climate change impacts on the sediment load for the Nogoa catchment of the Fitzroy Basin*.

Abstracts have been submitted to the joint International Grasslands and Rangelands Congress in China in June 2008 titled *Land use change and impacts of climate change on sediment load in the Fitzroy Basin* and *Impacts and adaptation to climate change in beef production systems in central Queensland*.

9 Acknowledgements

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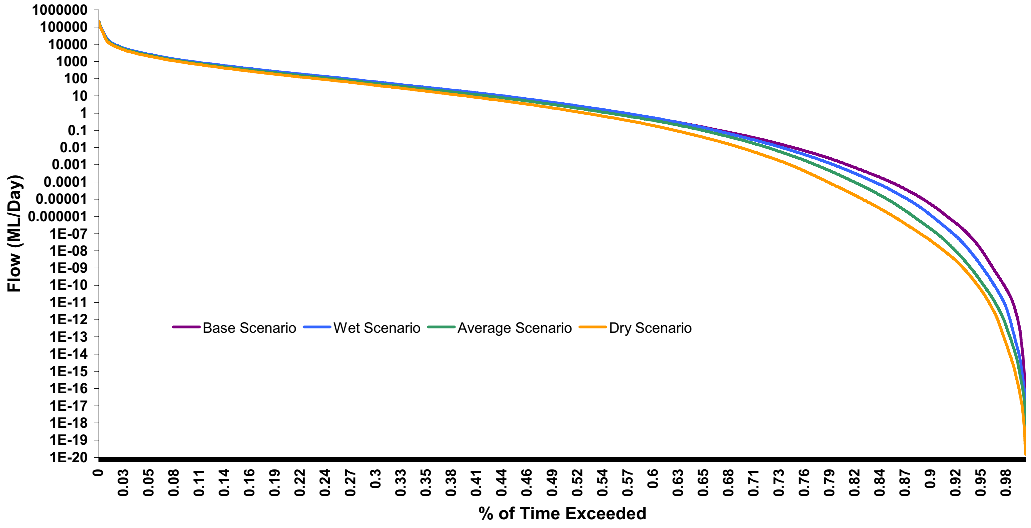
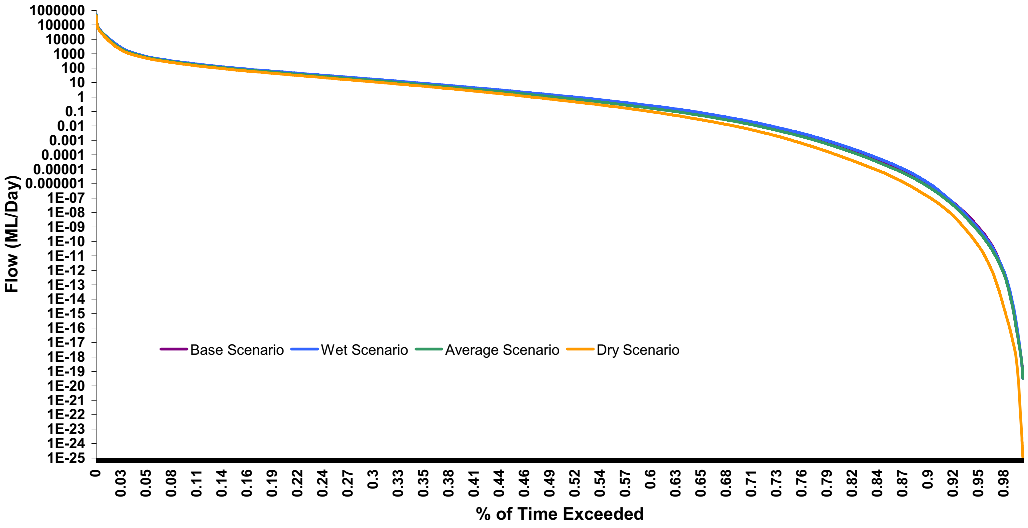
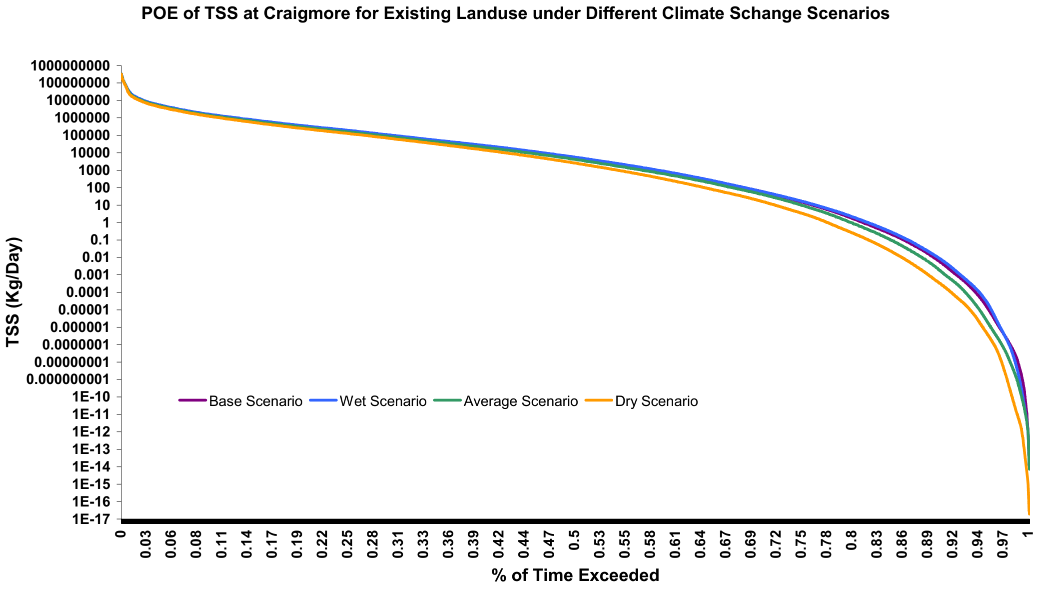
11 Appendix 1 – Exceedance Curves for Daily Flow

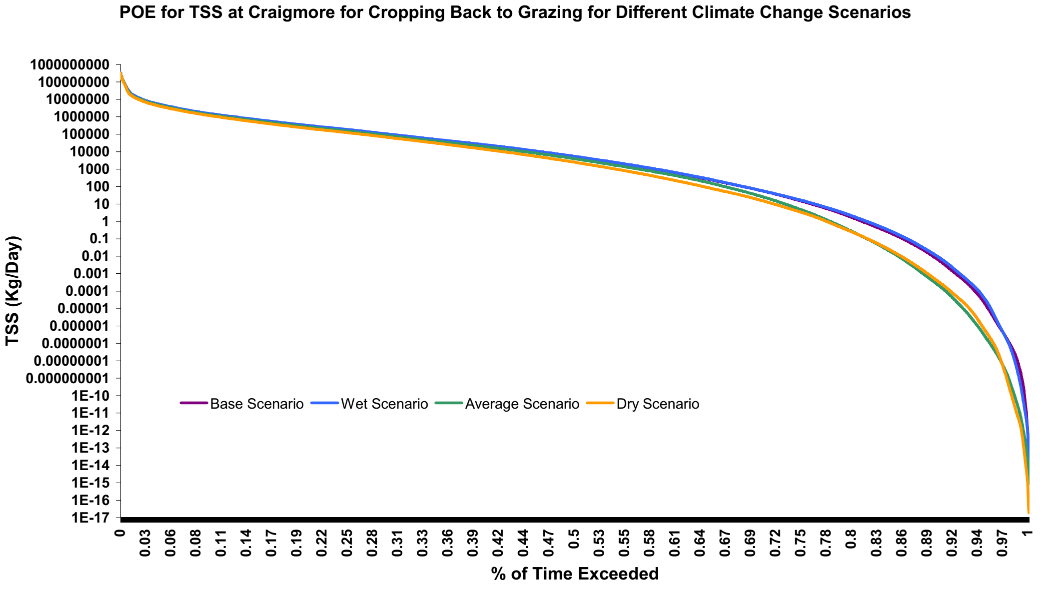

POE of Flow at Craigmore for Different Climate Change Scenarios

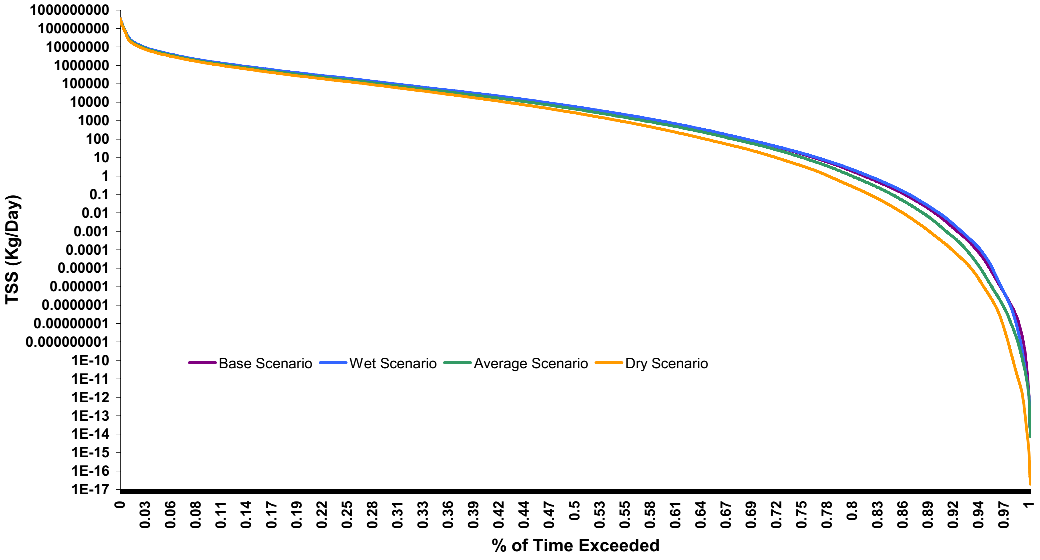

POE for Flow at Retreat Creek for Different Climate Change Scenarios

12 Appendix 2 – Exceedance Curves for Daily TSS

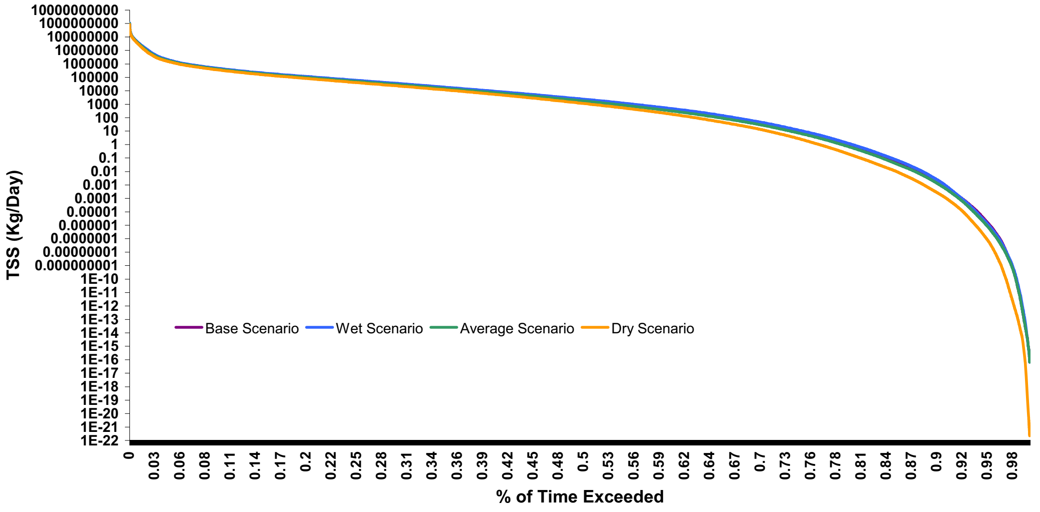
CRAIGMORE



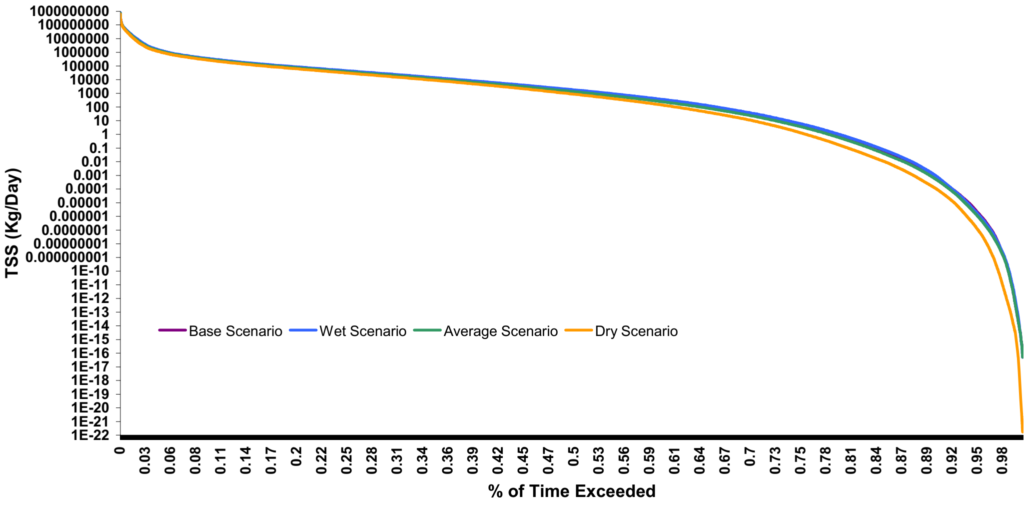



POE for TSS at Craigmore for Cropping up 6% for Different Climate Change Scenarios

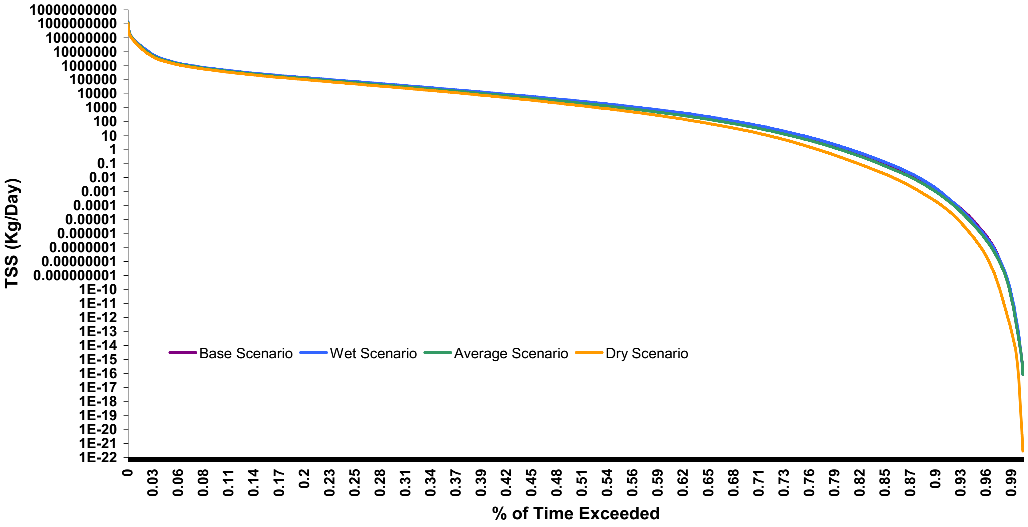
THERESA CREEK


POE Graph of Daily TSS at Retreat Creek for Existing Landuse for Different Climate Change Scenarios

POE Graph for Daily TSS at Retreat Creek for Cropping Back to Grazing fo Different Climate Change Scenarios



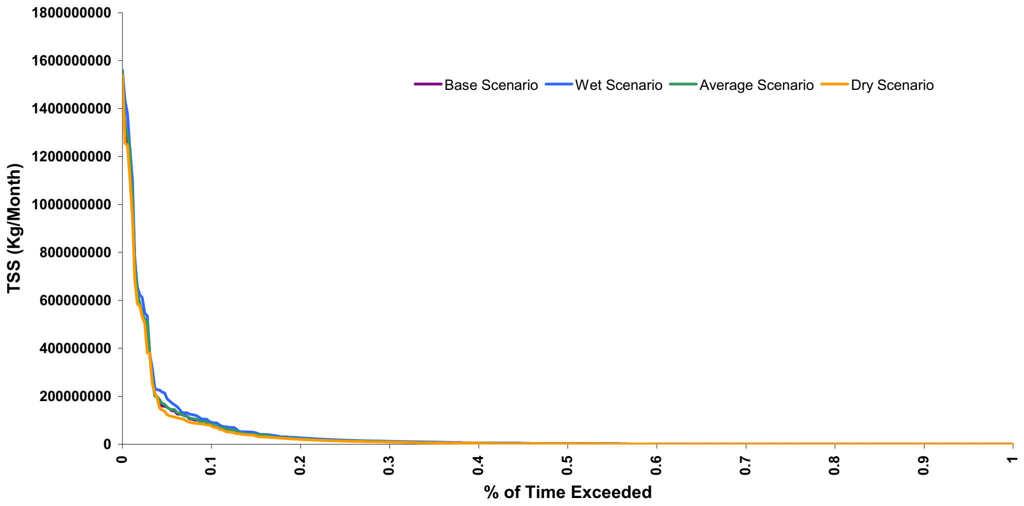
POE for Retreat Creek with an Increase in Cropping by 6% for Different Climate Change Scenarios



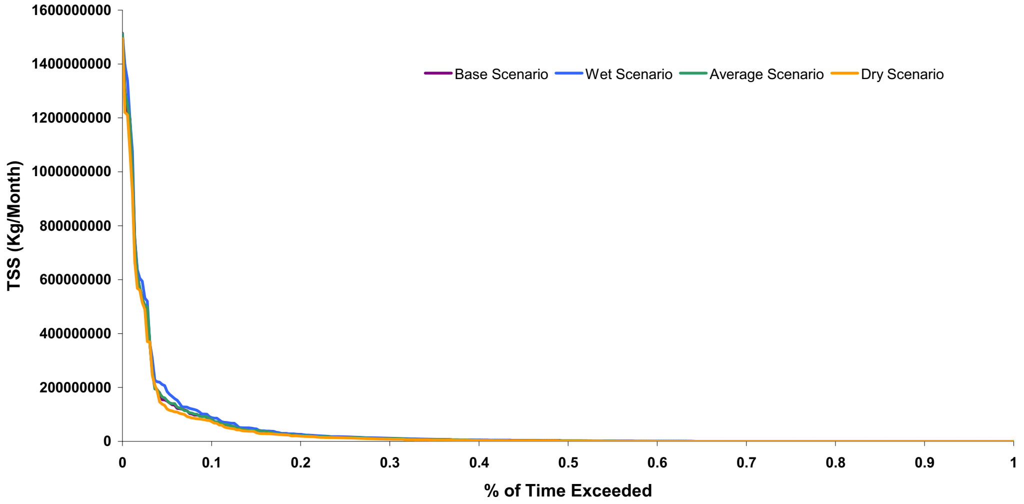
13 Appendix 3 – Exceedance Curves for Monthly TSS

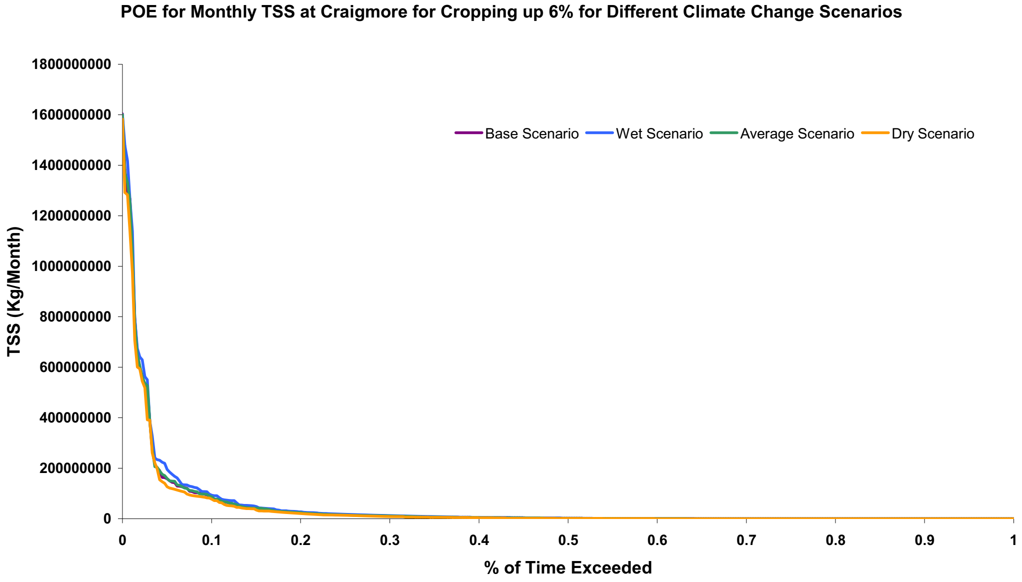
CRAIGMORE

POE Graph of Monthly TSS for Existing Land Use at Craigmore for Different Climate Change Scenarios

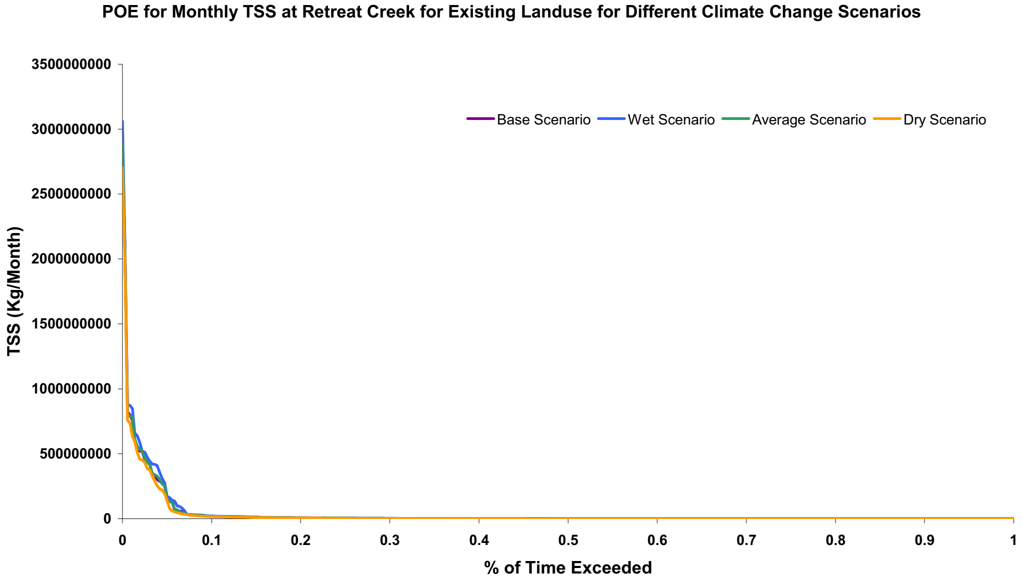


POE Graph of Monthly TSS at Craigmore for Cropping to Grazing for Different Climate Change Scenarios

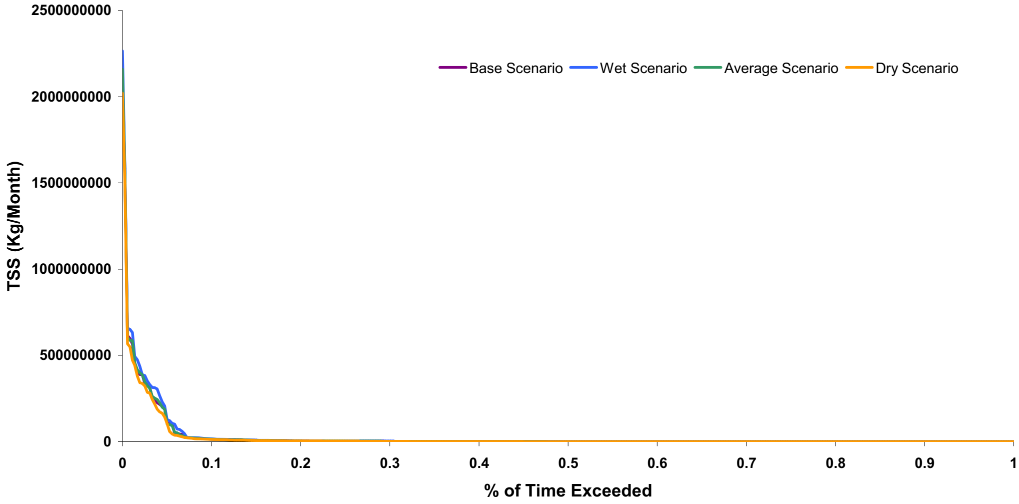




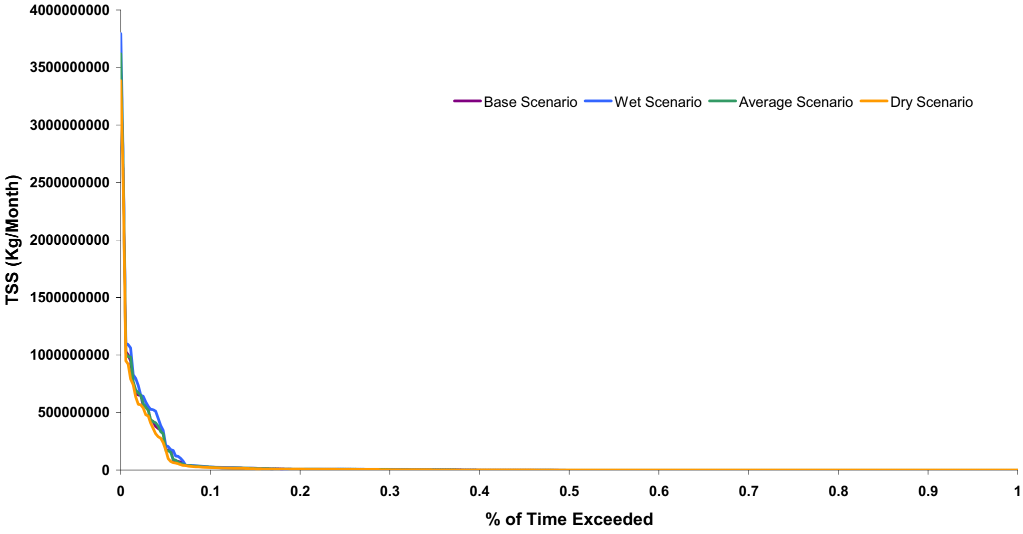
<u>THERESA CREEK</u>



POE for Monthly TSS at Retreat Creek for Cropping to Grazing for Different Climate Change Scenarios

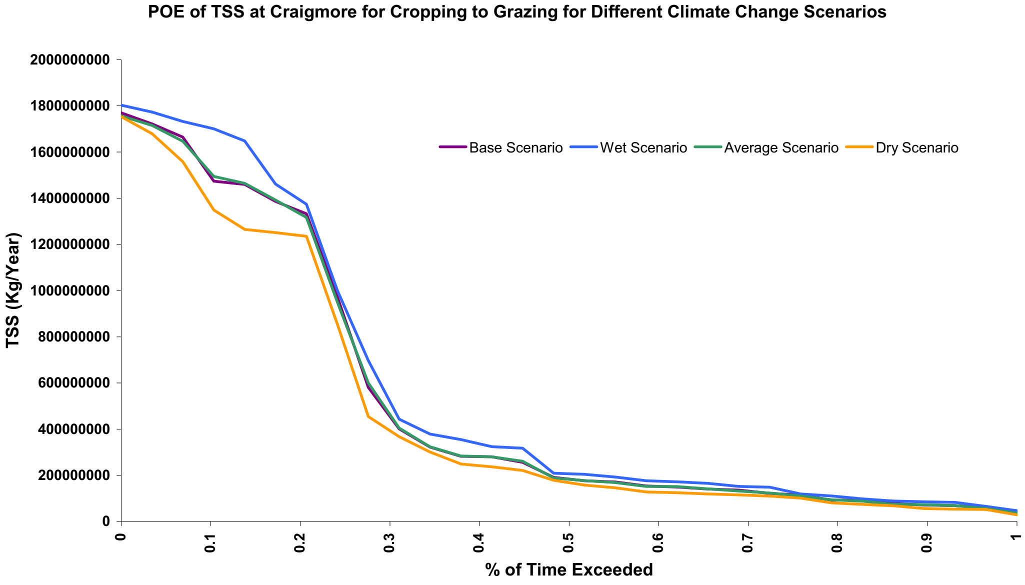


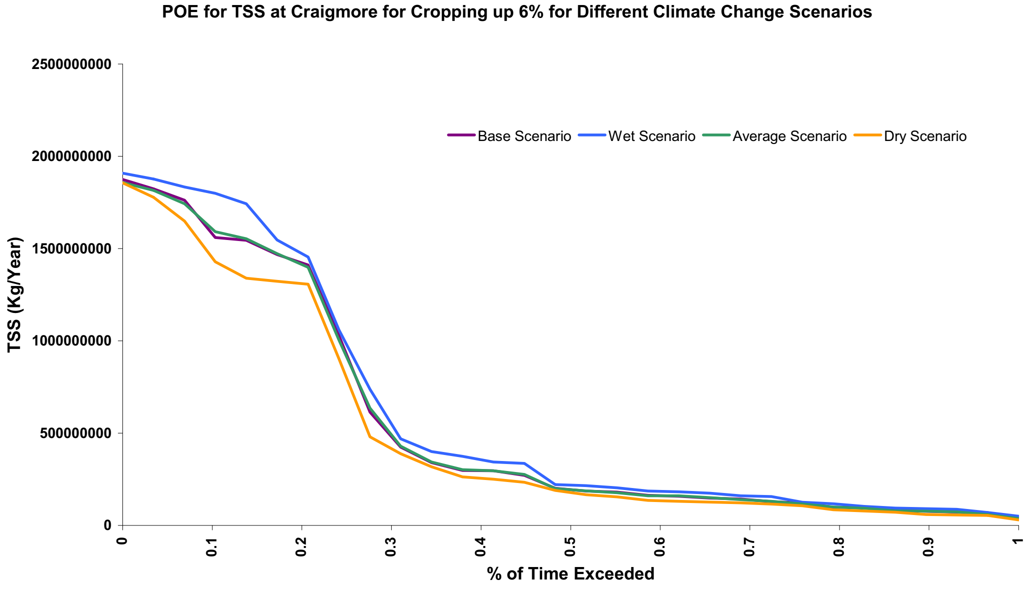
POE for Monthly TSS at Retreat Creek for Cropping up 6% for Different Climate Change Scenarios



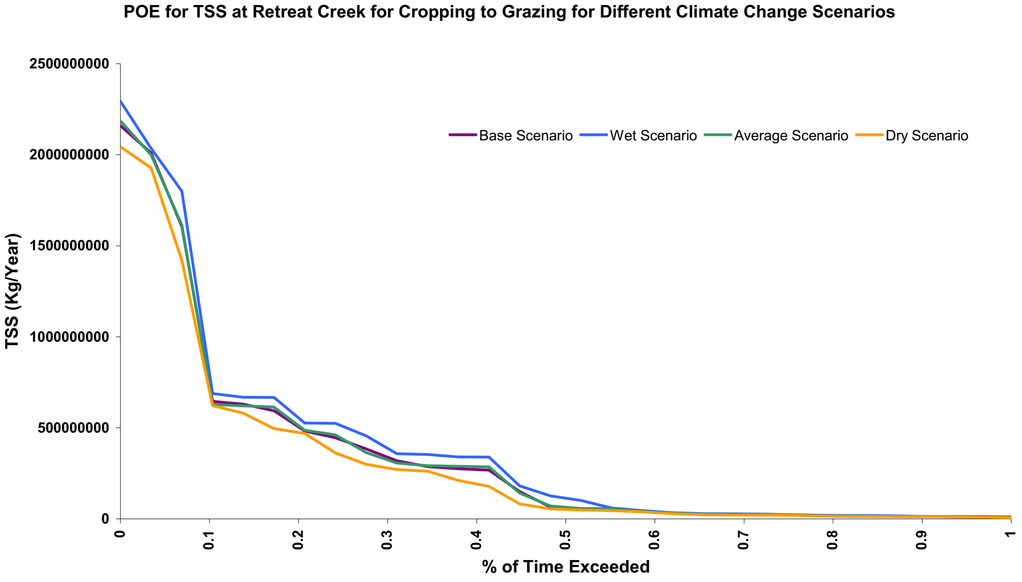
14 Appendix 4 – Exceedance Curves for Annual TSS

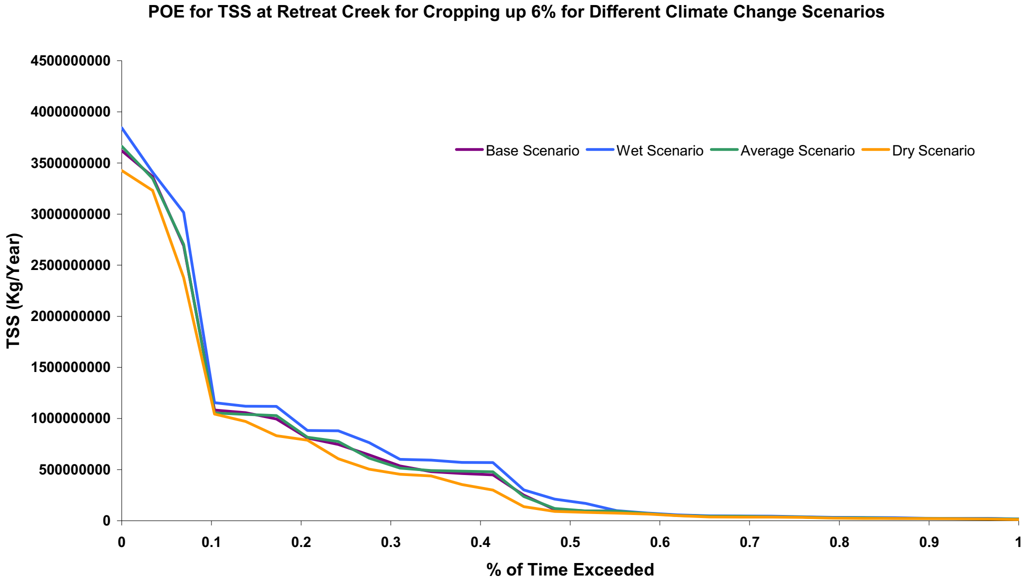
CRAIGMORE





THERESA CREEK





15 Appendix 5 – Scatterplots and POE curve plots of observed and simulated flows and TSS at Craigmore and Theresa Creek

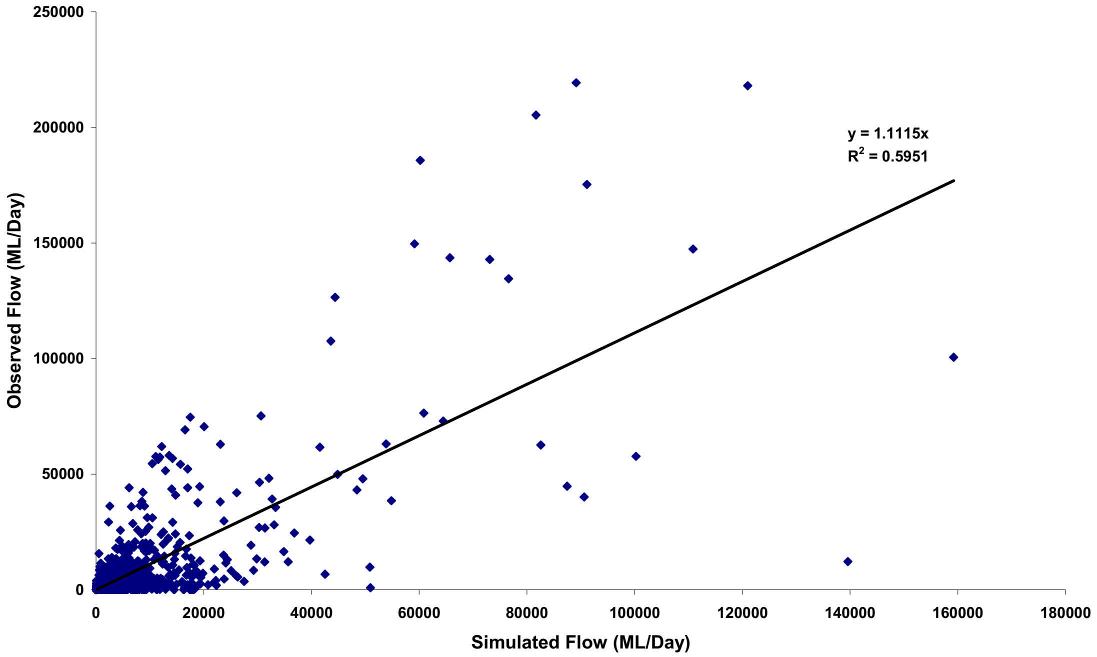


Figure 16. Scatterplot showing the relationship between the observed and simulated flow at Craigmore using the Simhyd model in E2.

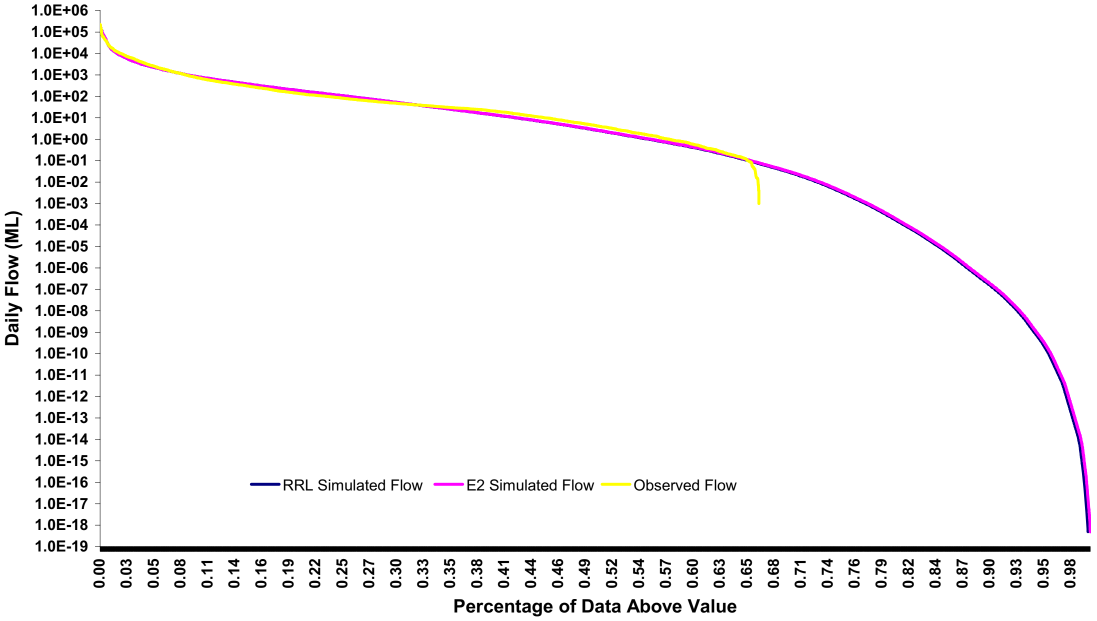


Figure 17. POE curves showing the relationship between the observed and simulated flows at Craigmore using the Simhyd model from the RRL and E2.

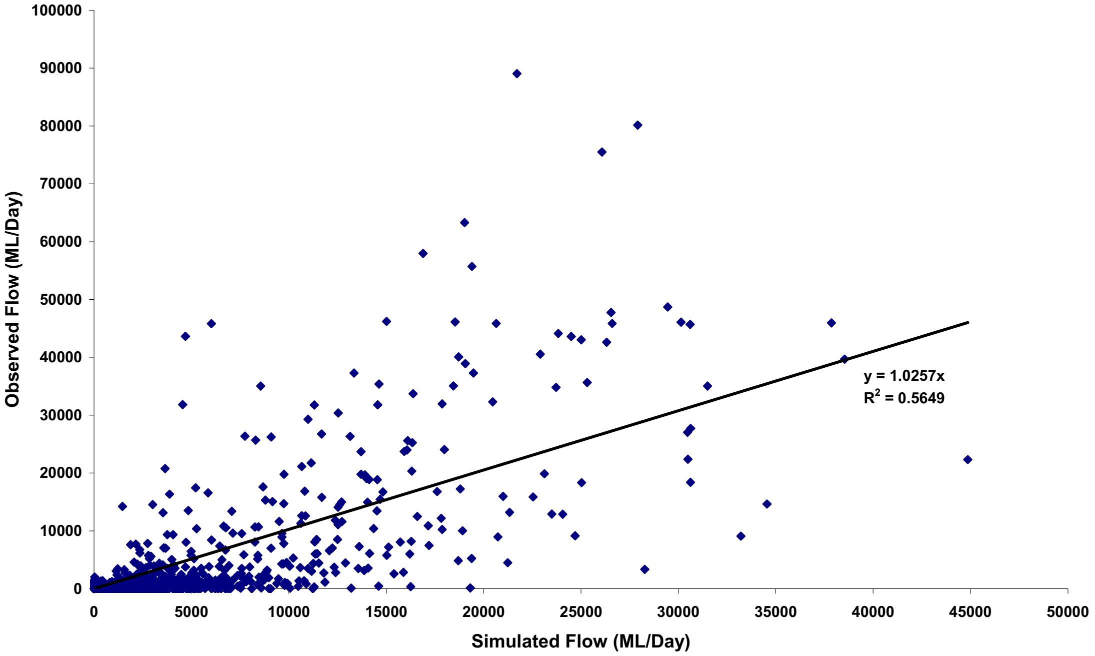


Figure 18. Scatterplot showing the relationship between the observed and simulated flow at Theresa Creek using the Simhyd model from the RRL.

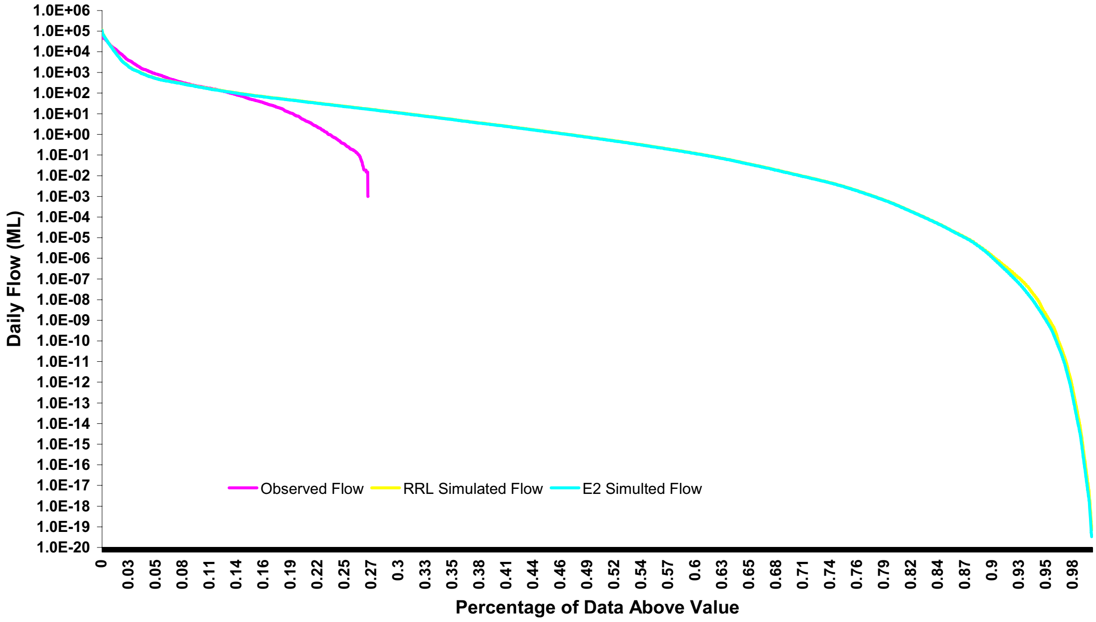


Figure 19. POE curves showing the relationship between the observed and simulated flows at Theresa Creek using the Simhyd model from the RRL and E2.

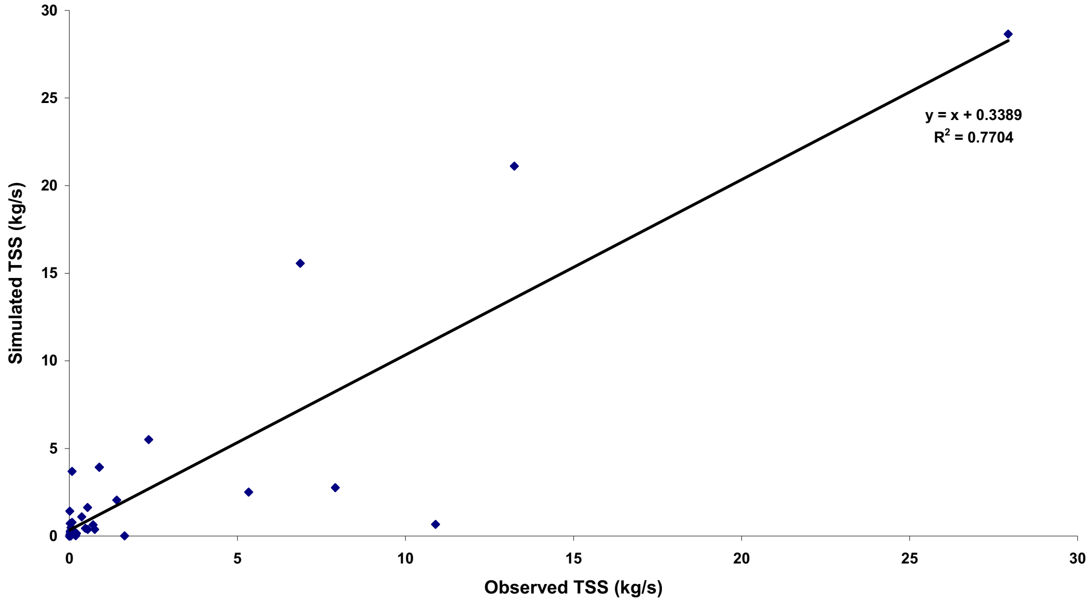


Figure 20. Scatterplot showing the relationship between the observed and simulated TSS at Craigmore using the dry weather concentration/event mean concentration sediment model in E2.

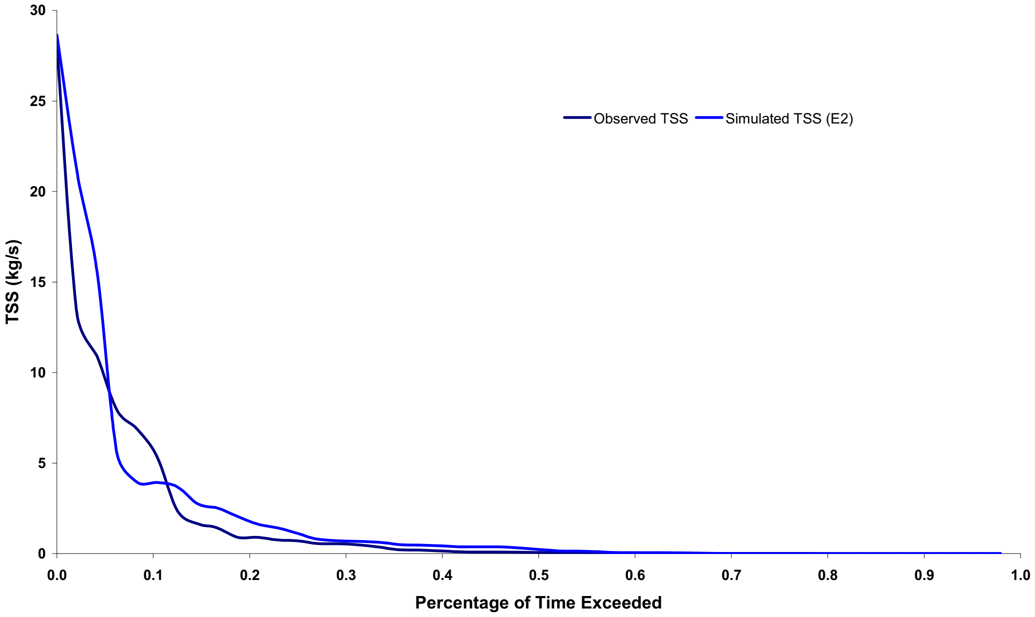


Figure 21. POE curves showing the relationship between the observed and simulated TSS at Craigmore for the dry weather concentration/event mean concentration sediment model in E2.

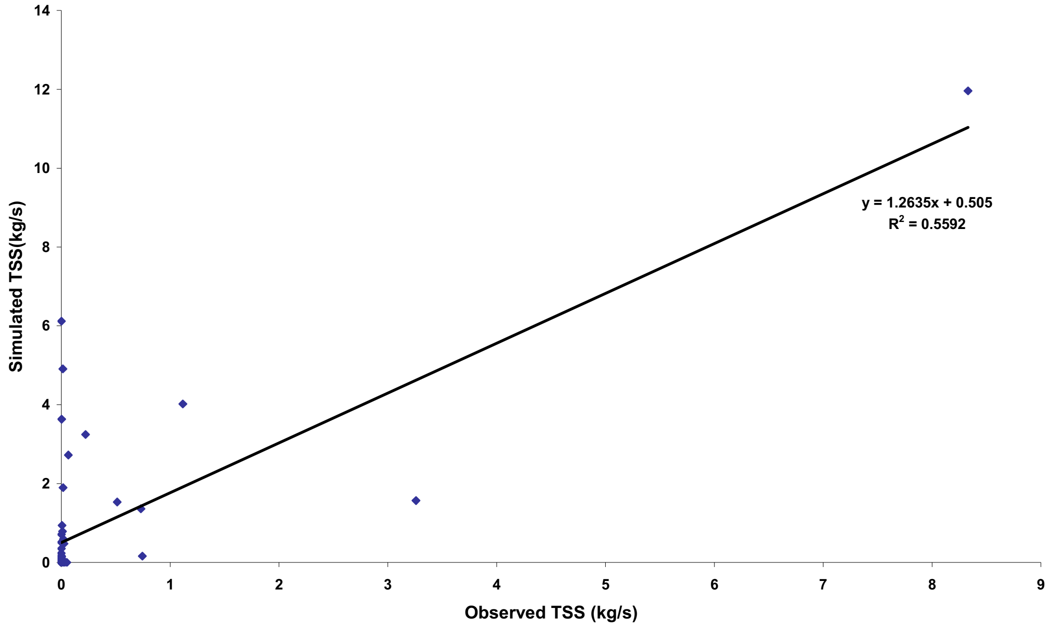


Figure 22. Scatterplot showing the relationship between the observed and simulated TSS at Theresa Creek using the dry weather concentration/event mean concentration sediment model in E2.

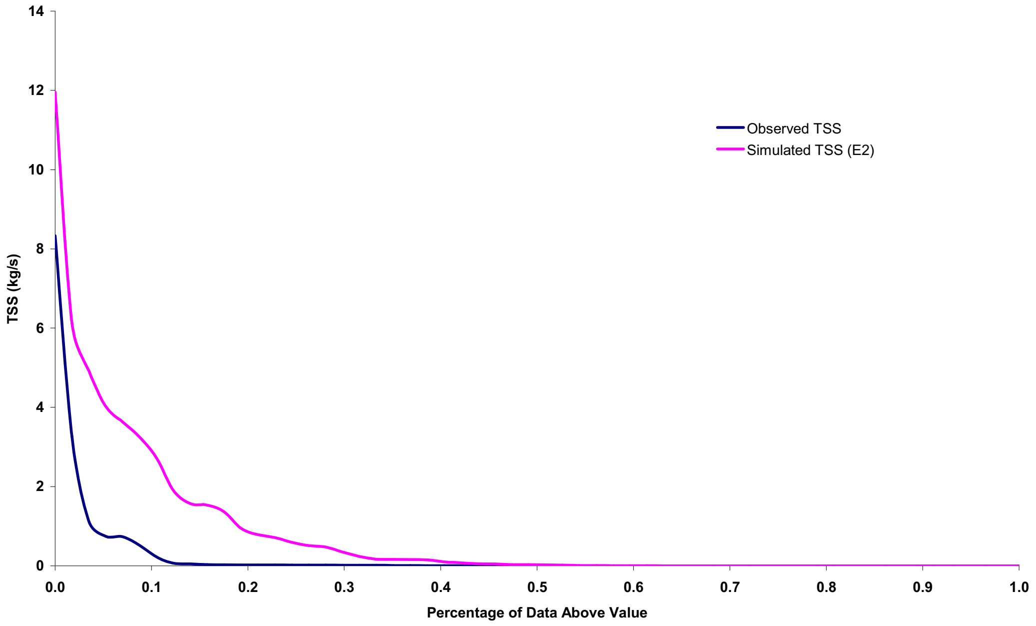


Figure 23. POE curves showing the relationship between the observed and simulated TSS at Theresa Creek for the dry weather concentration/event mean concentration sediment model in E2.