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PRACTICAL ADAPTATION TO CLIMATE CHANGE IN REGIONAL NATURAL RESOURCE MANAGEMENT

Queensland Case Studies – Desert Channels Queensland Report

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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PRACTICAL ADAPTATION TO CLIMATE CHANGE IN REGIONAL NATURAL RESOURCE MANAGEMENT

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Qld Case Studies – Report for Desert Channel Queensland Case Study – Climate Change Impacts on Water Resources of the Cooper Creek Catchment.

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Executive Summary

A number of general circulation models (7) and greenhouse gas emission scenarios (2) 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 Thomson River. Resulting changes in flood inundation downstream of Currareva were assessed and potential changes in vegetation identified. Changes in climate and water flow were measured against a base period from 1961-1990.

The **dry scenario for 2030 was associated with a mean temperature increase of 1.7°C, reduced annual rainfall of 4% and higher evaporation of 9%. The wet scenario for 2030 was associated with a mean temperature increase of 1.0°C, higher annual rainfall of 1% and higher evaporation of 3%.**

The range of change from the driest and wettest extremes of regional climate change indicate a range of change in mean annual rainfall in the catchment upstream of Currareva from approximately -4% to +1% by 2030. The change was driven by less early spring (SO) and more summer (NDJF) rainfall in the wet extreme and less late winter to early summer rainfall (ASOND) in the dry extreme. **These changes *per se* are unlikely to have a significant impact on vegetation**, although 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.

The range of change in annual potential evaporation was approximately 3% to 9% higher by 2030. **Annual pan evaporation of 2.5 m may increase by 200 mm which may reduce waterhole persistence and connectivity, so occasional irregular flows will become more important to sustain aquatic refugia.** More work is needed using finer resolution climate models and differential changes in summer temperatures and wind speed to assess the extreme evaporation period over summer.

The range of change in annual flow at Currareva was approximately -7% to +2% by 2030. A reduction in flow of this magnitude (3.16 to 2.94 million ML/year) may not be significant against the background of high flow variability, however **significant impacts downstream of Currareva may occur given that most of the run-off is generated in the northern part of the catchment and that there are significant downstream transmission losses.**

Most of the difference in average monthly flows at Currareva occurred in summer and autumn with little difference in winter and spring. Summer floods produce native sorghum, summer grasses, legumes and forbes, where as autumn floods produce cooper clover, herbage and a wide variety of winter plants. **The timing of average monthly flows did not change in this analysis, and as such, there was no evidence for changes in vegetation types associated with timing of floods and climate change.**

Climate change was associated with extended lengths of long periods of no flow. The longest simulated period of no flow was 280 days for the base scenario and 361 days for the average scenario, an increase of nearly 30%. If we apply a 30% increase to the recorded (1939-1989) maximum no-flow period (21 months from 1951-1952), **the extended period of no-flow due to climate change of 27 months could be associated with most waterholes drying to within 10% of their bankfull volumes** (Hamilton *et al.* 2005). These estimates assume that there is no major abstraction from waterholes, and that pumping for stock, irrigation and domestic supply will further reduce persistence times.

The mean number of days per year of no flow at Currareva was nearly 2 weeks longer for the average and dry scenarios compared to the base scenario. The longer periods of no flow associated with the average and dry scenarios may have an adverse impact on the natural and human systems downstream of Currareva. Further discussion with regional experts and natural resource scientists is needed. The base and wet scenarios were not different.

The average and dry scenarios were associated with a reduced frequency of low daily flows (<1000 ML/d) at Currareva compared to the base scenario. The magnitude of the reduction in low flow frequencies was small (e.g. 10 ML/day was exceeded 46% of the time for base scenario and 43% for dry scenario) but the reduction was consistent throughout the range of low flows (i.e. 1-1000 ML/day). **The impact maybe associated with reduced waterhole persistence and connectivity during periods of drought, particularly downstream.**

A reduction in persistence of waterholes may have consequences for the plant and animal life that rely on these water sources. Higher mineral concentrations may result from reduced replenishment of waterholes, which may change vegetation in and around waterholes to that more tolerant of higher mineral concentrations. In addition reduced connectivity of waterholes may limit passage of aquatic biota between waterholes and extend residence time in one waterhole. This may reduce aquatic biota biodiversity in waterholes.

The maximum flow under the dry scenario was 11% lower than the base scenario. This finding requires further investigation because these extreme flood events play important roles in natural desiltation of waterholes and in delivering the water required to reach and fill the large downstream water storages such as the Coongie Lakes and Lake Eyre in South Australia. These water storages support important ecosystems and biodiversity through natural cycles of wet and dry and this role may be more important under dry climate change conditions. A reduction in maximum flows may also result in decreases in inundation on the borders of floodplains, which may result in decreases in biodiversity in these areas, shrinking the floodplain. Annual and short-lived grass species may also be replaced by perennial grass species from neighbouring communities.

The average and dry scenarios were also associated with a small reduction (2-9%) in high daily flows (99, 95, 90 and 88 percentile) and the wet scenario a small increase (3-4%) in high daily flows (99, 95, 90 and 88 percentile) compared to the base scenario. These differences are only small and maybe insignificant against the background of high variability in natural flows.

The relationship between recorded peak discharge at Currareva and recorded area of inundation shows beneficial flooding downstream started at a flow of 8370 ML/day, equivalent to a height of 2.9 metres (9 feet 6 inches). The inundation area downstream from Currareva was very sensitive to small increases in flow volume and height around this level, which was the equivalent of 87 percentile flows.

Within the range of small event floods (88-92 percentile flows) **the wet scenario was associated with an increased inundation area of up to 32% and the dry scenario a decreased inundation area of down to 75%.** This change in inundation area of small event floods may have an impact on the production of herbage, natural resources and biodiversity near the main channels. Less inundation of small flood events on the floodplains may also mean that pastures in the outer country are used more. The increased grazing pressure on the outside country may lead to the degeneration of perennial grasses due to the decrease in available recovery time.

Channel, gutter, handy and good floods are types of floods described in this report. They refer to the flow volume and height of water in relation to the extent of flooding downstream of Currareva. Channel floods occurred when the simulated height of water at Currareva was 3.05 m (10 feet), gutter floods at 3.66 m (12 feet), handy floods at 4.57 m (15 feet) and good floods at or above 5.49 m (18 feet). The minimum daily flow volumes for these four flood types are approximately 10,170 ML/day, 18,620 ML/day, 46,130 ML/day and 114,260 ML/day. The corresponding floodplain inundation areas are 553 km^2, 2274 km^2, 4855 km^2 and 7436 km^2. Gutter floods were the most common and good floods the least common in all scenarios. There were minor reductions in the annual frequency of handy flood heights at Currareva under average and dry scenarios compared to the base scenario. Although these findings at Currareva may be insignificant, we should be weary of extrapolating this finding downstream without some work looking at runoff, flows and transmission losses between Currareva and Innamincka.

1 Project overview

The project involved seven regional natural resource management (NRM) organisations - including Desert Channels Queensland (DCQ), 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 DCQ 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 Desert Channels Queensland (DCQ) (Park 2005), and is available from the DCQ regional office in Longreach or the Queensland Murray Darling Committee in Toowoomba. A meeting was held in Longreach (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. Water flows and inundation areas in the Thomson River
3. Potential shifts in vegetation (qualitative assessment).

3 Desert Channels Queensland

Desert Channels Queensland (DCQ, Figure 1) is 509,900 square kilometres and makes up the Queensland section of the Lake Eyre Basin., which is the worlds largest internally draining basin covering around 1.3 million km^2 (15% of the Australian continent). The DCQ region comprises of seven biographic regions including the eucalypt woodlands of the Desert Uplands through the Mitchell Grasslands and the vast floodplains of the Channel Country to the Simpson Dunefields.

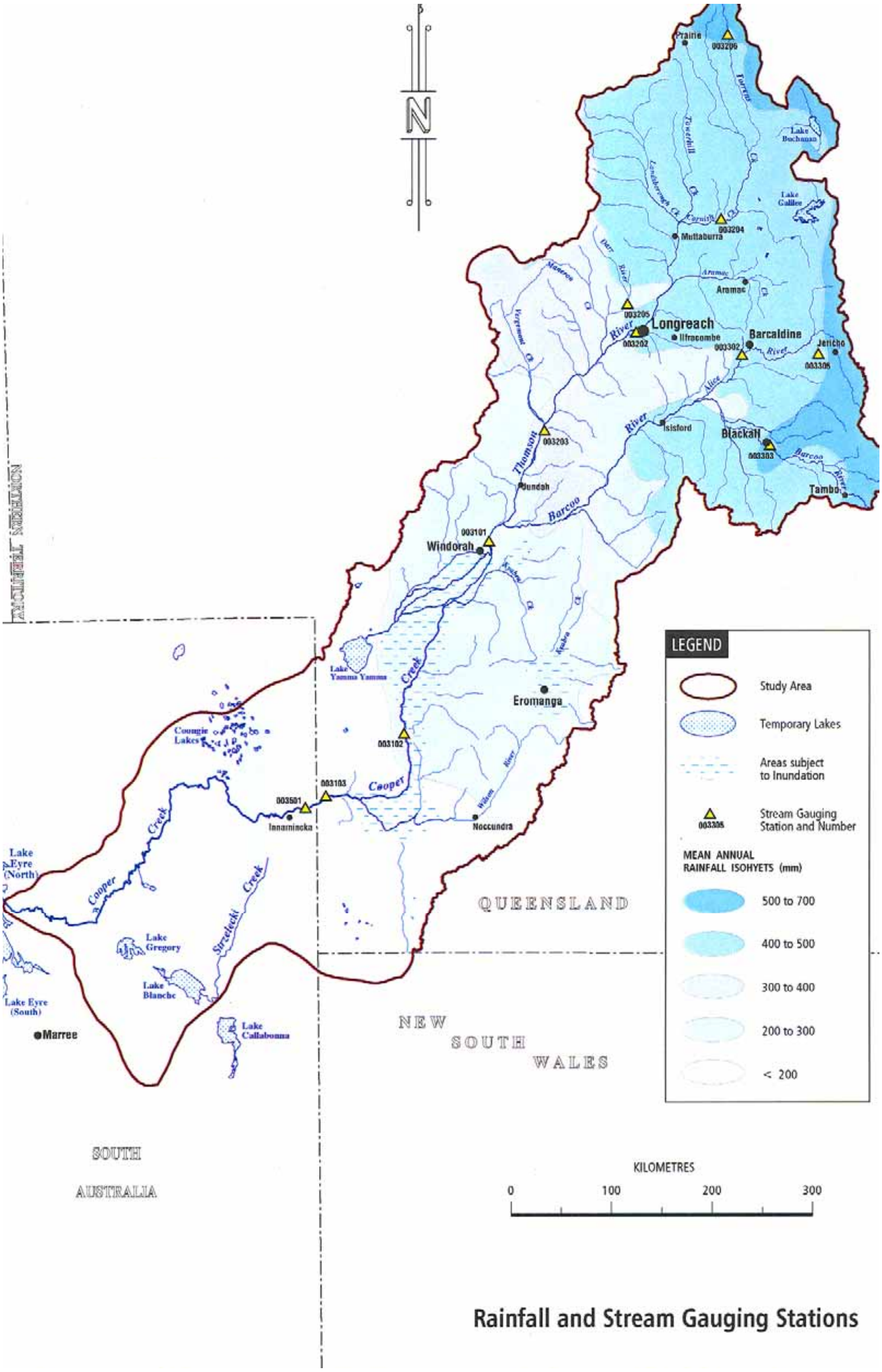
The Lake Eyre Basin is an ancient, weathered landscape with soil varying from the dune sands of the Simpson Desert, through the grey and brown clays of the Mitchell Grass Downs, the heavy and grey clays on the flooded areas of the Channel Country to the duplex soils, red earths and sands of the Desert Uplands and the Mulga Lands. The five major native pasture types in the DCQ regions are the Mitchell grasslands, Spinifex, Channel Country, Mulga and Gidgee. The DCQ region is also rich in natural assets. The Desert Uplands bioregion is home to 22 rare or threatened animals and 29 rare or threatened plants. The DCQ region also has 23 wetlands recognised by the State and Australian governments as being of national significance because of their uniqueness, or value to biodiversity conservation.

Most of the area's surface water is found in waterholes along the river systems. The channel country is an extensive natural flood irrigation system that often receives its floodwaters from rain that has fallen hundreds of kilometres away. The channel country refers to floodplains in the mid to lower reaches of three anastomosing[#] river systems; Cooper Creek, Georgina River and Diamantina River. Beneficial flooding is recognised as making a significant contribution to floodplain ecosystem processes and to pastoral productivity. Although the floodplains have changed little since the first explorers, the public focus has been on preserving the extensive natural wetlands and the vast native flora and fauna that habitat these areas. A possible threat to preserving this biodiversity is a reduction in the volume, height and frequency of flood waters due to climate change.

Since the introduction of the Natural Landcare Program and the formation of the NRM Catchment groups studies have been completed that document the biodiversity of flora and fauna, the wealth of knowledge of past and present land managers and the likely impacts of agriculture and mining on natural resources. The experiences of land managers provide useful assessments of the relationships between flood heights, timing of floods and the inundation levels and plant species dynamics.

This case study modelled the water flows (seasonal, annual) in the Thomson River and compared them to those likely as a consequence of climate change. Water flows and stream height were used to compare the change (historical and climate change) in the inundation level in the reaches of the lower Thomson River of four floods (significant but different in terms of inundation level) that occurred between 1984 and 1991. These changes in flood inundation levels were assessed against the existing expert knowledge of responses of channel country pasture to temporal (seasonal, annual) and spatial flooding patterns. Six managers/owners of land downstream of Currareva were interviewed about the likely impact of climate, flow and inundation changes on natural resources and agricultural production.

[#] An anastomosing river contains two or more interconnected channels that enclose floodbasins



Rainfall and Stream Gauging Stations

Figure 1. Lake Eyre Basin. The Queensland section is known as Desert Channels Queensland (DCQ).

4 The climate change scenarios

4.1 UNCERTAININITY 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 2, which shows the range in global warming to 2100, based on the Special Report on Emission Scenarios (SRES; Nakiçenovic *et al.*, 2000) and Inter Governmental 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.

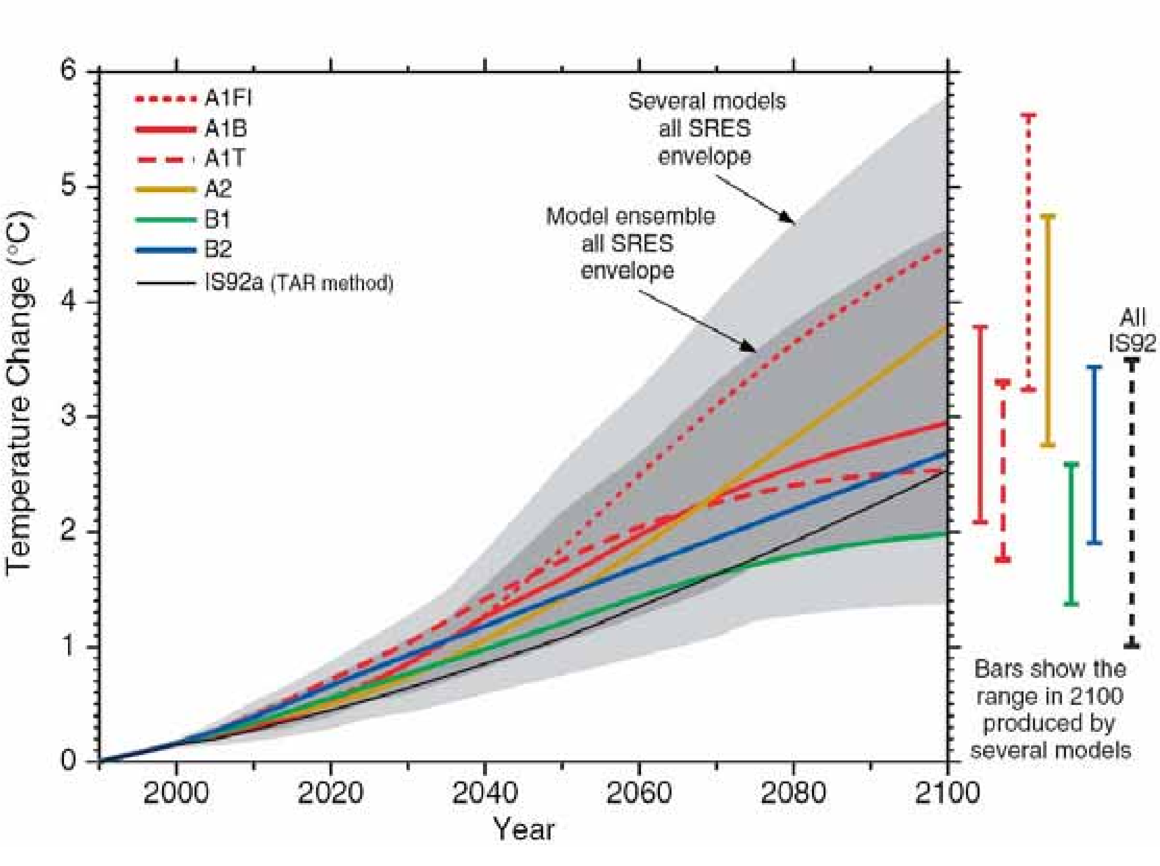


Figure 2. Global mean temperature projections for the six illustrative SRES scenarios using a simple climate model tuned to a number of complex models with a range of climate sensitivities. Also for comparison, following the same method, results are shown for IS92a. The darker shading represents the 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 is a regional climate model

Centre	Model	Emissions Scenarios post-1990 (historical forcing prior to 1990)	Years	Horizontal resolution (km)
CSIRO, Aust	Mark2	IS92a	1881–2100*	~400
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 and ECHAM4 Models were run for both medium and high climate sensitivities, all other models were run with medium climate sensitivity.

In the region surrounding the Cooper Creek Catchment, annual rainfall projections range from slightly wetter, to much drier than the historical climate of the past century. Seasonally, changes are uncertain in DJFM and MJ but are dominated by decreases in ASO. Over successive generations of climate model, estimates of rainfall change have become drier, but increases in the upper Cooper Creek 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 Cooper Creek Catchment are shown in Table 2. All the models show increases in potential point evaporation, however increasing rainfall usually 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 upper Cooper Creek catchment, simulated by the models in Table 1, expressed as a percentage change per degree of global warming with medium sensitivity

Model	Rainfall	Point Potential Evaporation
Mark2	-4.82	4.89
CCCM1	-2.68	5.81
DARLAM125	2.84	4.16
ECHAM4	1.50	3.53
HadCM3	-3.22	7.40
NCAR	1.52	4.32

Seasonal changes are shown in Figure 3 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.

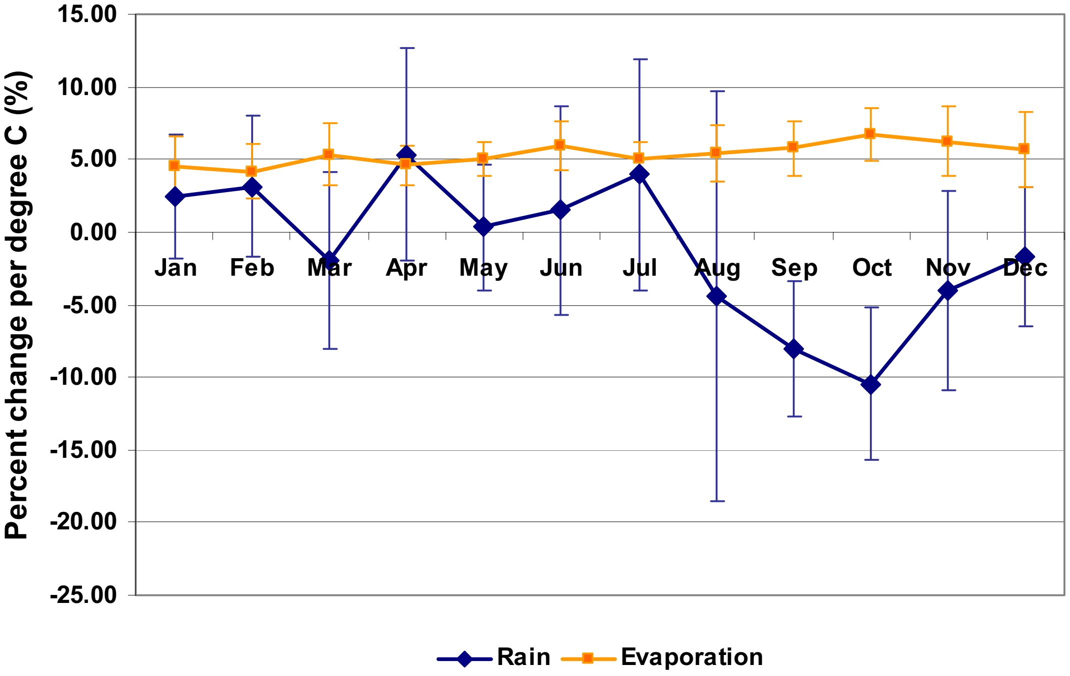


Figure 3. Average monthly percentage change in rainfall and potential evaporation for the upper Cooper Creek (see Table 4 for the 12 locations) per degree of global warming using the seven climate models and emissions scenarios with medium sensitivity shown in Table 1 with one standard deviation.

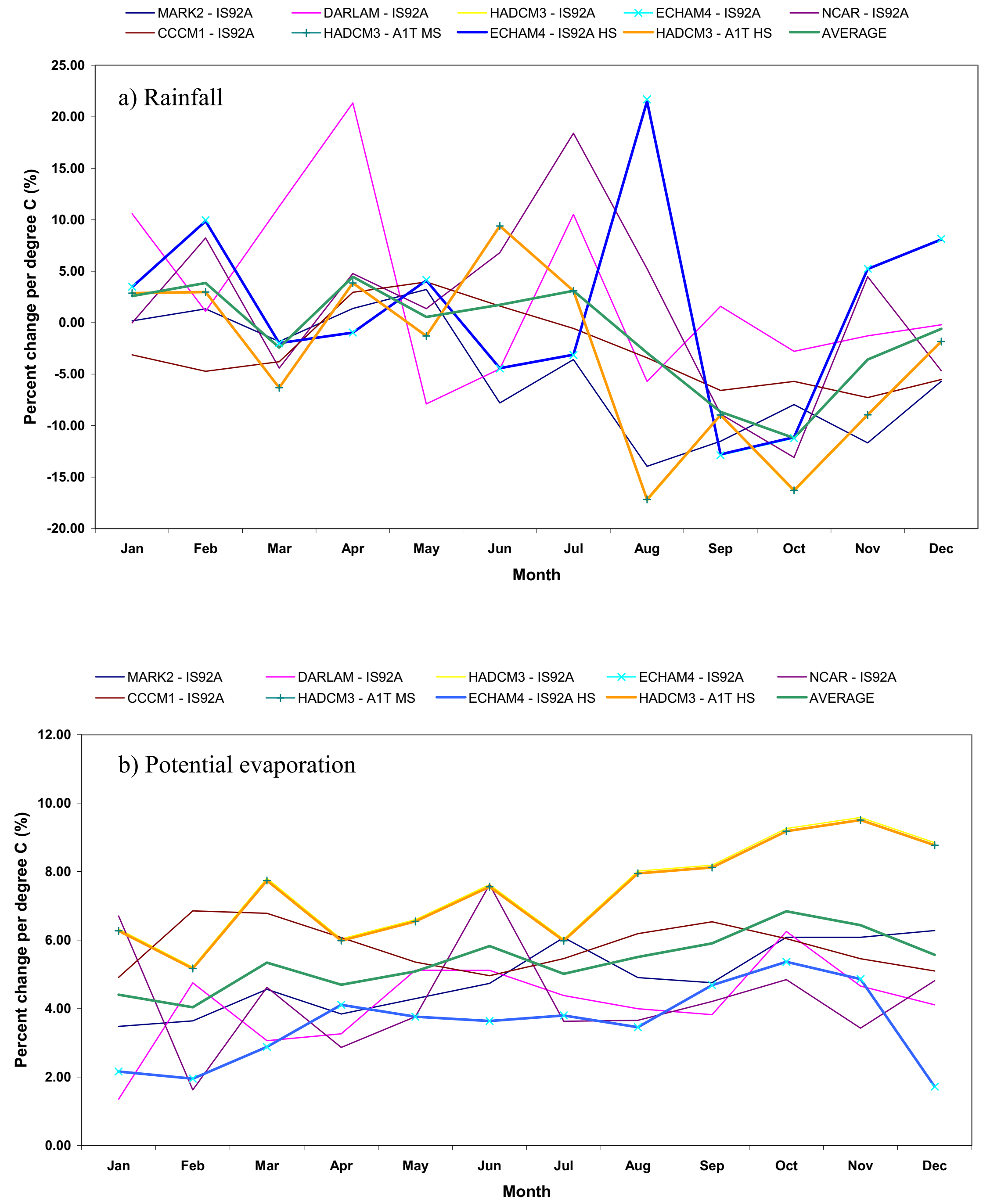


Figure 4. Average monthly percentage change in a) rainfall and b) potential evaporation for the upper Cooper Creek (see Table 4 for the 12 locations) per degree of global warming for the seven climate models shown in Table 1 at medium (MS) and high sensitivity (HS).

4.3 CLIMATE CHANGE SCENARIOS

This report presents the range of possible changes provided by dry, wet and average scenarios for the Cooper Creek 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 A1T greenhouse gas scenario in 2030 forced by high climate sensitivity with regional rainfall and potential evaporation changes expressed by the HadCM3 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 Cooper Creek 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 Cooper Creek catchment

Scenario	**Dry**	**Average**	**Wet**
Global warming scenario	A1T	Average of All	IS92a
GCM	HadCM3	Average of All	ECHAM4
Global mean warming (°C)	1.24	Average of All	0.78
Regional minimum temperature change (°C)	Not Available	Average of All	1.00
Regional maximum temperature change (°C)	Not Available	Average of All	0.90
Regional mean temperature change (°C)	1.70	Average of All	1.00
Change in annual rainfall (%)	-3.99	-0.98	1.16
Change in annual potential evaporation (%)	9.17	4.02	2.75

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 seven 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 Integrated Quantity Quality Model (IQQM) to produce output that was conditioned on 2030 climate.

5.2 PERTURBING HISTORICAL DATA

The locations of climate stations within the Cooper Creek Catchment of the Lake Eyre Basin (Figure 1) close to the Thomson and Barcoo Rivers 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
Longreach	-23.45	144.25
Muttaburra	-22.59	144.55
Aramac	-22.97	145.24
Prairie	-20.87	144.60
Barcaldine	-23.55	145.29
Blackall	-24.42	145.47
Isisford	-24.26	144.44
Jericho	-23.60	146.13
Jundah	-24.83	143.06
Tambo	-24.88	146.26
Stonehenge	-24.35	143.29
Windorah	-25.42	142.66

These stations covered a large area of the catchment 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 and 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 upper Cooper 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 4) 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 HADCM3 model with A1T emissions warming at high climate sensitivity. The model for the average scenario was first chosen to be the DARLAM 125 model with an IS92a scenario, however after investigating some of the output for the factors produced by this model it was decided to replace it with 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 4 and Table 6).

5.3 OVERVIEW OF SACRAMENTO RAINFALL-RUNOFF MODEL

System inflows are the total measure of surface runoff and base-flow feeding into streamflow in the Cooper Creek Catchment. This was carried out using the Sacramento rainfall-runoff model, which is incorporated into IQQM.

The Sacramento rainfall-runoff model has been used in previous climate change studies where IQQM has been perturbed according to a range of climate scenarios (e.g. O'Neill *et al.* 2004). The Sacramento model is a physically based lumped parameter rainfall-runoff model (Burnash *et al.* 1973). The processes represented in the model include; percolation, soil moisture storage, drainage and evapotranspiration. The soil mantle is divided into a number of storages at two levels. Upper-level stores are related to surface runoff and interflow, whereas baseflow depends on lower-level stores. Streamflows are determined based on the interaction between the soil moisture quantities in these stores and precipitation. Sixteen parameters define these stores and the associated flow characteristics, of which ten have the most significant effect on calibration. The values for all sixteen parameters are derived based on calibration with observed streamflows. Burnash *et al.* (1973) describe storage details, their interactions, procedures and guidelines for initial parameter estimations.

5.4 MODEL SET-UP AND CALIBRATION

5.4.1 Sacramento and IQQM

The Sacramento rainfall-runoff model was previously configured and calibrated for the sub-catchments of the Cooper Creek Catchment by the Queensland Department of Natural Resources (Schreiber 1997). This calibration was based on records of historic streamflow, historic rainfall and Class A pan evaporation for the period 1969-1995. From the calibrated model a daily streamflow model (IQQM Version 5.7) was developed for the period 01/01/1889 to 31/12/1995. Because of IQQM limitations on the number of nodes and reach lengths the model was segmented into three separate models 1) upstream of Longreach 2) Longreach to Currareva and 3) Currareva to Nappa Merrie. Segments 1 and 2 are used in this study.

Two IQQM models were used to cover the study area 1) upstream of Longreach and 2) from Longreach to Currareva. Each model was run in turn with output from one used as input into the next. The two models were divided into a total of 40 sub-areas (14 upstream of Longreach, 26 between Longreach and Currareva). Forty historical rainfall files (one for each sub-area) and four historical evaporation files were perturbed using monthly climate change factors for the dry, average and wet scenarios using a macro in Microsoft Excel.

Sacramento models for each of the forty sub-areas were run using historical rainfall and evaporation then rerun using the modified rainfall and evaporation files to produce simulated historical runoff and runoff for each scenario. The simulated runoff/flow files were then used as input for IQQM, firstly for the upper Longreach region followed by the Longreach to Currareva region. Flows for the base and climate change scenarios were then obtained at Longreach, at the junction of the Darr and Thomson Rivers, Isisford, and Currareva.

5.4.2 Inundation levels

Flooding in the Cooper Creek system is the key driver of beef production in the region as the floodwaters stimulate the growth of high quality ephemeral pastures, replenish waterholes necessary for stock-watering and redistribute the grazing pressure. The volume and height of flood waters are associated with the extent of inundation. The extent of beneficial flooding downstream of the junction of the Barcoo and Thomson Rivers was investigated by the Department of Natural Resources (1998). The area of inundation of four floods (1984, 1986, 1990 and 1991) ranging from a small event to a very large flood was determined by Landsat multi-spectral scanner satellite imagery. The recorded peak flood height, peak discharge and magnitude of the inundation area are shown in Table 5.

Table 5. Recorded peak flood height and peak discharge at Currareva and the area of inundation in Queensland downstream of the junction of the Thomson and Barcoo Rivers

Date of flood peak at Currareva	Peak height at Currareva (m)	Peak discharge (ML/day)	Area of inundation (km^2)
December 1984	3.90	26100	3200
February 1986	6.32	178000	8700
February 1991	6.70	457000	11500
April 1990	7.95	1460000	14600

The relationship between recorded peak discharge and area of inundation (Figure 5) shows beneficial flooding downstream of Currareva starts at a flow of 8370 ML/d and a height of 2.9 metres. These relationships were applied to the modelled flows under climate change conditions and the change in area of inundation from this base level was determined.

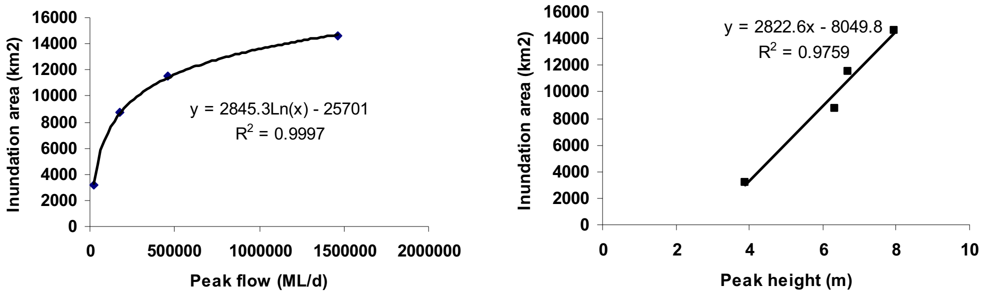


Figure 5. The relationship between recorded peak flow and peak height at Currareva and the area of inundation downstream in Queensland.

5.5 APPLICATION OF THE CLIMATE CHANGE FACTORS

Base data is comprised of 32 years of daily data from 1961 to 1992 for 40 rainfall and 4 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 4. The climate change factors that were used to modify the base data for precipitation and evaporation are shown in Table 6.

Table 6. Climate change factors (% change from base scenario) for the dry, average and wet scenarios for 2030 over the Cooper Creek catchment

Variable	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	**Wet**	2.70	7.69	-1.55	-0.75	3.20	-3.45	-2.43	16.78	-9.97	-8.68	4.06	6.30
	Average	1.88	2.76	-2.20	2.93	0.24	2.06	2.03	-3.29	-6.26	-8.56	-3.00	-0.36
	Dry	3.56	3.70	-7.85	4.77	-1.60	11.65	3.85	-21.29	-11.12	-20.19	-11.10	-2.26
Evaporation	**Wet**	1.68	1.52	2.25	3.20	2.93	2.84	2.96	2.70	3.65	4.18	3.79	1.34
	Average	3.29	2.94	4.02	3.47	3.74	4.28	3.63	4.15	4.42	5.09	4.90	4.25
	Dry	7.77	6.41	9.60	7.42	8.11	9.37	7.41	9.86	10.07	11.39	11.79	10.88

5.6 GENERATION OF MODIFIED SYSTEM FLOWS

IQQM was then run normally, calculating the streamflow under normal conditions, and then run using the modified climate files in order to obtain the flows for the wet, average and dry scenarios.

6 Results of impact assessment

6.1 ANNUAL FLOW CHANGES

The results show that based on the set of scenarios, either increases or decreases in stream flow are possible for the Cooper Creek Catchment depending on which scenario is most closely associated with observed climate in the future. The change in mean annual flow for Currareva ranges from approximately -7.1% to +1.5% by 2030. Table 7 shows the change in mean annual flow for each of the scenarios. Figure 6 shows the mean annual flows at Currareva for the base scenario and each of the climate change scenarios.

Table 7. Changes in mean annual stream flow for Currareva for the dry, average and wet climate change scenarios for 2030

Scenario	**Dry**	**Average**	**Wet**
Global warming scenario	A1T	Average of All	IS92a
GCM	HadCM3	Average of All	ECHAM4
Global mean warming (°C)	1.24	Average of All	0.78
Regional minimum temperature change (°C)	Not Available	Average of All	1.00
Regional maximum temperature change (°C)	Not Available	Average of All	0.90
Regional mean temperature change (°C)	1.70	Average of All	1.00
Change in annual rainfall (%)	-3.99	-0.98	1.16
Change in annual potential evaporation (%)	9.17	4.02	2.75
Change in annual streamflow at Currareva (%)	-7.1	-4.4	+1.5

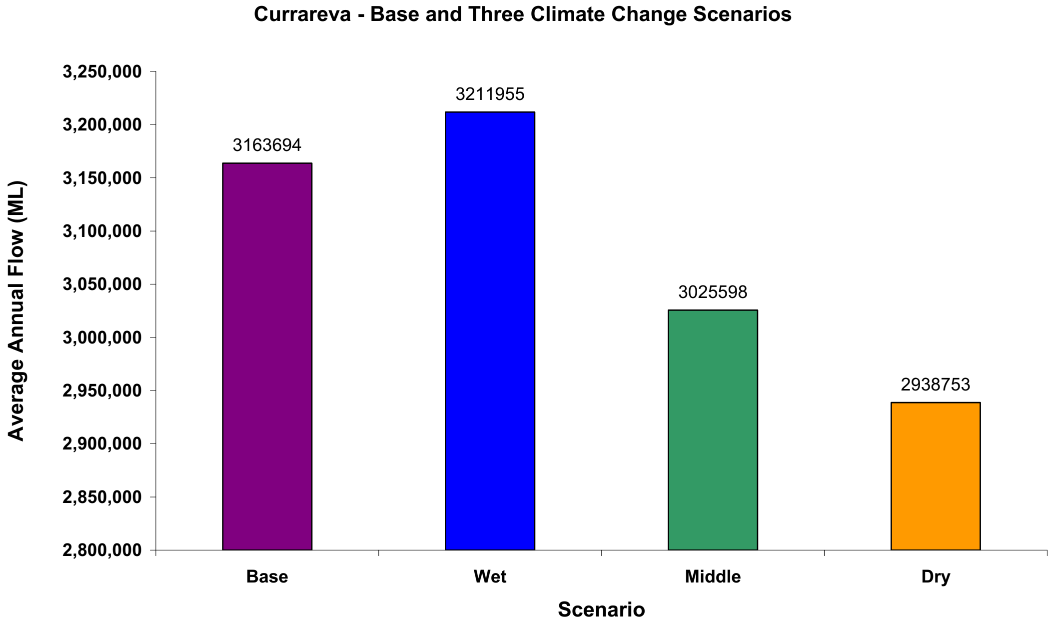


Figure 6. Mean annual streamflow for Currareva for the base scenario and the dry, average and wet climate change scenarios for 2030.

6.2 MONTHLY FLOW CHANGES

Figure 7 shows the average monthly flows for Currareva. The highest average flows occur for summer and autumn; the wet scenario had the highest flows and the dry scenario the lowest flows. Flows decrease for winter and spring with little difference between flows for each scenario. These results are consistent with the flows at Longreach, Isisford and at the junction of the Darr and Thomson Rivers (Appendix 2). Seasonal flows for all four locations are shown in Appendix 3. Figure 8 shows the 12 month moving average flows for each scenario. The wet and base scenarios had the highest average flows followed by the average and then dry scenarios.

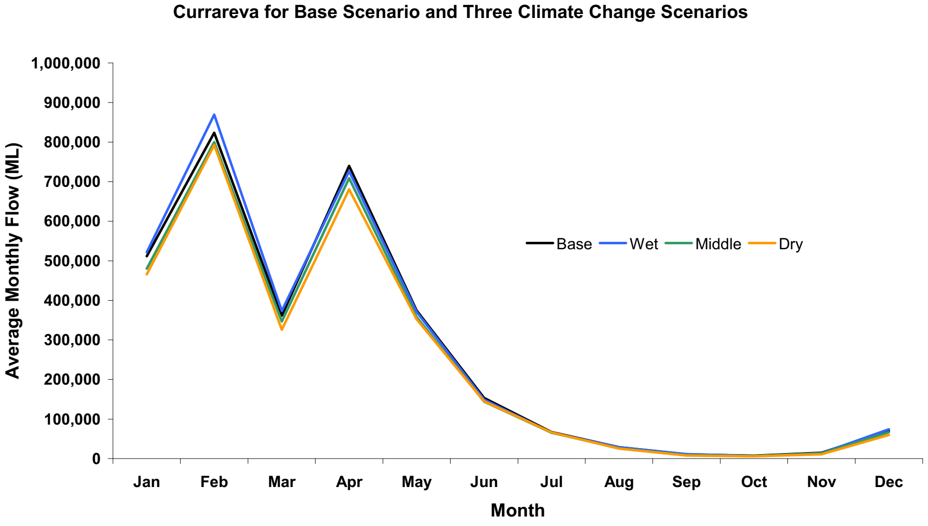


Figure 7. Simulated average monthly flow for Currareva for the base scenario and the dry, average and wet climate change scenarios for 2030.

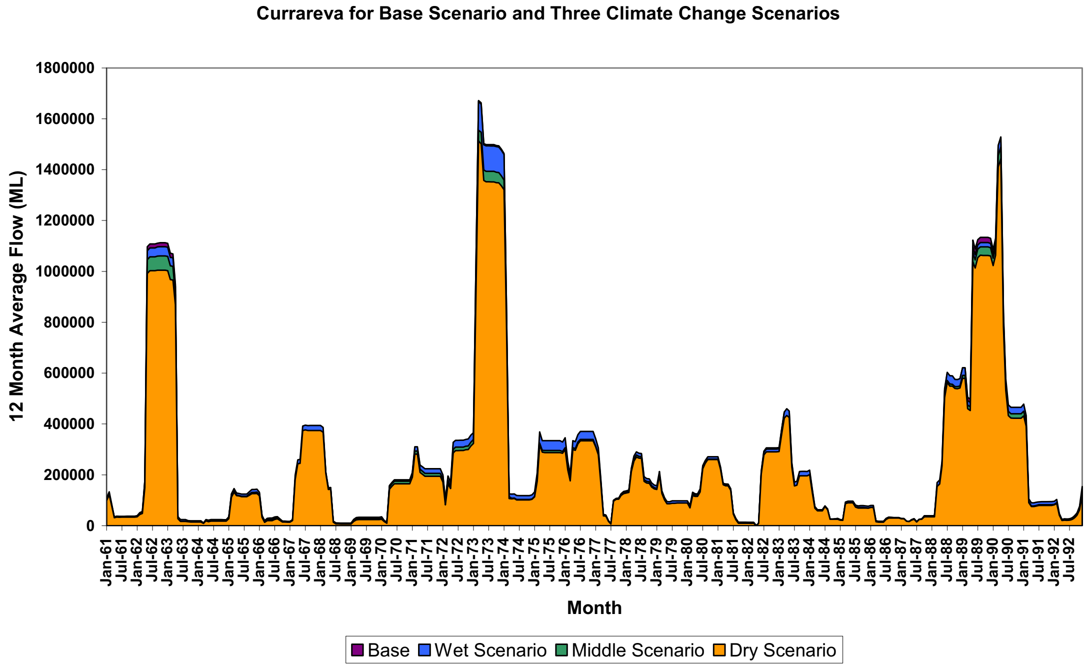


Figure 8. Simulated 12 month moving average flow at Currareva for base conditions and under the dry, average and wet climate change scenarios for 2030.

6.3 DAILY FLOW CHANGES

Changes in the frequency of daily flow for Currareva for each scenario are shown in Figure 9. There was little difference in the frequency of daily flows (high or low) between the base and wet scenarios. However the average and dry scenarios were associated with a reduced frequency of low flows (<1000 ML/d) compared to base. This pattern was similar at Longreach, Isisford and the junction of the Darr and Thomson Rivers (Appendix 1). The impact is likely to be associated with reduced waterhole persistence and connectivity during periods of drought.

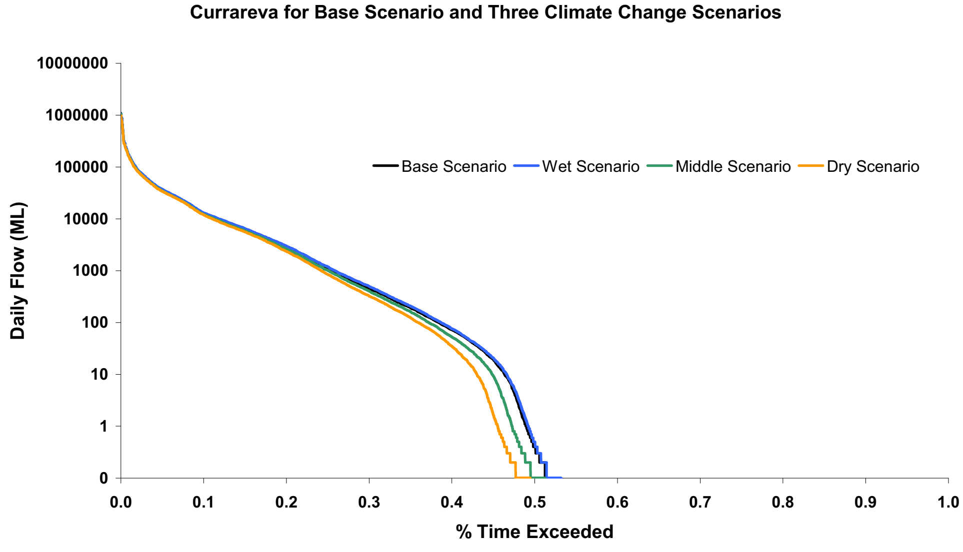


Figure 9. Daily flow exceedance curves for the base scenario and the dry, average and wet climate change scenarios for Currareva in 2030.

The 100 percentile flow under the dry scenario was 11% lower than the base scenario (Table 8). This finding requires further investigation because these extreme flood events play an important role in delivering the water required to reach, and eventually fill the large downstream water storages such as the Coongie Lakes and Lake Eyre in South Australia. These water storages support important ecosystems and biodiversity through natural cycles of wet and dry and this role may be more important under dry climate change conditions.

Other than the 100 percentile flow the average and dry scenarios were associated with a small reduction (5-9%) in high flows (99, 95, 90 and 88 percentile) and the wet scenario a small increase (2-4%) in high flows (99, 95, 90 and 88 percentile) compared to the base scenario.

Table 8. Simulated daily 50 - 100 percentile flows for the base scenario and for the dry, average and wet climate change scenarios for 2030. Percentage change in flow from the base scenario is shown

		Flow (ML/d)			Change in flow (%)		
Percentile	Base	Wet Scenario	Average Scenario	Dry Scenario	Wet Scenario	Average Scenario	Dry Scenario
100	1092027	1073222	1045449	973391	-2	-4	-11
99	171700	175284	169459	162936	2	-1	-5
95	36592	37888	35224	34361	4	-4	-6
92	20647	20934	19886	19303	1	-4	-7
90	12902	13279	12372	12199	3	-4	-5
88	9572	9917	9179	8734	4	-4	-9
85	6162	6580	5931	5655	7	-4	-8
80	2848	3049	2669	2405	7	-6	-16
75	1138	1213	1032	862	7	-9	-24
70	467	509	411	333	9	-12	-29
65	197	211	165	126	7	-17	-36
60	73	77	54	36	5	-27	-51
55	20	21	10	2	7	-51	-90
50	1	1	0	0	20	-80	-100

6.4 NO FLOWS

6.4.1 Frequency of no flows

The mean number of days per year of no flow at Currareva was higher (P<0.01, paired t test) for the average and dry scenarios compared to base. The base and wet scenarios were not different.

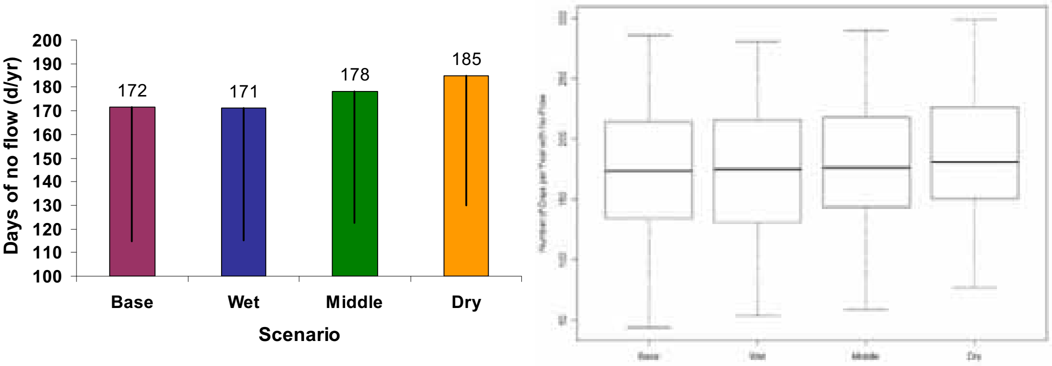


Figure 10. a) Mean number of days per year of no flow (-SD) and b) boxplot of no flow days per year for the base, dry, average and wet scenarios in 2030.

6.4.2 Duration of no flows

The longest simulated duration of no flow at Currareva for the base scenario was 280 days. The average scenario had a 361 day period of no flow which was associated with a lower climate change factor in February for rainfall, compared to the other scenarios, producing insufficient rain and a period of no flow at a time when the other scenarios had small flows (<540 ML/d for 1 month). This shows that climate change has the potential to dramatically increase the duration of no flows by reducing the frequency of low flows. The frequency plots of the duration of no flow are shown in Appendix 4.

Table 9. Duration of no flows at Currareva for the base scenario and the wet, average and dry climate change scenarios

Probability of exceeding (%)	Duration of no flow (days)			
	Base	Wet	Average	Dry
0	280	280	361	286
0.2	139	161	161	175
0.4	87	79	88	100
0.6	47	43	34	42
0.8	13	12	14	13

Under the dry scenario 20% of the no flow periods lasted longer than 175 days compared to 139 days for the base scenario, a difference of 36 days longer (Table 9). The difference for wet and average scenarios was 22 days longer. The climate change scenarios were associated with extended lengths of the long periods of no flow.

The chance of long periods (150-200 days) of no flows was higher for the dry scenario than the base scenario (Table 10). Under dry climate change conditions there was a greater risk of long periods (150-200 days) of no flow being extended which will affect waterhole replenishment and may at times reduce the quantity and quality of water available for human, stock and wildlife use.

Table 10. Chance of exceeding 150 and 200 day durations of no flows at Currareva for the base scenario and the wet, average and dry climate change scenarios

Duration of no flows (days)	Chance of exceeding (%)			
	Base	Wet	Average	Dry
150	19	21	21	24
200	6	8	8	11

The median duration of no flow was 65, 64, 75 and 79 days respectively for the base, wet, average and dry scenarios (Figure 11b). The climate change scenarios were not different (Kruskal Wallis non-parametric statistical test>0.05) to base climate and the differences are unlikely to have any practical significance.

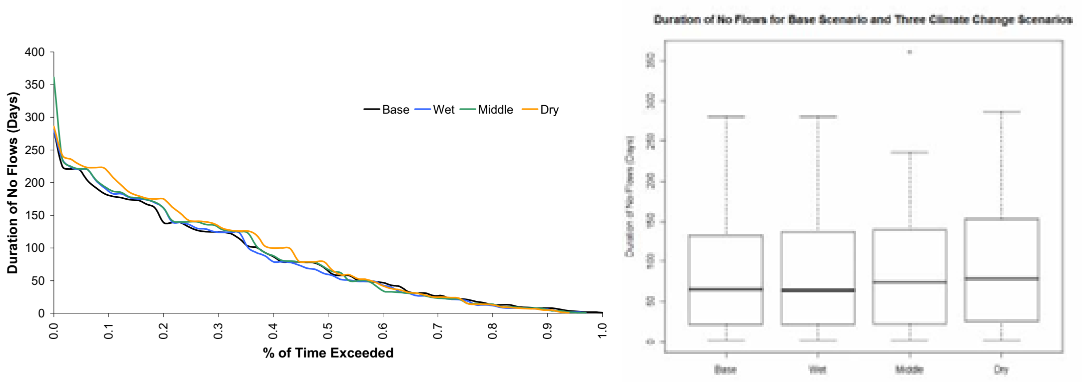


Figure 11. a) Chance of exceeding duration of no flows and b) boxplot of duration of no flows at Currareva for the base scenario and the wet, average and dry climate change scenarios in 2030.

6.5 HIGH FLOWS

The volume and height of water at Currareva is associated with flood inundation areas (see Figure 5) however beneficial flooding occurs once certain flow thresholds are exceeded. The beneficial flood threshold (BFT) was the transition point where flows at Currareva began to produce beneficial flooding downstream. The BFT occurred at a flow of 8370 ML/d at a height at Currareva of 2.9 meters (see Figure 5). The inundation area increased rapidly when flows increased from the BFT (c. 87 percentile) to 90 percentile, which were represented by flows of 8195 and 12906 ML/d respectively for the base scenario.

The frequency of flows exceeding the BFT is therefore critically important for over-bank flows and flooding beyond main water courses such as floodplains. Herbage growth on the floodplains and replenishment of waterholes are important to for cattle production and native flora and fauna.

The percentile flows at which BFT occurred were 87.2, 86.9, 87.5 and 87.8 for the base, wet, average and dry scenarios respectively.

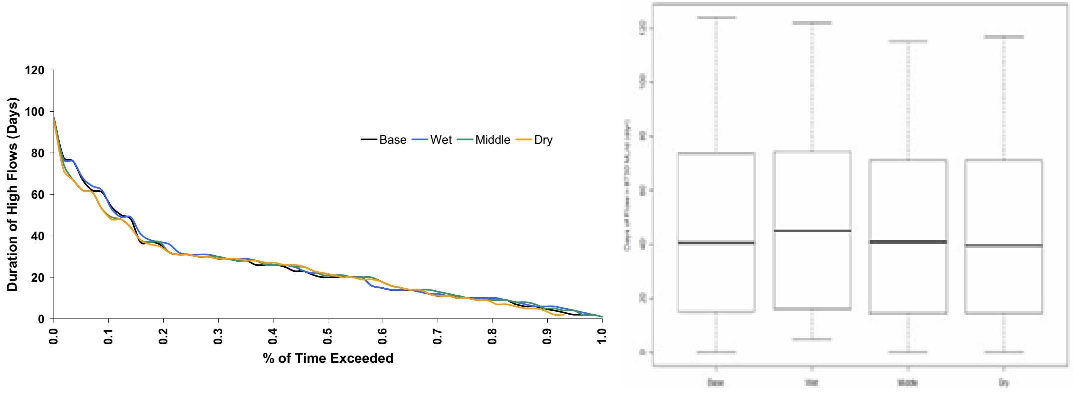


Figure 12. a) Chance of exceeding duration of flows >8370 ML/d and b) number of days per annum of flows >8370 ML/d at Currareva for the base scenario and the wet, average and dry climate change scenarios in 2030.

6.6 FLOOD TYPES AND EXTENTS

Four flood types were identified by pastoralists in the channel country, these included channel, gutter, handy and good floods. Channel floods occur when the main channels run but water does not escape to the surrounding floodplain. These floods are valuable as they fill waterholes and prevent existing waterholes from becoming salty. Gutter floods occur when water escapes from the main channels and spills over to many small waterways (gutters) that flow from the main channels. These floods provide growth of a good body of herbage along the gutters as well as providing additional water points for cattle. Handy floods occur when water escapes from gutters connecting up to form large sheets of water for which the area is famous. They can cover up to 50% of the floodplain with water of varying depths. Good floods cover a much larger percentage of the floodplain (75% or more of the floodplain is covered). Channel floods occurred when the height of water at Currareva was 3.05 m (10 feet), gutter floods at 3.66 m (12 feet), handy floods at 4.57 m (15 feet) and good floods at or above 5.49 m (18 feet). Table 11 shows the height for each flood type with its corresponding inundation area and minimum daily flow volume.

Table 11. Simulated flood heights with corresponding inundation areas and minimum daily flows for Currareva.

Flood Type	Flood height (m)	Inundation area (km^2)	Flow volume (ML/Day)
Channel	3.05	553	10171
Gutter	3.66	2274	18621
Handy	4.57	4855	46127
Good	5.49	7436	114263

Figure 13a shows boxplots of annual frequencies for each flood type and climate change scenario. Gutter floods occurred most often at Currareva with annual frequencies in all scenarios reaching up to 70 days/year. Good floods were the least common. The interquartile ranges of annual frequencies of each flood type did not differ between scenarios. Histograms for each flood type and climate change scenario are shown in Figure 13b. Compared to the base and wet scenarios, the dry and average scenarios show flood events skewed towards the lower annual frequencies for handy floods. These minor reductions in the annual frequency of handy flood heights at Currareva under average and dry scenarios may be insignificant; however we should be weary of extrapolating this finding downstream without completing further work.

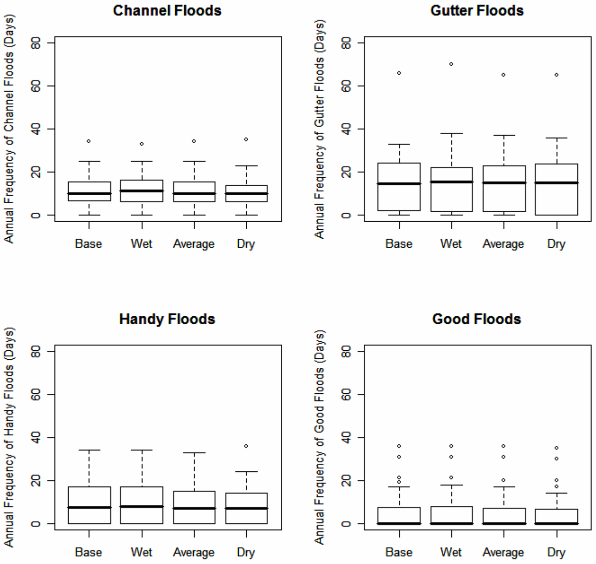
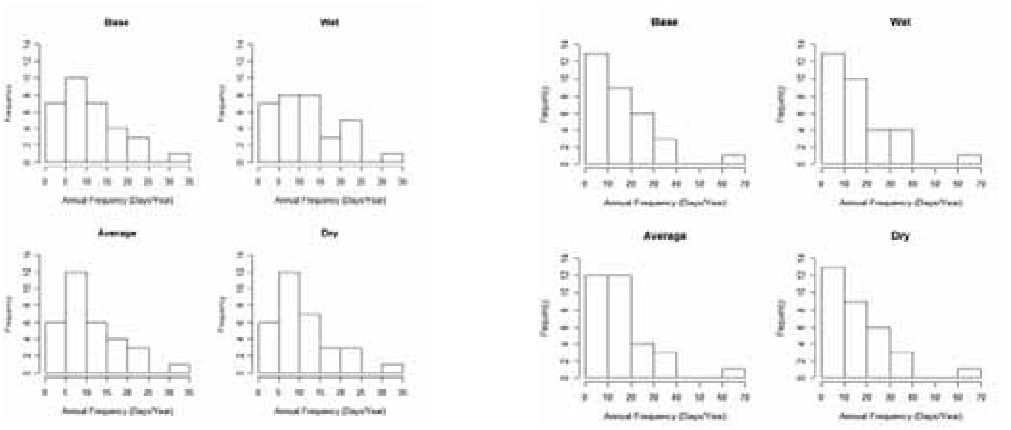
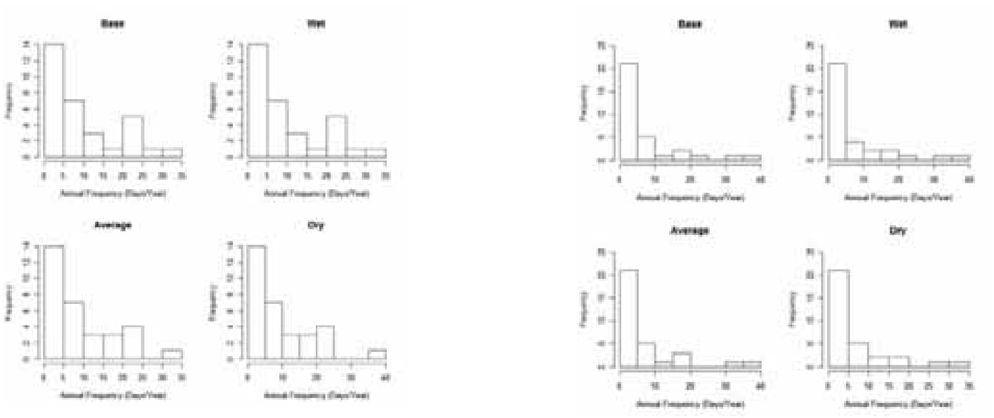


Figure 13 a) Boxplots of annual frequencies for four different types of floods for the base scenario and each climate change scenario.



Channel Floods

Gutter Floods



Handy Floods

Good Floods

Figure 13 b) Histograms for each type of flood event for the base scenario and each climate change scenario.

6.7 FLOOD INUNDATION CHANGES

The inundation area downstream of Currareva was near zero at flows between the 87 and 88 percentiles (Figure 14) for base and climate change scenarios. The flow at zero inundation was 8370 ML/d at a height at Currareva of 2.9 meters (beneficial flood threshold – see Section 5.5). The inundation area increased rapidly when flows increased from the 87 to 90 percentile, which were 8195 and 12906 ML/d respectively for the base scenario.

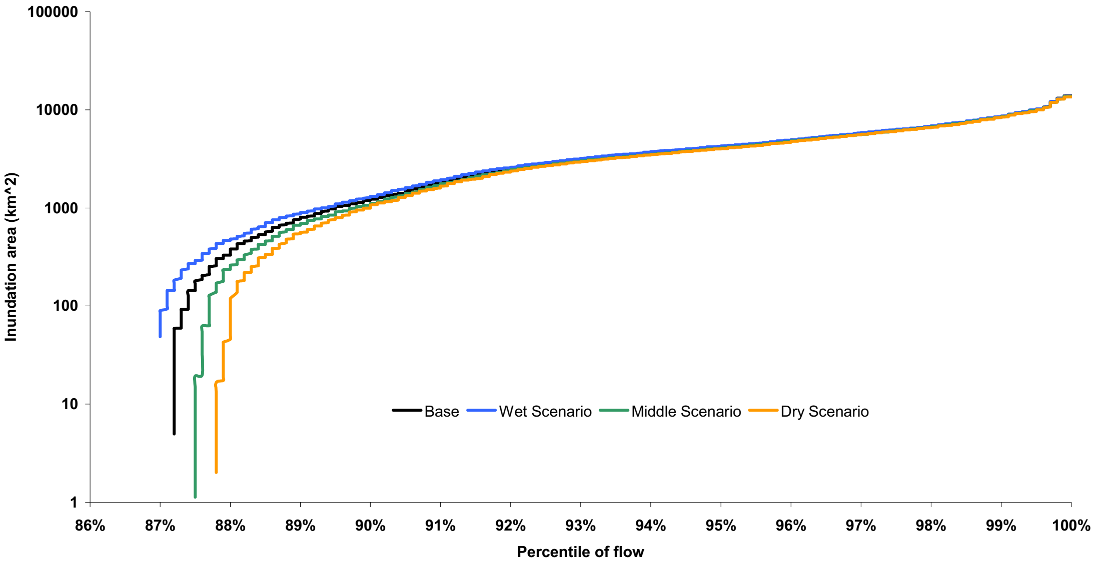


Figure 14. Flood inundation area and percentile of high flows in Queensland downstream of Currareva for the base, dry, average and wet scenarios in 2030.

The small difference in high flows between the base and climate change scenarios shown in Table 8 was associated with a large difference in inundation area for flows in the 88 to 92 percentile range (Figure 15). Within this range of small event floods the wet scenario was associated with an increased inundation area of up to 32% and the dry scenario with a decreased inundation area of down to 75% (Table 12). This change in inundation area of small event floods may have an impact on the production of herbage, natural resources and biodiversity near the main channels.

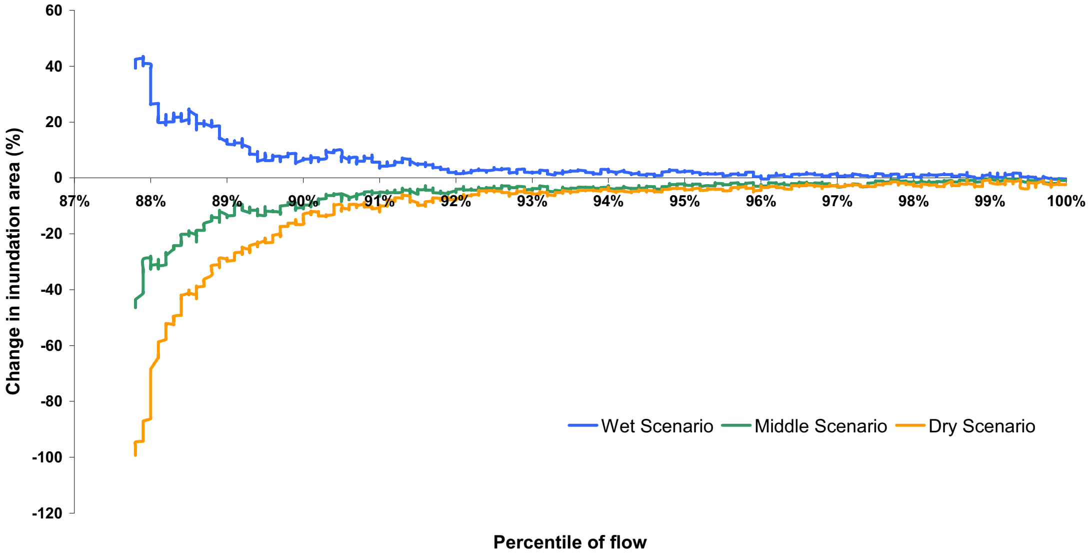


Figure 15. Percentage change from the base scenario in inundation area in Queensland downstream of Currareva for the dry, average and wet scenarios in 2030.

Table 12. Inundation area calculated from the relationship with peak discharge (see Figure 5) at the 100, 99, 95, 92, 90 and 88 percentiles. Inundation areas are in Queensland downstream of Currareva for the base scenario and for the dry, average and wet climate change scenarios for 2030. Percentage change in inundation from the base scenario is shown

		Inundation area (km^2)			Change in inundation area (%)		
Percentile	Base	Wet Scenario	Average Scenario	Dry Scenario	Wet Scenario	Average Scenario	Dry Scenario
100	13859	13809	13735	13532	0	-1	-2
99	8501	8594	8451	8403	1	-1	-1
95	4169	4266	4066	4002	2	-2	-4
92	2541	2587	2428	2346	2	-4	-8
90	1212	1292	1085	1032	7	-10	-15
88	359	474	249	90	32	-31	-75

7 Conclusions and recommendations

7.1 SUMMARY OF RISK ANALYSIS

In this study we have assessed the likelihood of changes to mean annual flow by perturbing input data to the Cooper Creek Catchment Integrated Quality Quantity 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), regional changes in rainfall and potential evaporation encompassing the results from seven different climate models. The methods used are primarily designed to manage uncertainty and its impact on processes impacting on water supply. Other aspects of uncertainty within the water cycle, such as land use change, or demand change, have not been addressed.

The range of change from the driest and wettest extremes of regional climate change indicate a wide range of change in mean annual flow ranging from approximately -7.1% to +1.5% by 2030. This was driven by less early spring (SO) and more summer (NDJF) rainfall in the wet extreme and less late winter to early summer rainfall (ASOND) in the dry extreme.

The difference in average monthly flows occurred in summer and autumn with little difference in winter and spring. Summer floods produce native sorghum, summer grasses, legumes and forbes, where as autumn floods produce cooper clover, herbage and a wide variety of winter plants. The timing of average monthly flows did not change in this analysis, and as such, there was no evidence for changes in vegetation types associated with timing of floods and climate change.

The average and dry scenarios were associated with a reduced frequency of low daily flows (<1000 ML/d) compared to base. The impact is likely to be associated with reduced waterhole persistence and connectivity during periods of drought. The reduction in persistence of waterholes may have consequences for the plant and animal life that rely on these water sources. Also increased salinity may result from the reduced replenishment of waterholes, which may result in the changing of vegetation in and around waterholes to that which is more tolerant of higher mineral concentrations. In addition, reduced connectivity of waterholes will mean less passage of aquatic biota between waterholes restricting them to one waterhole for extended periods. This may reduce biodiversity of aquatic biota in waterholes.

The 100 percentile flow under the dry scenario was 11% lower than the base scenario. This finding requires further investigation because these extreme flood events play an important role in delivering the water required to reach, and eventually fill the large downstream water storages such as the Coongie Lakes and Lake Eyre in South Australia. These water storages support important ecosystems and biodiversity through natural cycles of wet and dry and this role may be more important under dry climate change conditions. Reduction in maximum flows may also result in decreases in inundation on the borders of floodplains, which may result in decreases in biodiversity in these areas, shrinking the floodplain. Annual and short-lived grass species may also be replaced by perennial grass species from neighbouring communities.

The average and dry scenarios were also associated with a small reduction (2-9%) in high daily flows (99, 95, 90 and 88 percentile) and the wet scenario with a small increase (3-4%) in high daily flows (99, 95, 90 and 88 percentile) compared to the base scenario. These differences are only small and are probably insignificant against the 'noise' associated with the modelling process.

Climate change was associated with extended lengths of long periods of no flow. The longest simulated period of no flow was 280 days for the base scenario and 361 days for the average scenario, an increase of nearly 30%. If we apply a 30% increase to the recorded (1939-1989) maximum no flow period (21 months from 1951-1952), the extended period of no flow due to climate change of 27 months could be associated with most waterholes drying to within 10% of their bankfull volumes (Hamilton *et al.* 2005). These estimates assume that there is no major abstraction from waterholes, and that pumping for stock, irrigation and domestic supply will further reduce persistence times.

The mean number of days per year of no flow at Currareva was statistically higher for the average and dry scenarios compared to base. Nearly 2 weeks per year more of no flows under the dry scenario may not have an adverse impact on the natural or human systems downstream of Currareva but further discussion with regional experts and natural resource scientists is needed. The base and wet scenarios were not different. An increase in no flows is likely to affect waterhole persistence and salinity, which may have consequences for animals and plants within and external to waterhole environments.

Climate change has the potential to dramatically increase the duration of no flows by reducing the frequency of low flows. Under dry climate change conditions their was a greater risk of long periods (150-200 days) of no flow being extended which will affect waterhole replenishment and may at times reduce the quantity and quality of water available for human, stock and wildlife use. Reduced replenishment of waterholes may also affect aquatic biota within waterholes by reducing water quality and the available space to move and hide. Reduced replenishment of waterholes may also mean decreased inundation of large floods due to waterholes needing to be filled first.

Within the range of small event floods the wet scenario was associated with an increased inundation area of up to 32% and the dry scenario a decreased inundation area of down to 75%. This change in inundation area of small event floods may have an impact on the production of herbage, natural resources and biodiversity near the main channels. Less inundation of small flood events on the floodplains may increase the utilisation of pastures in the outer country. This may threaten the survival of perennial grasses through reduced recovery time and higher grazing pressure.

Of the four flood types (channel, gutter, handy and good) gutter floods were the most common at Currareva and good floods the least common in all scenarios. There were minor reductions in the annual frequency of handy flood heights at Currareva under average and dry scenarios compared to the base scenario. Although these findings at Currareva may be insignificant, we should be weary of extrapolating this finding downstream without some work looking at runoff, flows and transmission losses between Currareva and Innamincka.

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, checked for their ability to simulate the current Queensland climate).

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.

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.

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. Mitchell (2003) has shown this method to be 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 1997; Chiew *et al.* 2003). Further work comparing the sensitivity of the Sacramento rainfall-runoff model used in IQQM to other commonly used Australian rainfall-runoff models which have been tested for their sensitivity, would help put the results provided here in a broader context. In addition, there is uncertainty associated with differences between recorded values and those generated by the runoff and flow models.

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 change is considerable. Despite large uncertainties in the spread of possible results, the further one looks into the future the more likely the range of results will be 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:

- Assess the impact of small changes in volume, height and duration of flows at Currareva on flows into key waterholes and gauging stations downstream.
- Identify the impacts of climate change on the volume, height and duration of flows between Currareva and Nappa Merrie.
- Improve understanding of waterhole persistence and connectivity downstream of Currareva by using higher resolution climate models and identifying differential changes in daily rainfall and the number of raindays and applying to runoff and water flow models.
- Improve understanding of waterhole persistence and connectivity downstream of Currareva by using higher resolution climate models and identifying differential changes in summer temperatures and wind speed to assess vulnerability of waterholes to evaporation under climate change conditions.
- Conduct further assessment of potential changes in wet-season rainfall, which is the largest driver of changes in water supply, to constrain uncertainties.
- Identify flood inundation patterns for a range of flood events, relate to antecedent conditions and correlate to known indicators.
- Complete a vulnerability assessment of waterholes susceptible to climate change in terms of persistence, connectivity and importance to natural biodiversity.
- Study of the sediment load, nitrogen and phosphorus at Currareva. Relate to algal blooms.

8 Presentations and publications

The project team accepted invitations to present the research findings at the following conferences,

1) The LEB Community Advisory Committee in Longreach on 2 August 2006.
2) The Lake Eyre Basin Conference held in Renmark, South Australia on 7-8 September 2006. The printed paper that appears in the conference proceedings entitled *Future implications for climate change in the Lake Eyre Basin* is shown in Appendix 5.
3) The S Kidman & Co Managers Conference in Adelaide on 27 November 2006.

An abstract has been submitted and accepted for the MODSIM 2007 Conference titled *Climate change impacts on the water resources of the Cooper Creek Catchment*.

9 Acknowledgements

This work was funded by the Australian Greenhouse Office. Dr Roger Jones provided the scaling factors for the GCM's and emissions scenarios. Bob Young, Angus Emmott, Marie Morton, Sandy Kidd, Peter Douglas and Allan Hubbard provided some practical interpretation of the likely downstream impacts. The Department of Primary Industries supported this project though most of its life before it was transferred to the Department of Natural Resources and Water. The Department of Natural Resources and Water provided the water models.

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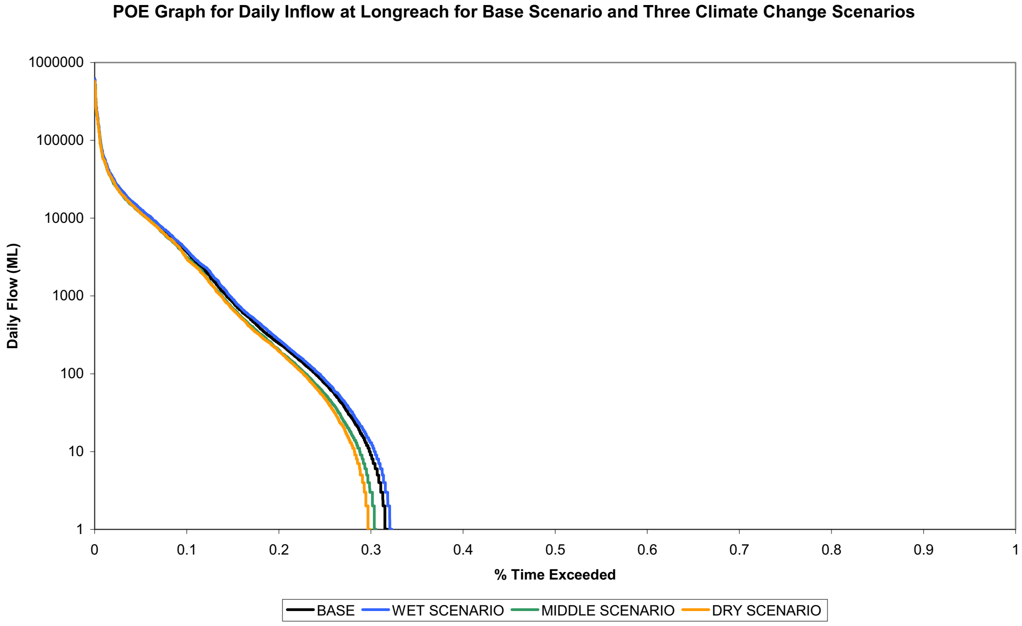
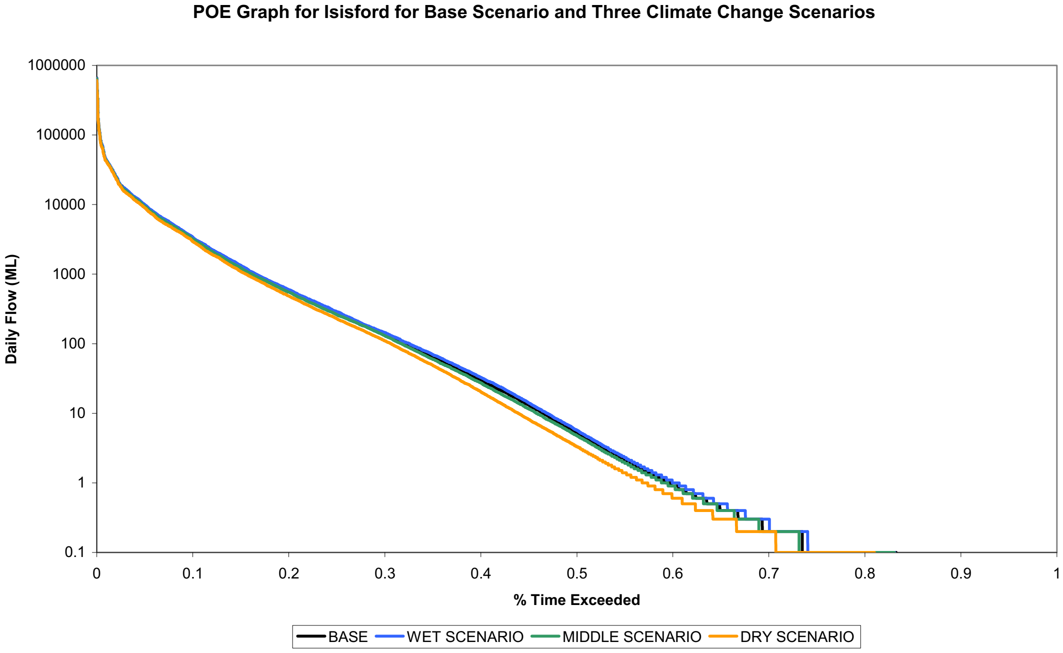
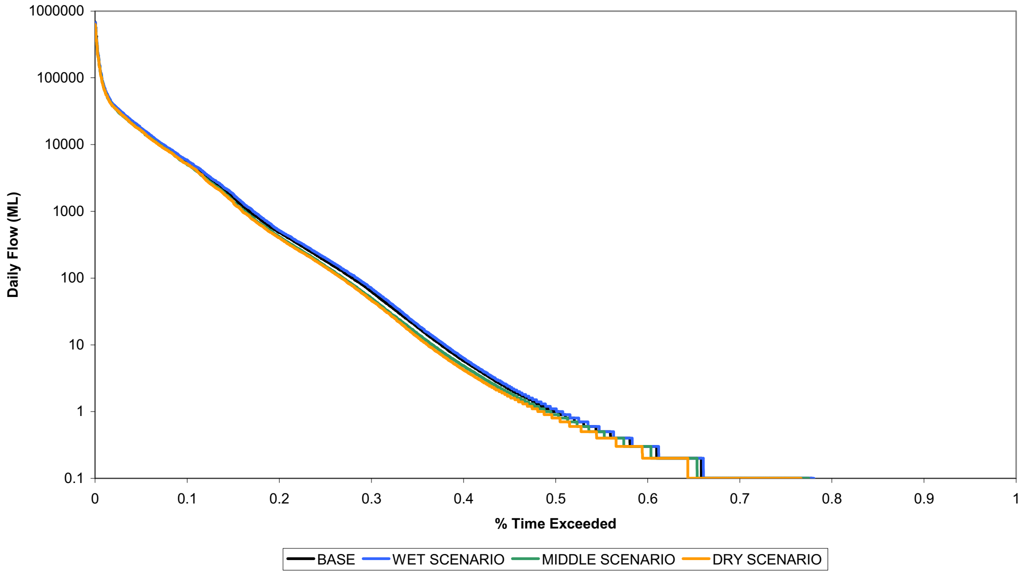
11 Appendix 1 – Exceedance curves for daily flows at other locations

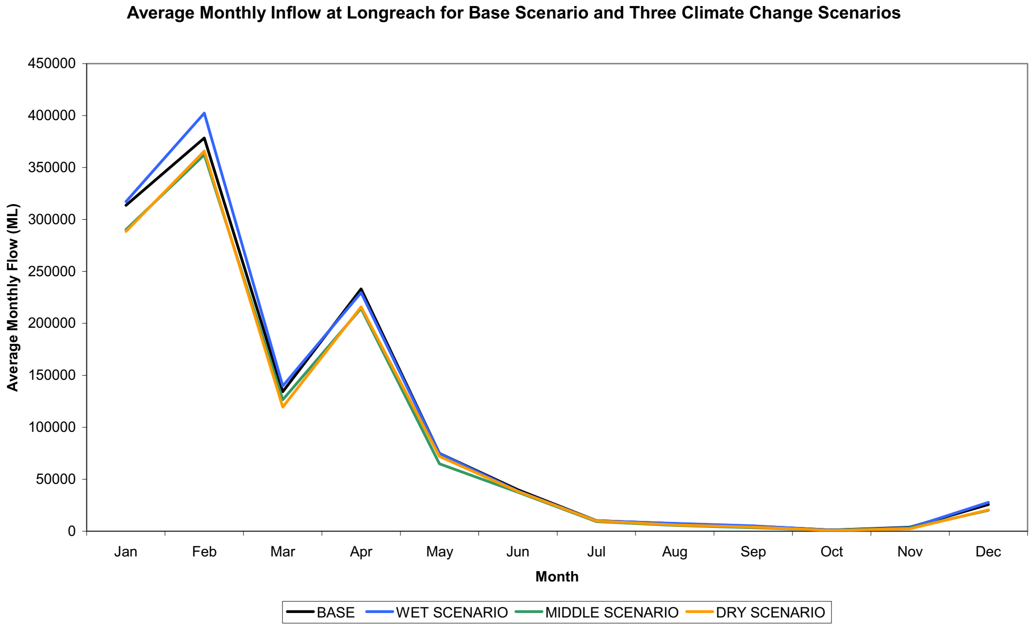


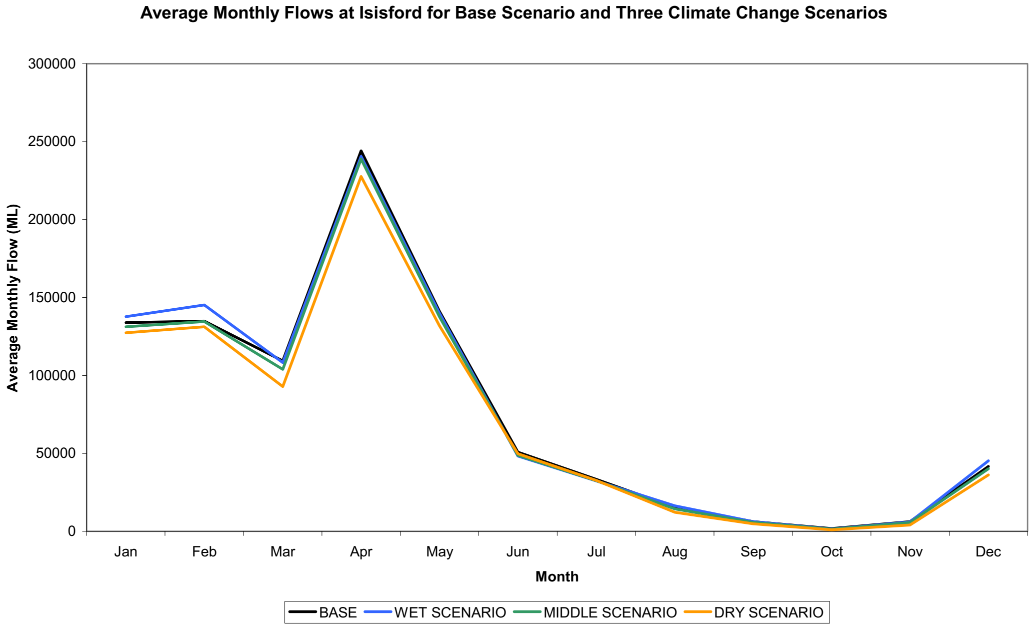


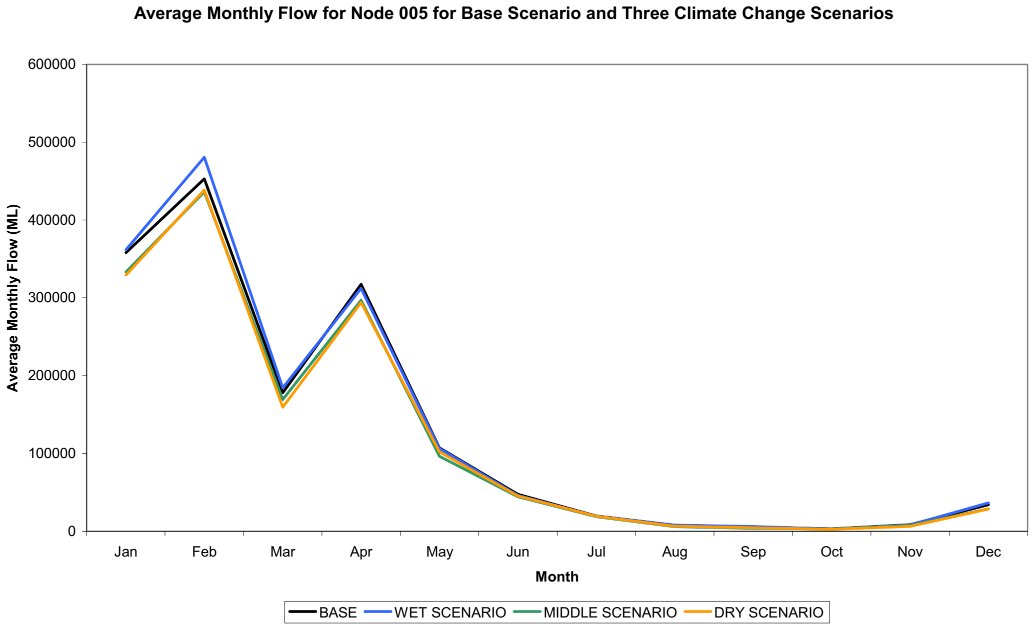
POE Graph for Daily Flows at Node 5 for Base Scenario and Three Climate Change Scenarios



12 Appendix 2 – Average monthly flows at other locations






Average Monthly Flow for Node 005 for Base Scenario and Three Climate Change Scenarios
600000
500000
400000
300000
200000
100000
0
Average Monthly Flow (ML)
Jan
Feb
Mar
Apr
May
Jun
Jul
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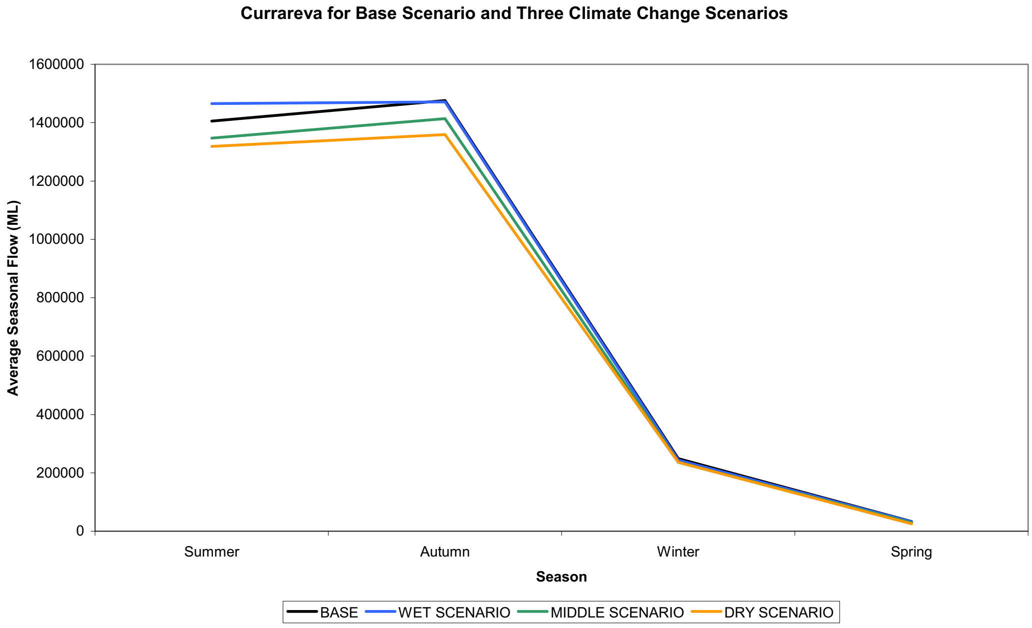
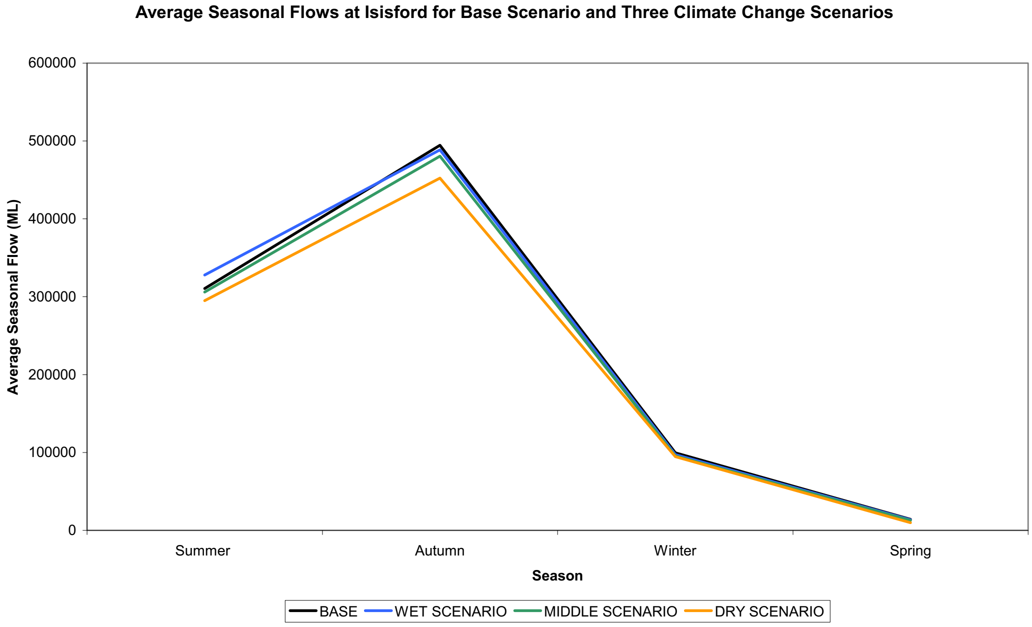
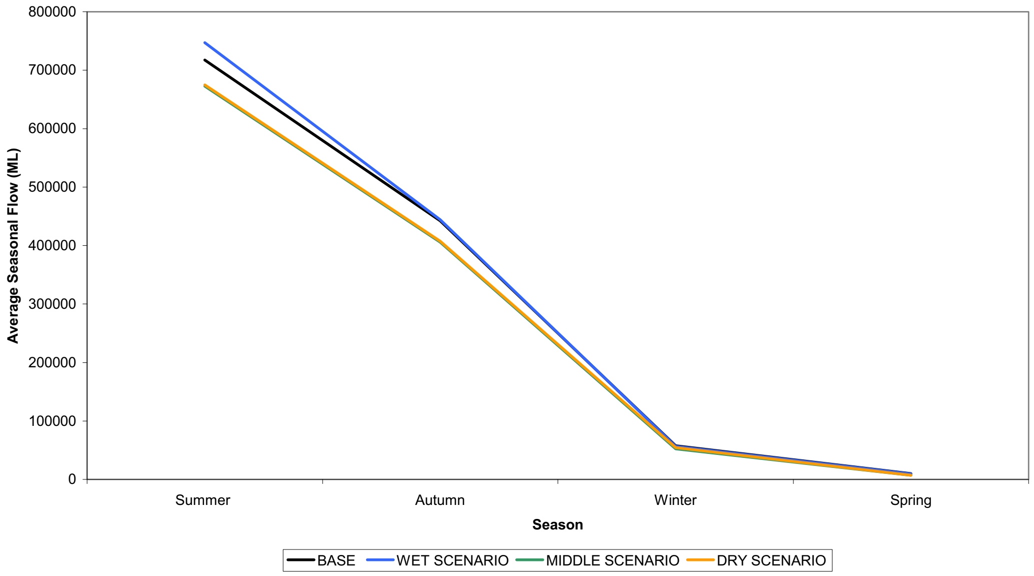
Nov
Dec
Month
BASE
WET SCENARIO
MIDDLE SCENARIO
DRY SCENARIO

13 Appendix 3 – Average seasonal flows

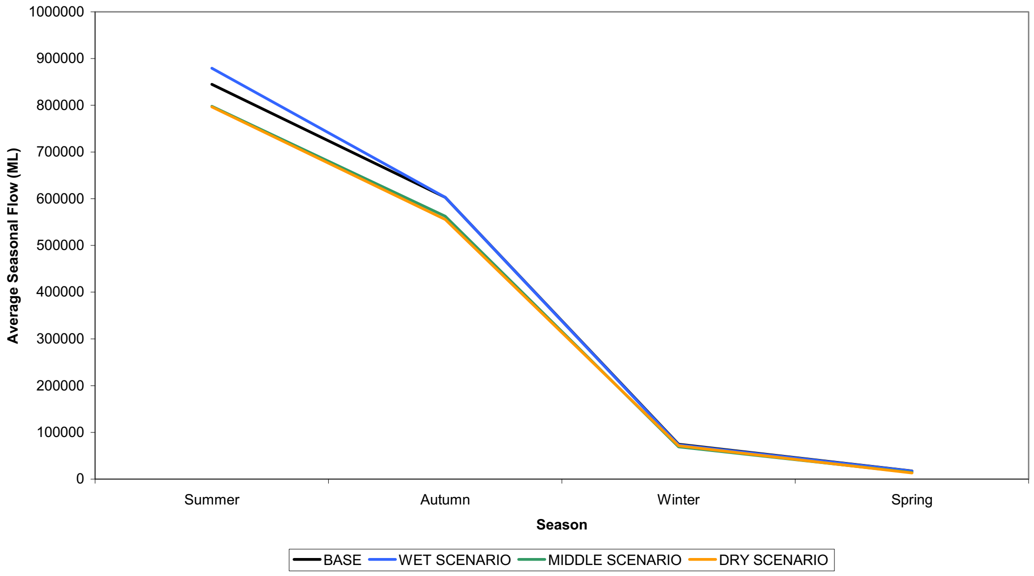




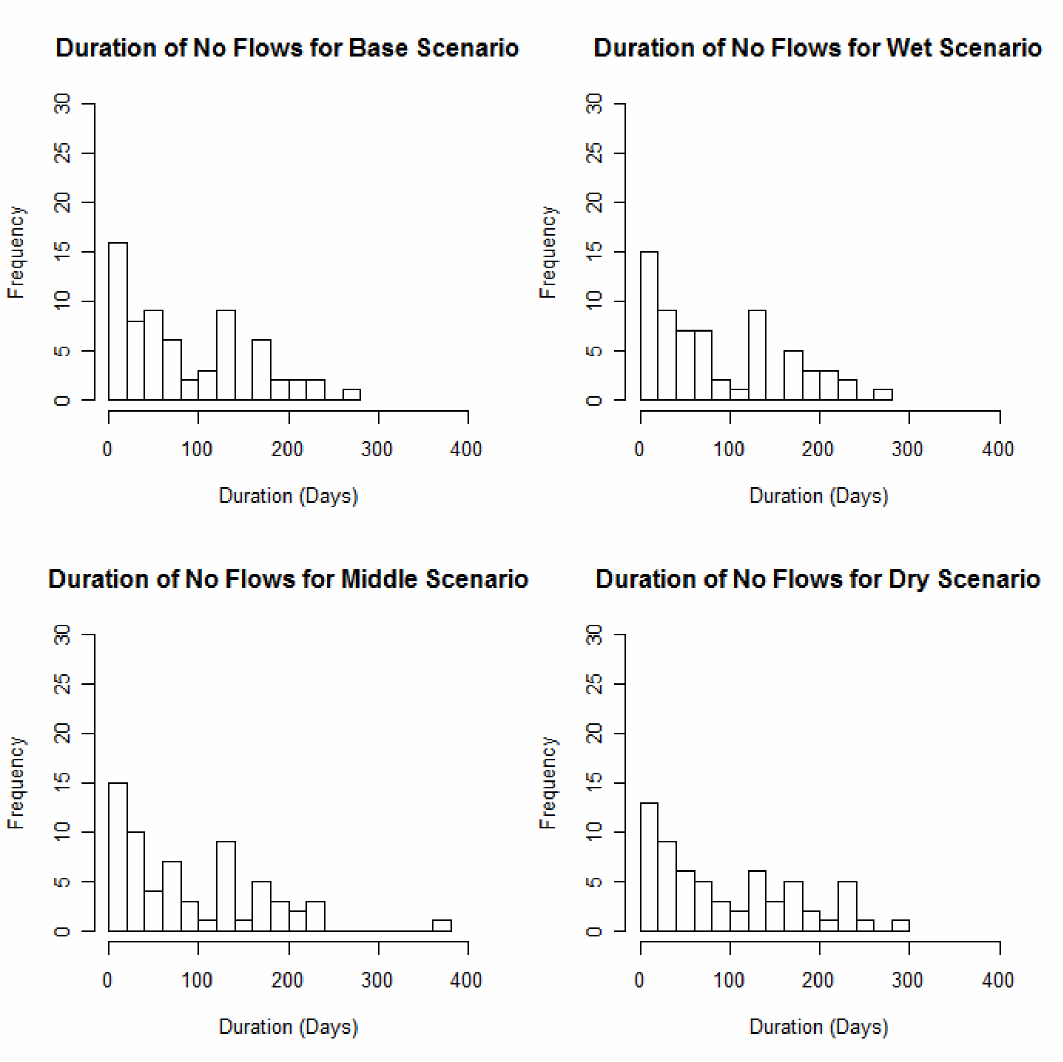
Average Seasonal Inflow at Longreach for Base Scenario and Three Climate Change Scenarios



Average Seasonal Flow for Node 005 for Base Scenario and Three Climate Change Scenarios



14 Appendix 4 – Frequency plots showing duration of no flows



15 Appendix 5 – Paper presented at the LEB Conference, Renmark September 2006

Future implications of climate change in the Lake Eyre Basin

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1.0 Introduction

The Lake Eyre Basin (LEB) is one of the world's last unregulated wild river systems supporting vast natural biodiversity and productive beef systems reliant on variable water flows that occur with floods and droughts. The average temperature in the LEB has risen between 0-0.3°C since 1950. The trend in rainfall has varied depending on location – in the NE LEB rainfall has decreased by 50mm/decade since 1950, but increased by 5mm/decade in NW LEB. Global climate models (GCM) suggest a warming in LEB of 0.8-2.0°C by 2030, an increased evaporation of 2-10% and change in rainfall between -6 to 3%. Along with these changes, heat waves will be more frequent, frosts less frequent, rainfall more variable and intense with more frequent and intense droughts. Arid and semi-arid systems already experience low and highly variable annual rainfall and will be particularly vulnerable to increased moisture stress and the intensification of El Nino Southern Oscillation events.

2.0 Changes already underway and coming soon

Observed changes in temperature (maximum, minimum, mean) and rainfall in the LEB show overall reductions in moisture availability, although this varies with location and the period over which the trends are assessed. Trends for the last 30, 50 and 100 years are shown in Table 1. The 50-year trend may be particularly important as 'this is the period during which the global climate has moved outside the bounds of experience during the last 1,000 years, at least' (Bureau of Rural Sciences, 2004). Projected changes indicate increased warming and evaporation however rainfall changes are variable and less certain (Table 2). Along with these changes heat waves will be more frequent, frosts less frequent, rainfall more variable and intense with more frequent and intense droughts

Table 1. Observed changes in annual temperature (maximum, minimum, mean) and annual rainfall in the LEB (Bureau of Meteorology)

Period	**Rainfall**	**Temperature (°C/10 yrs)**			**Notes**
	(mm/10 yrs)	**Mean**	**Maximum**	**Minimum**	
Annual					
1910-2005	-10 to 15	0-0.25	-0.05 to 0.25	0-0.3	Rainfall – most of region is upward
1950-2005	-50 to 15	0-0.3	0-0.3	-0.1 to 0.4	Rainfall – NE LEB is downward, NW LEB is upward
1970-2005	-50 to 5	0-0.6	0-0.5	-0.1 to 0.6	Rainfall – most of LEB is downward
Summer					

1950-2005	-30 to 15	-0.1 to 0.3	-0.1 to 0.4		Summer temps warming
1970-2005	-50 to 5	0-0.6	0 to 0.8		
Winter					
1950-2005		0-0.3		-0.2 to 0.3	Winter temps warming
1950-2005		-0.1 to 0.6		-0.1 to 0.8	

Table 2. Projected changes to 2030 in rainfall, mean temperature and evaporation in the LEB for wet and dry scenarios selected from seven GCMs (CSIRO, OzClim)

	Rainfall (%)		**Mean temperature (^{o}C)**		**Evaporation (%)**	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
Change	-2 to 3	-6 to 3	0.8 to 1.3	1.4 to 2.0	2 to 4	6 to 10

3.0 Pressures, resource condition changes, impacts, adaptive capacity and vulnerabilities

A workshop involving community members held in Longreach in September 2005 completed a conceptual mapping exercise to document the drivers, pressures, resource condition changes, impacts and management responses required to help land and water managers adapt to climate change (Clifton and Turner 2005). Vulnerability of a natural system to climate change was assessed by its exposure and sensitivity to climate change and whether adaptive mechanisms were likely to be effective at mitigating pressures or avoiding adverse impacts. Land, water and ecosystems were considered separately.

3.1 Water and climate change (see Figure 1)

The two major water resources are surface water flows and groundwater from the Great Artesian Basin (GAB). The latter is much less exposed and sensitive to climate change than surface water, due to the very large scale of the GAB system. Increased temperature may also lead to increased demand for stock water and on town water supplies. Changes in rainfall regime may see rain falling in fewer, more intense events. Floods may increase in magnitude, but decline in frequency. This could have serious consequences for towns and grazing operations dependent on surface water supplies, for aquatic communities dependent on permanent waterholes and for floodplain ecosystems (and dependent grazing operations) that require relatively regular flooding. Increased event intensity may lead to increased erosion, loss of water quality and sedimentation in weirs and some areas of channel country. Traditional, inefficient uses of GAB groundwaters have placed considerable pressure on them and has led to declining resource availability (e.g. through lower pressure) and impacts on mound springs ecosystems.

3.2 Land and climate change

The main climate change-related challenges anticipated by participants were associated with extreme climate and weather events, particularly drought and intense rainfall events. If the frequency and severity of drought increased, this would be to the detriment of groundcover and possibly grassland composition. Increased deep soil cracking with more frequent or intense droughts would particularly affect perennial grasses. More intense rainfall events could increase erosion and diminish the productive capacity of the land. Exposure to climate change was generally assessed as being moderate to high. Sensitivity was variable, with soils considered to be more sensitive than pastures. Mitchell grass pastures were considered to be well adapted naturally to climate variability and not especially vulnerable to climate change. Adaptive capacity and vulnerability to climate change for soils was considered to be variable regionally. On more fragile soils and outside Mitchell grass grasslands, soils were considered to have lower adaptive capacity and greater vulnerability.

3.3 Climate change and ecosystems

Ecosystems were divided into the two main classes, aquatic and terrestrial, with flood country and riparian ecosystems forming an intermediate group. Aquatic ecosystems included wetland and mound spring systems. Climate change could bring change in native ecosystems and, in the long-term, lead to the loss of populations, communities and perhaps more vulnerable species. Such impacts are likely to occur in response to changes in rainfall regime and the frequency and intensity of drought (the main pressures for land and water). Land use pressures (from livestock and feral grazing, weeds and unmanaged used of GAB groundwater) add to those likely from climate change. Increased drought may result in changes in vegetation composition in grassland, savannah and wetland communities, with more adapted species (including weeds) displacing less adapted species. Fauna that are dependent on water holes for maintenance of populations may be threatened if inflow events become less frequent. The vulnerability assessment considered flood and 'jump up' country, plains and aquatic ecosystems. With the exception of 'jump up' country, all were considered to be highly exposed and sensitive to climate change. Adaptive capacity was thought to be low for plains, 'jump up' and aquatic ecosystems and moderate for flood country. The assessment of high vulnerability for plains ecosystems is probably inconsistent with the assessment under land.

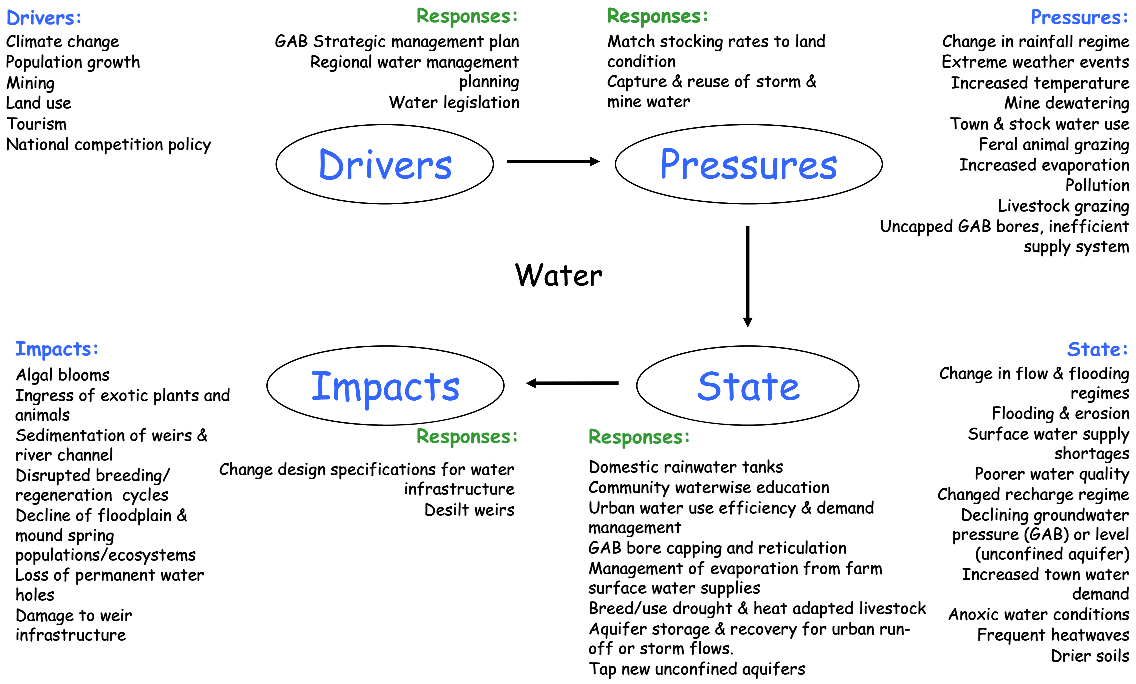

Figure 1. Interactions between climate change and water for consumptive and environmental uses.

3.4 The most vulnerable

Interpretation of the conceptual mapping exercise highlights the most vulnerable components of the regional natural resource system, as follows:
Water for the environment – river flows in the region are almost completely unregulated. Climate change is likely to alter the flow regime, with potential implications for ecosystems that are dependent on flows and flooding. While the ecosystems are generally well adapted to

climate variability, there is almost no capacity to artificially modify flow regimes to reduce any adverse impacts of climate change.
Floodplain and aquatic ecosystems – the dependence of these systems (with the exception of GAB mound springs) on river flows is considered to heighten their vulnerability to climate change, for the reasons outlined above.

Because of the importance of water flows in maintaining healthy natural and productive systems we completed a modelling exercise to assess the impact of climate change on flows and inundation area.

4.0 Water flow and inundation changes in the upper Cooper catchment

To investigate how changes in climate might affect river flows and inundation in the LEB a modelling exercise was completed upstream of Currareva. The impact of projected changes in climate on river flow was compared to a base period from 1961-1990. The 'wet', 'average' and 'dry' scenarios for 2030 were selected from seven GCM's, and the modified climate was used to model water flows at the junction of the Thomson and Barcoo Rivers at Currareva. Annual river flow under climate change conditions increased by 2% under the wet scenario, and decreased by 4% for the average and 7% for the dry scenarios compared to an average base period flow of 3.16 million ML. There was little difference in the frequency of low daily flows (<1000ML/d) between the base period and wet scenario for 2030, however, the dry scenario is likely to be associated with reduced waterhole persistence and connectivity during extended periods of drought (Figure 2). The impact of climate change on the area of beneficial flood inundation southward of Currareva was examined. Ninety percentile water flows at Currareva produced an estimated inundation area of 1200 km^2 for the base period. Climate change conditions for 2030 changed the area of inundation by 7% (wet scenario), -11% (average scenario) and -15% (dry scenario) compared to the base period (Figure 3).

Reduced low flow and extended periods of 'no water flow' may contribute to increased water temperature and reduce the natural connectivity between waterholes (Hamilton et al. 2005). The impact will depend on the extent to which species can move and migrate to more suitable habitats. Aquatic organisms are sensitive to changes in the frequency, duration and timing of extreme flow events. Therefore changes in flow and thermal regime have the potential to disrupt reproductive processes and contribute to ecosystem decline (Bunn et al. 2006, Arthington et al. 2005). Identifying and monitoring the biodiversity hotspots will be important in the early recognition of adverse changes. Loss of permanent waterholes may contribute to increased competition between native fauna and livestock so managing total grazing pressure, excluding livestock from sensitive areas and erosion mitigation are likely adaptive responses.

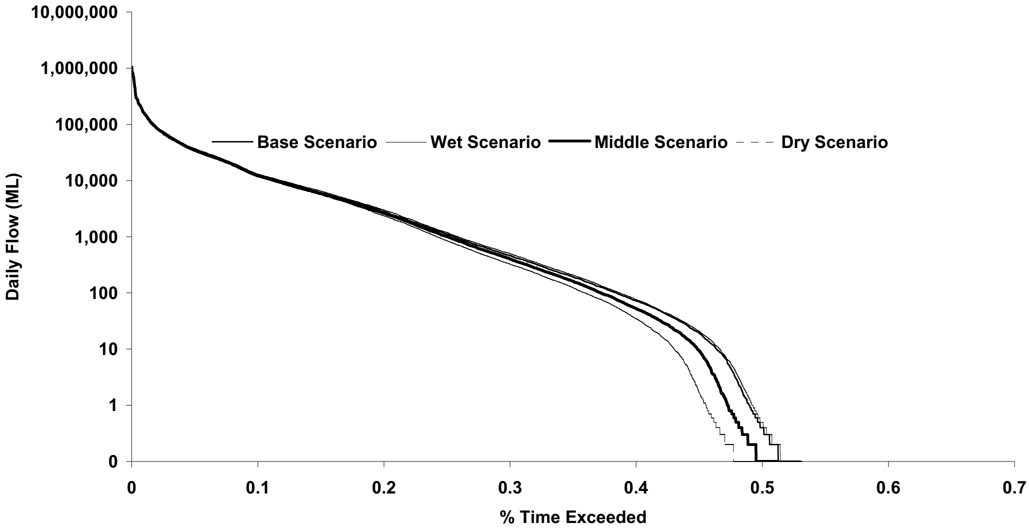

Figure 2. Percentage exceedance of daily flows at Currareva for the base, wet, average and dry climate change scenarios.

Reduced inundation of floodplains downstream of Currareva may contribute to loss of ephemeral plant diversity and reduced plant biomass and livestock production. Competitive relationships between many species in natural assemblages may also be affected. For example, C3 plants (e.g. cool season pasture species, legumes, scrubs, cotton) may be advantaged over C4 plants (e.g. tropical grasses) under increased CO_2 because their growth will be relatively more enhanced. Although CO_2 increases may provide initial benefits to C3 plants that offset the negative impacts from climate change, the balance is expected to become negative with warmings in excess of 2-4°C and associated rainfall decreases (Cobon et al. 2005). By the mid to late 21st century the net effects on plant growth are likely to be negative leading to changes in land use patterns. Grazing management strategies that match pasture availability to stock numbers may help avoid a change in the long-term financial performance of grazing enterprises.

The relationship between streamflow and ENSO can be used to forecast streamflow several months ahead. The forecast can be used to help manage water resource systems and allow decisions on irrigation water allocations, water restriction rules and environmental flows to be more realistically based (Chiew et al. 2003). Although the rivers in LEB are relatively unregulated, low water availability in highly regulated catchments that have large urban, irrigation and industrial demands may exert external pressure on less regulated systems such as the LEB, where water may be perceived to be available. Australian governments experience major confrontation and conflict over water sharing during periods of drought. Such pressure is likely to increase under the reduced water availability regime likely in a changing climate and further research data is needed to defend future large scale water extractions.

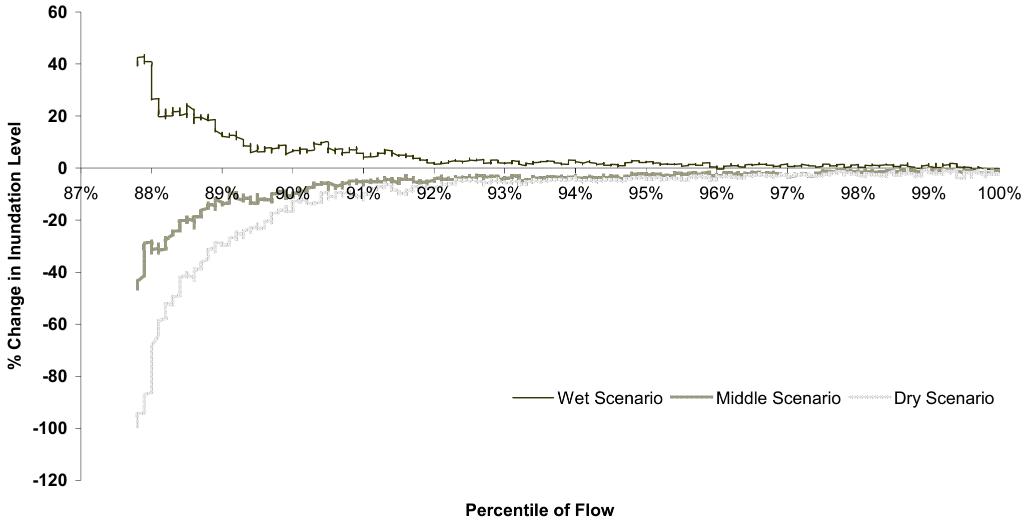

Figure 3. Percentage change in inundation area southward of Currareva from base scenario for wet, average and dry climate change scenarios.

5.0 Adaptation actions

5.1 Research, Monitoring and Understanding Uncertainty

Virtually no research and development has been completed to pinpoint the extent of climate change impacts at the regional scale within the LEB. Better climate change projections at the regional scale, expanded collection of natural resource and agricultural production data, calibrated models and decision tools are needed for researchers and land and water managers to develop adaptation actions to manage climate change. Despite the uncertainty of climate change projections there is little room for complacency about potential impacts. Understanding uncertainty is important in developing adaptive management programs that contain a balanced mixture of adaptive action and continued monitoring. Uncertainty is not an excuse for inaction.

5.2 Identify biodiversity hotspots and preserve

The rate of environmental change is predicted to be faster than any change in the past so adequate response through adaptive evolution is unlikely for most species and fragmentation of natural landscapes presents formidable barriers to natural migration (Hughes 2003). The most vulnerable species will be those with long generation times, low mobility and small or isolated range. Remnant populations along permanent waterholes and within reserves may be particularly vulnerable. Many existing activities will assist to preserve biodiversity such as fencing riparian areas, maintaining or restoring connectivity in the landscape, erosion mitigation, maintaining environmental flows, reduced land clearing and preventing introduction of potentially invasive species.

5.3 Manage the variability of natural and productive systems caused by climate variability

Understanding the current impact on natural resource and agricultural systems will help in the detection and management of future climate change. Climate variability information has been used successfully to improve the management of dryland and irrigated broad acre crops, small acre crops, extensive grazing, bushfire risk, water diversion, environmental flows and fisheries.

6.0 Conclusion

Research and development is needed to pinpoint the extent of these impacts at the regional scale within the LEB. Better climate change projections at the regional scale, natural resource and agricultural production data, calibrated models and decision tools are needed for researchers and land and water managers to develop adaptation actions to manage climate change. Until then understanding the current impact of climate variability on natural and agricultural systems will help in the detection and management of future climate change.

7.0 Acknowledgements

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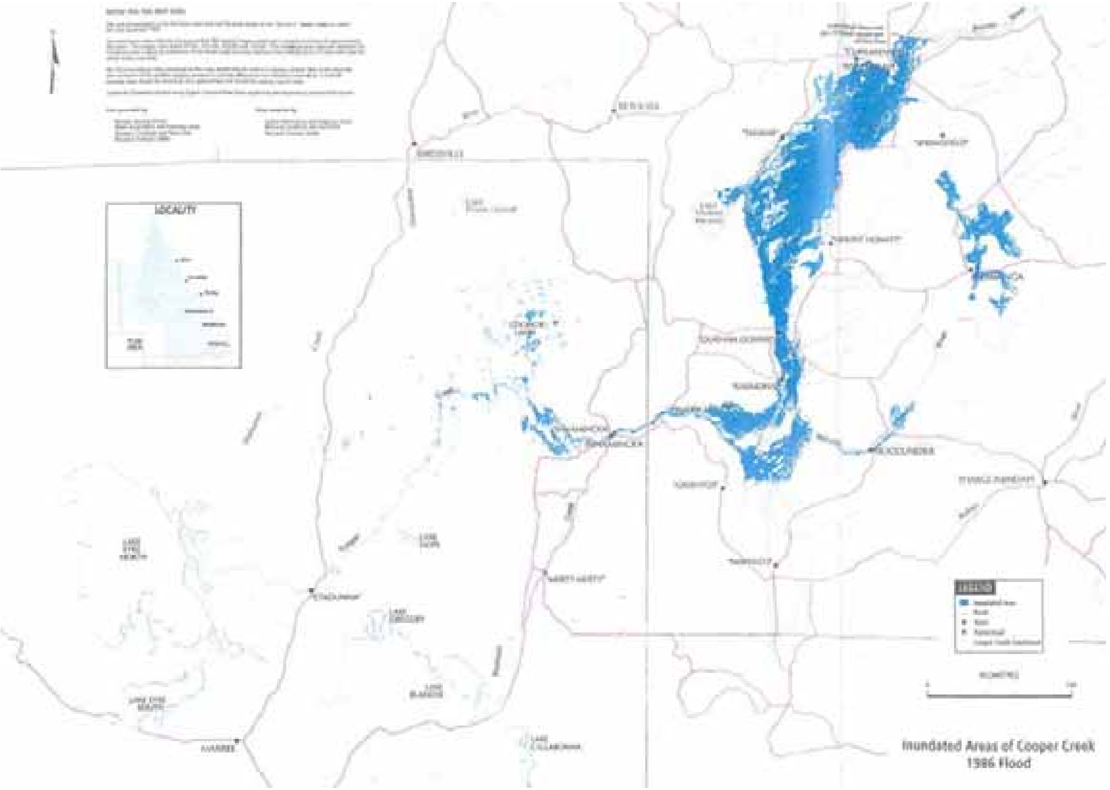
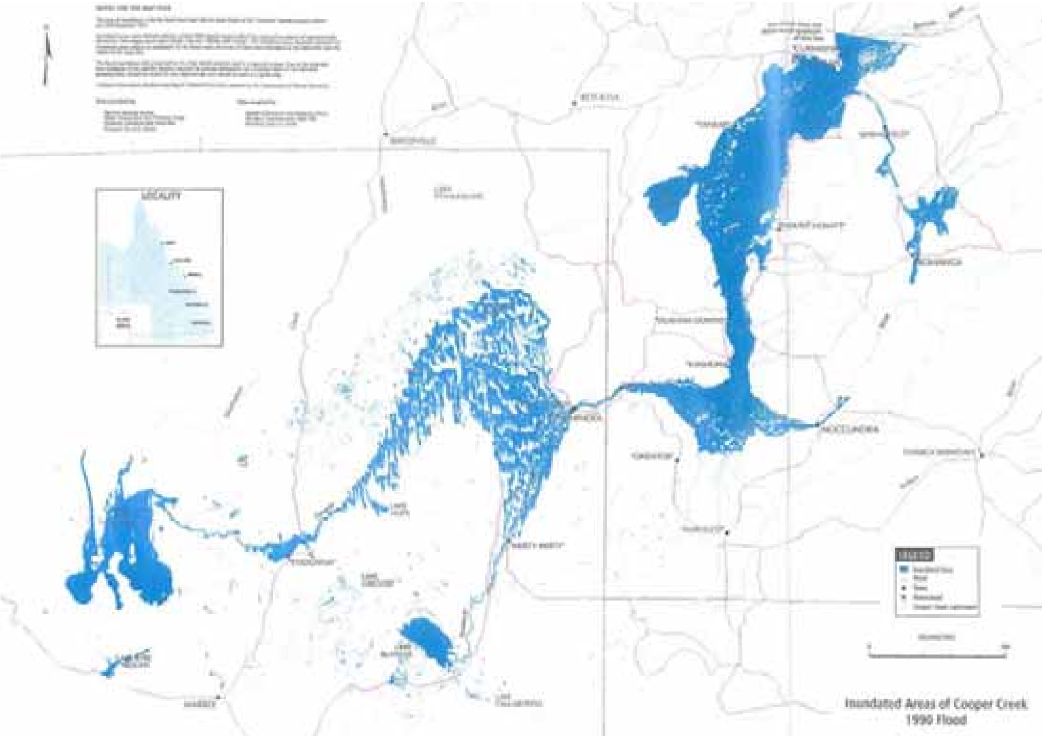
16 Appendix 6 – Maps showing inundation area for the December 1984, February 1986, February 1991 and April 1990 floods

1986



1990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1990 Flood

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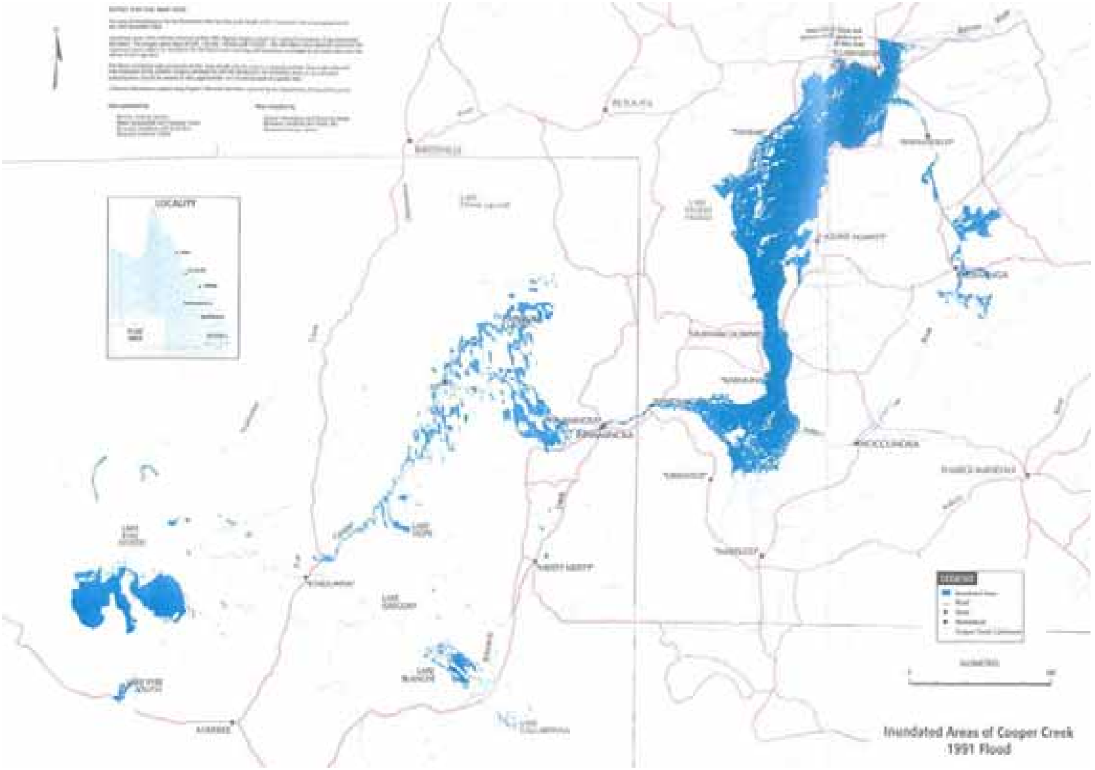
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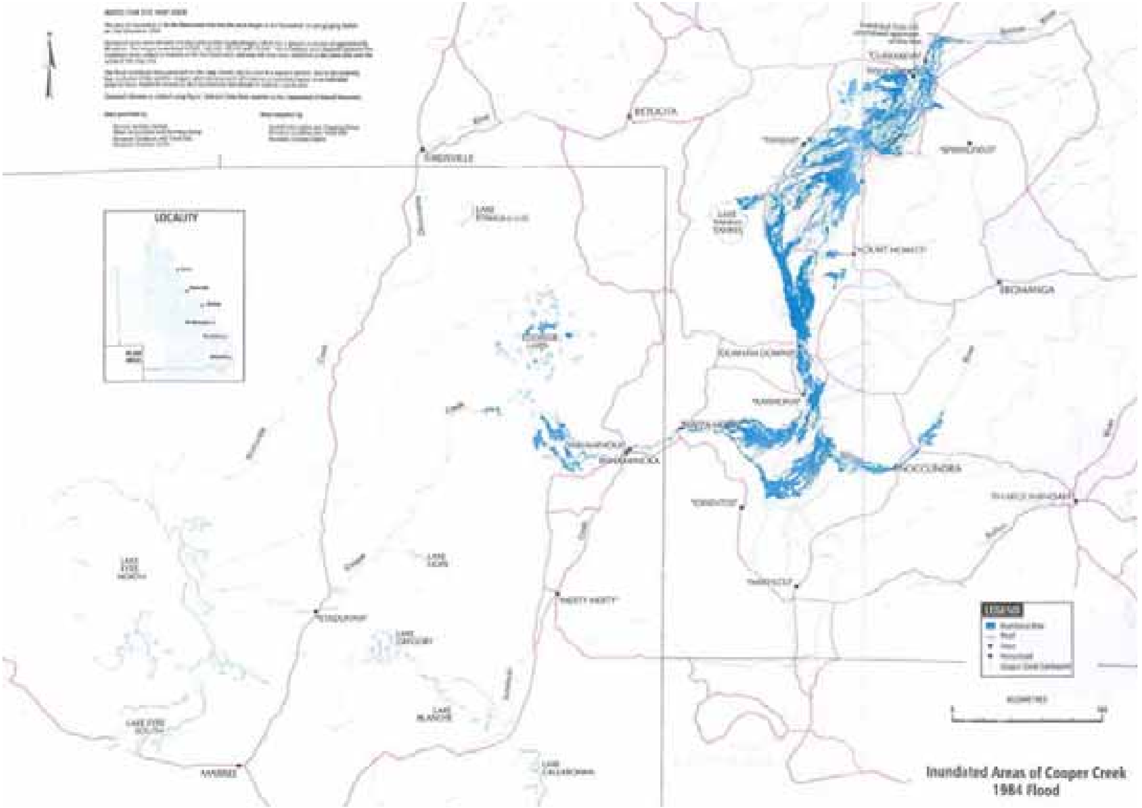

Inundated Areas of Cooper Creek
1984 Flood