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PRACTICAL ADAPTATION TO CLIMATE CHANGE IN REGIONAL NATURAL RESOURCE MANAGEMENT

Queensland Case Studies – South East Queensland Western Catchments 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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AN INTEGRATED REGIONAL NATURAL RESOURCE MANAGEMENT PLAN FOR THE WESTERN CATCHMENTS OF SOUTH-EAST QUEENSLAND
Queensland Murray Darling Committee Inc.
SINCLAIR KNIGHT MERZ SKM
Australian Government
Department of the Environment and Heritage
Australian Greenhouse Office
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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Project No: EP08

Qld Case Studies – Report for SEQWC Case Study – Climate Change Impacts on Water Resources of South-East Queensland Western Catchments

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Cover: Water infrastructure and resources in south-east Queensland. Photos courtesy of staff in the Department of Natural Resources and Water

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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 and driest climate scenarios for the region were used in hydrological models to assess changes in water flow for the Brisbane River. Changes in climate, water flow and water supply were measured against a base period from 1961-1990.

Annual rainfall projections range from slightly wetter, to drier than the historical climate. Six of the nine models expressed an annual drying trend. Seasonally, changes are uncertain in DJFM and AMJJ but are dominated by decreases in ASON. Changes in potential evaporation are much more certain, always increasing and showing a slight inverse relationship with rainfall.

The **dry scenario for 2030 was associated with reduced annual rainfall of 5%, a mean temperature increase of 1.2^{o}C and higher evaporation of 8%**. The **wet scenario for 2030 was associated with higher annual rainfall of 2%, a mean temperature increase of 0.8^{o}C and higher evaporation of 2%.**

Based on the set of scenarios, either increases or decreases in stream flow are possible for the Brisbane River downstream of Mt Crosby Weir depending on which scenario is most closely associated with observed climate in the future. **The change in mean annual flow ranged from -28% to +14% by 2030**. Average annual inflows into Somerset, Wivenhoe and Mt Crosby storages were 7-10% higher for the wet scenario and 12-20% lower for the dry scenario.

The dry/wet scenarios were associated with decreased/increased flows for the upper range (~10-50,000 ML/d) compared to the base scenario. The 60-99 percentile daily flows under the dry scenario were 20-81% lower than the base scenario. For the wet scenario these flows were 13-67% higher than the base scenario. There was no apparent difference in low and extreme high daily flows between the base, wet and dry scenarios.

The mean annual frequency of low daily flows (<10.0 ML/day) at the Brisbane River downstream of Mt Crosby Weir was higher for the dry scenario, and lower for the wet scenario, compared to base. The mean numbers of days of low flow per year for the base, wet and dry scenarios were 88, 84 and 110 days respectively.

The mean annual frequency of high daily flows (>1450 ML/day) at the Brisbane River downstream of Mt Crosby Weir was lower for the dry scenario, and higher for the wet scenario, compared to base. The mean numbers of days of high flow per year for the base, wet and dry scenarios were 36, 41 and 26 days respectively.

The longest simulated duration of low flow (<10.0 ML/day) at the Brisbane River downstream of Mt Crosby Weir for the base scenario was 31 days. The mean duration of high daily flows (>1450 ML/day) was 11 days for the base scenario. There was no difference ($P>0.05$) from the base scenario for all scenarios.

The effects of the dry scenario will be magnified by increased water demand from population and industrial growth in South East Queensland (SEQ). Demand may rise by 35% by 2030. Water planning processes in SEQ indicate additional urban and industrial supplies will be needed by 2021. However **to account for the risk associated with climate variability and climate change a 16% reduction in water yield has been allowed for, reducing the period existing supplies meet demand to 2011. This allowance is likely to be within the range of reduced water yields reported in this study for the dry scenario.** A wet scenario is likely to extend the period SEQ will need additional urban and industrial supplies beyond 2021. The capacity to supply sufficient water to SEQ under climate change conditions requires further investigation.

1 Project overview

The project involved seven regional natural resource management (NRM) organisations - including the South East Queensland Western Catchments (SEQWC), 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 SEQWC 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 South East Queensland (Fry and Willis 2005) and is available from the SEQWC office in Brisbane or QMDC in Toowoomba. A meeting was held in Gatton (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. Surface flow in the upper Brisbane River (Wivenhoe and Somerset Dams) and the reliability of water supply
3. Future demand of water from agricultural, consumptive and environmental uses.

3 South East Queensland Western Catchments

The region's surface water is a major feature of its landscape. There are a total of thirteen water bodies in the region, the majority of which are associated with impoundments in Somerset and Wivenhoe Dams (Figure 1). These dams supply water to well over a million people in urban centres throughout SEQ, although the majority of people are located outside the boundaries managed by SEQWC. Likewise, the City of Toowoomba is outside the region, and is supplied from Perseverance and Cressbrook Dams.

The Brisbane River is bounded by the Great Dividing Range to the west, and the D'Aguilar Ranges to the east. It rises in the north and flows generally south east to Moreton Bay.The catchment comprises the upper reaches of five river basins: Somerset-Stanley; Upper Brisbane – Wivenhoe; Lockyer Valley; Mid-Brisbane Valley; and, the Bremer River. Of these, the Brisbane River is the main river system.

Land use within the basin is a mixture of state forest, grazing, horticulture, and a large proportion of urbanised areas. Included in the catchment are the major cities of Brisbane and Ipswich, and the larger towns of Laidley, Gatton, Esk, Kilcoy, and Woodford.

The predominant land use is the grazing of beef cattle which accounts for approximately 42% of total land area. Grazing also extends into the 36.4% of natural bushland. Managed forests represent 9.4%, intensive agriculture 4.8% (producing a significant proportion of Queensland's vegetable crop), and 1.2% is formally protected conservation area. The remaining 6.2% accommodates all other activities, including urban development and industrial areas. Urban water supply is the major use of water within the catchment.

There are two significant supplemented irrigation schemes within the basin, in the Lockyer and Bremer sub-catchments. These schemes provide water for both irrigation and urban/industrial uses. Irrigation supplies are generally for horticulture or irrigated pastures.

South-east Queensland is home to one in seven Australians. Regional growth has accelerated to the point where an additional 50,000 new south-east Queenslanders must be accommodated each year. The current population of around 2.6 million is expected to increase to about 3.6 million by 2026. SEQ urban and industrial uses currently account for about three-quarters of total water use. Projections (under current water use practices with no restrictions) suggest water demand for these sectors will increase by 35% by 2030 compared to 2006 (South East Queensland Regional Water Supply Strategy 2005), with most of this attributed to population growth.

It is likely that urban development will increase slowly in the upper reaches of the Brisbane River prior to 2030, but these changes will be minor compared to changes in demand from urban growth on the suburban fringe downstream. As such, the water inflow changes to the system due to land use change will be relatively less important than changes to urban demand. Changes in demand from urban growth are expected to be significant and place more pressure on water for irrigation and environmental flows. Projected urban use of water was estimated from projections of population growth.

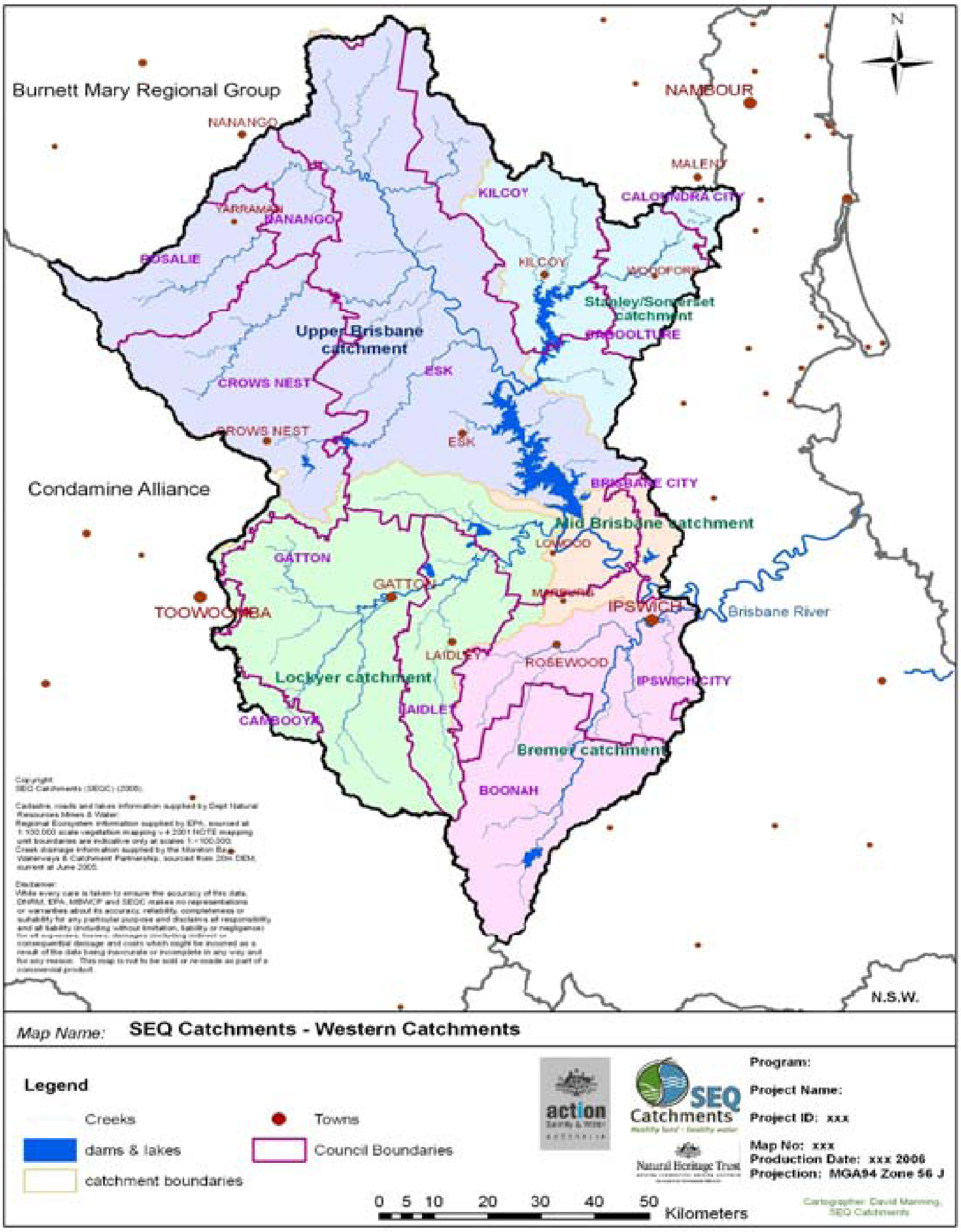

Figure 1. South East Queensland Western Catchments.

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 2, 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.

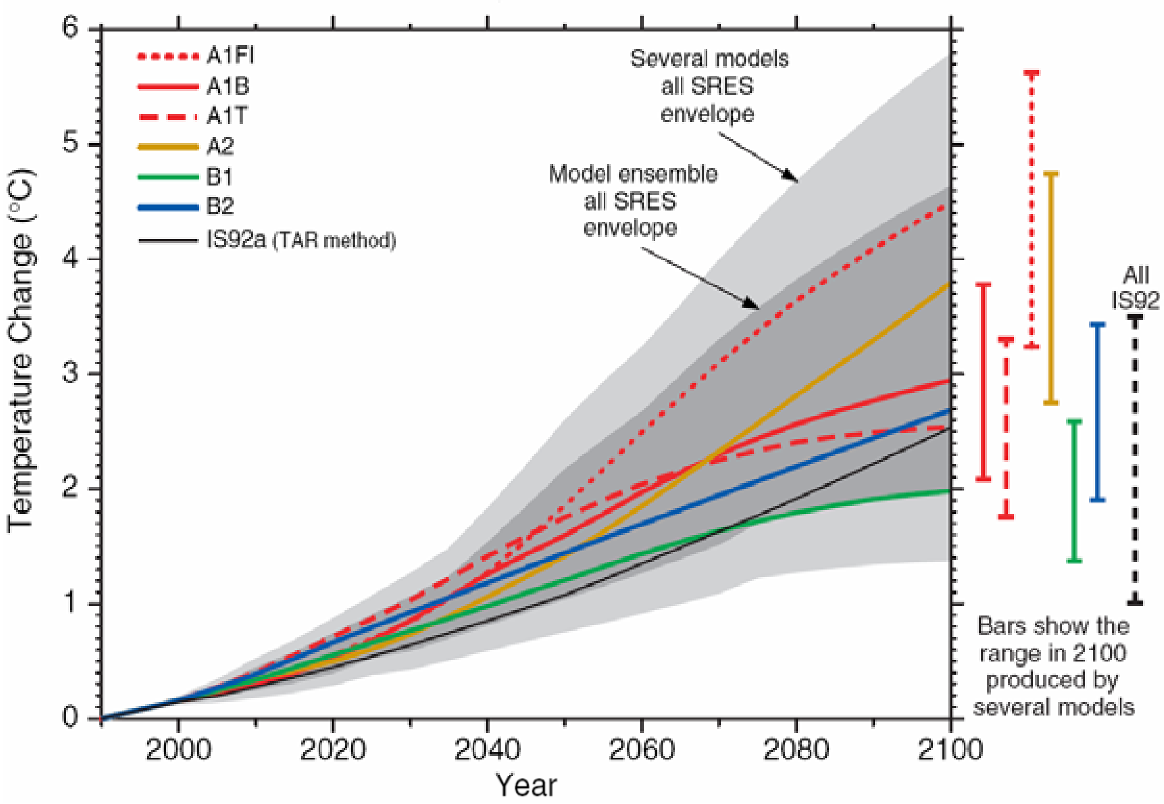

Figure 2. Global mean temperature projections for the six illustrative SRES scenarios using a simple climate model tuned to a number of complex models with a range of climate sensitivities. Also for comparison, following the same method, results are shown for IS92a. The darker shading represents the 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 DARLAM125 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 SEQWC, annual rainfall projections range from slightly wetter, to much drier than the historical climate of the past century. 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 most 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 SEQWC 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 a 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 South East Queensland Western Catchments, simulated by the models in Table 1, expressed as a percentage change per degree of global warming

Model	Rainfall	Point Potential Evaporation
CCCM1	-0.87	3.34
DARLAM125	2.47	4.35
NCAR	3.12	3.59
MARK2	-2.67	5.20
ECHAM4	2.86	2.30
HADCM3 - IS92A	-5.23	6.04
HADCM3 - A1T	-5.18	5.99
CC50	-5.05	8.32
MARK3	-2.20	6.47

Seasonal changes in mean monthly rainfall and potential evaporation per degree of global warming are uncertain in DJFM and AMJJ but are dominated by decreases in ASON (see Figure 3 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.

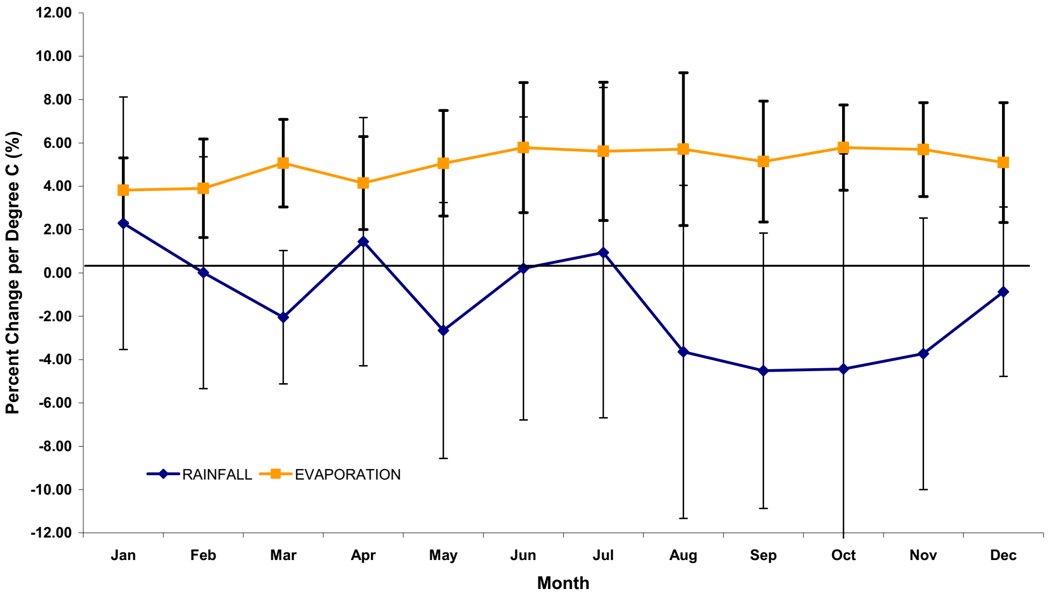

Figure 3. Average monthly percentage change in rainfall and potential evaporation for South East Queensland Western Catchments (see Table 4 for the 11 locations) per degree of global warming using the nine climate models and emissions scenarios with medium sensitivity shown in Table 1 with one standard deviation.

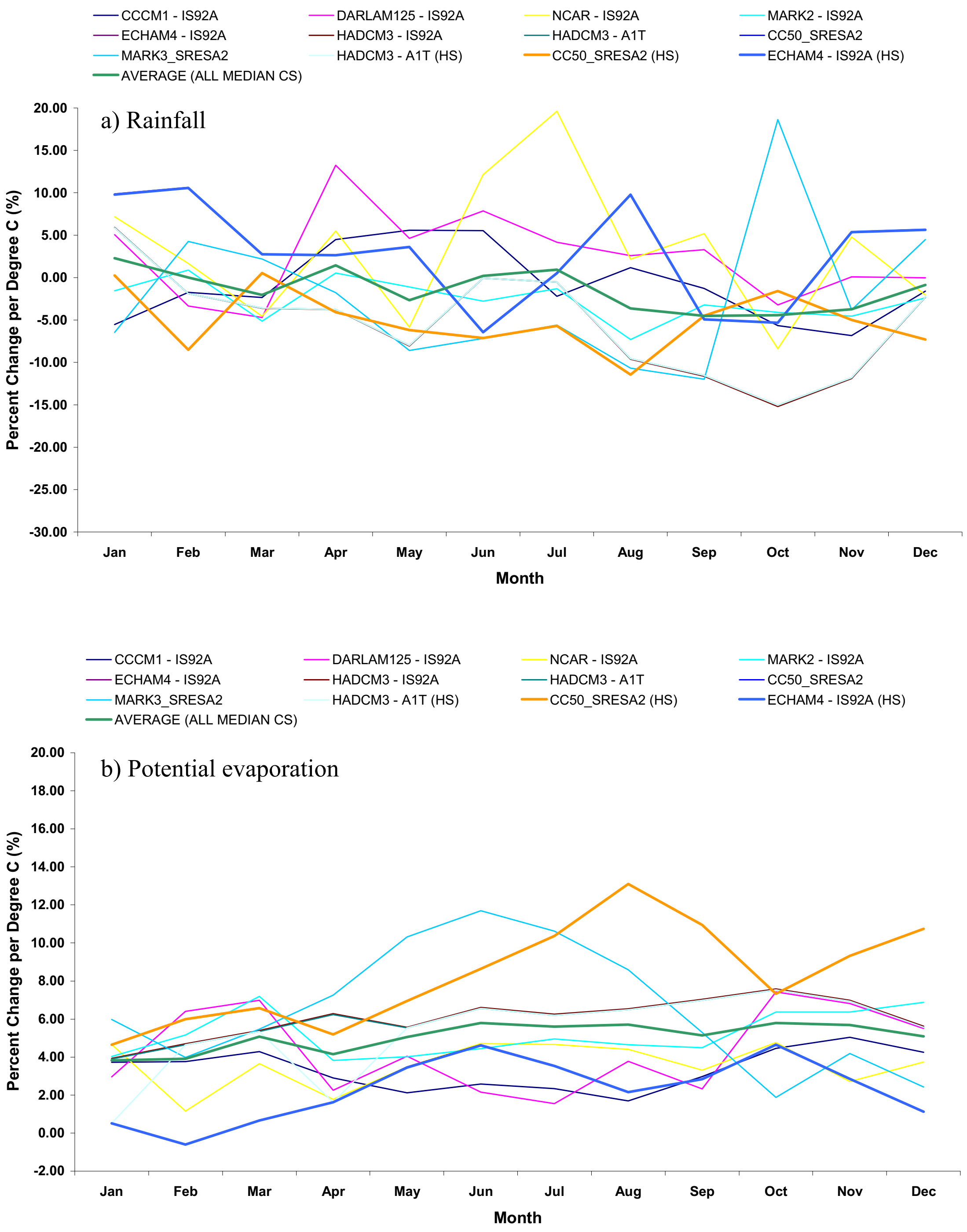

Figure 4. Average monthly percentage change in a) rainfall and b) potential evaporation for South East Queensland Western Catchments (see Table 4 for the 11 locations) per degree of global warming for the nine climate models shown in Table 1 at medium (MS) and high sensitivity (HS).

4.3 CLIMATE CHANGE SCENARIOS

This report presents the range of possible changes provided by dry and wet scenarios for South East Queensland Western Catchments 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 two 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 RCM.
- 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 SEQWC 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. Note that the SRES A2 greenhouse gas scenario contributes to the highest warming in 2030.

Table 3. Dry and wet climate change scenarios for 2030 for South East Queensland Western Catchments

Scenario	**Dry**	**Wet**
Global warming scenario	SRES A2	IS92a
GCM	CC50	ECHAM4
Global mean warming (°C)	0.92	0.78
Regional minimum temperature change (°C)	1.10	0.80
Regional maximum temperature change (°C)	1.20	0.80
Regional mean temperature change (°C)	1.20	0.80
Change in annual rainfall (%)	-4.65	2.21
Change in annual potential evaporation (%)	7.65	1.78

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 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 SEQWC (Figure 1) close to the Brisbane River 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
Yarraman	-26.84	151.98
Kilcoy	-26.94	152.56
Woodford	-26.94	152.76
Esk	-27.24	152.42
Crows Nest	-27.27	152.06
Gatton	-27.54	152.30
Laidley	-27.63	152.39
Rosewood	-27.64	152.59
Lowood	-27.46	152.57
Ipswich	-27.61	152.76
Marburg	-27.57	152.61

These stations covered a large area of the catchment and represented a range of climate change factors over the region. OzClim was used to produce maps showing changes in 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 SEQWC 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 two models for the wet 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 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.

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 Brisbane River system. This was carried out using the Sacramento rainfall-runoff model, which is incorporated into the Integrated Quantity Quality Model (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 – BRISBANE RIVER SYSTEM

The IQQM and Sacramento rainfall-runoff models were previously configured and calibrated for the Brisbane River system by the Queensland Department of Natural Resources and Water. The model was run using full and constant utiliation of existing entitlements for all scenarios. The calibration was based on records of historic streamflow, historic rainfall and Class A pan evaporation. This system contains sub-systems which include the upper Brisbane River system, the Stanley River system, the central and lower Brisbane River system and the Lockyer Creek system. A map of the Brisbane River system as well as the location of the node used for this analysis (IQQM node 203 – closest node downstream of Mt. Crosby Weir) is shown in Figure 5. Mean annual inflows into Somerset, Wivenhoe and Mt Crosby storages were simulated for the base and climate change scenarios.

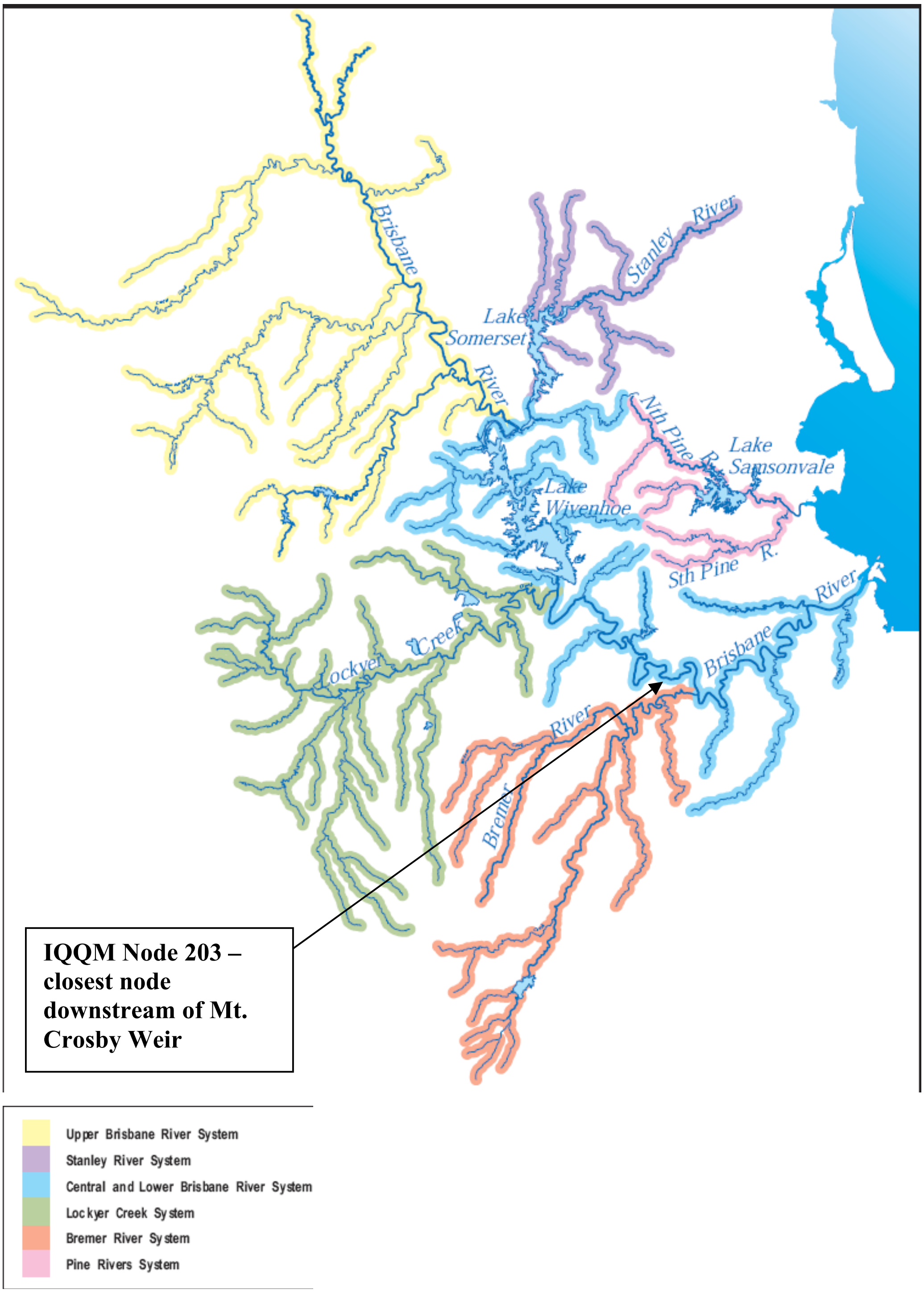

Figure 5. Map of Brisbane River system with sub-systems highlighted. The location of the node used for this analysis (IQQM node 203 – downstream of Mt. Crosby Weir) is also shown.

5.5 APPLICATION OF CLIMATE CHANGE FACTORS

Base data is comprised of 30 years of daily data from 1961 to 1990. Percentage changes were derived from OzClim for precipitation and evaporation for each month of 2030. 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 5.

Table 5. Climate change factors (% change from base scenario) for the dry and wet scenarios for 2030 over South East Queensland Western Catchments

Variable	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	**Wet**	7.64	8.24	2.15	2.06	2.82	-5.02	0.39	7.62	-3.84	-4.14	4.18	4.40
	Dry	0.22	-7.84	0.49	-3.77	-5.68	-6.56	-5.23	-10.52	-4.13	-1.46	-4.60	-6.72
Evaporation	**Wet**	0.40	-0.47	0.52	1.26	2.70	3.59	2.75	1.68	2.21	3.63	2.22	0.87
	Dry	4.27	5.51	6.05	4.77	6.40	7.96	9.53	12.05	10.07	6.74	8.58	9.88

6 Results of impact assessment

6.1 ANNUAL FLOW CHANGES

The results show that based on this set of scenarios, either increases or decreases in streamflow are possible for SEQWC depending on which scenario is most closely associated with observed climate in the future. **The change in mean annual flow of the Brisbane River downstream of Mt Crosby Weir (DMtCW, IQQM node 203) ranges from -28.3% to +14.2% by 2030.** Table 6 shows the change in mean annual flow for each scenario. Figure 6 shows the mean annual flows at the same location for the base scenario and each of the climate change scenarios.

Table 6. Changes in mean annual stream flow of the Brisbane River downstream of Mt Crosby Weir for the dry and wet climate change scenarios for 2030

Scenario	Dry	Wet
Global warming scenario	SRES A2	IS92a
GCM	CC50	ECHAM4
Global mean warming (°C)	0.92	0.78
Regional minimum temperature change (°C)	1.10	0.80
Regional maximum temperature change (°C)	1.20	0.80
Regional mean temperature change (°C)	1.20	0.80
Change in annual rainfall (%)	-4.65	2.21
Change in annual potential evaporation (%)	7.65	1.78
Change in annual streamflow at Node 203 (%)	-28.3	+14.2

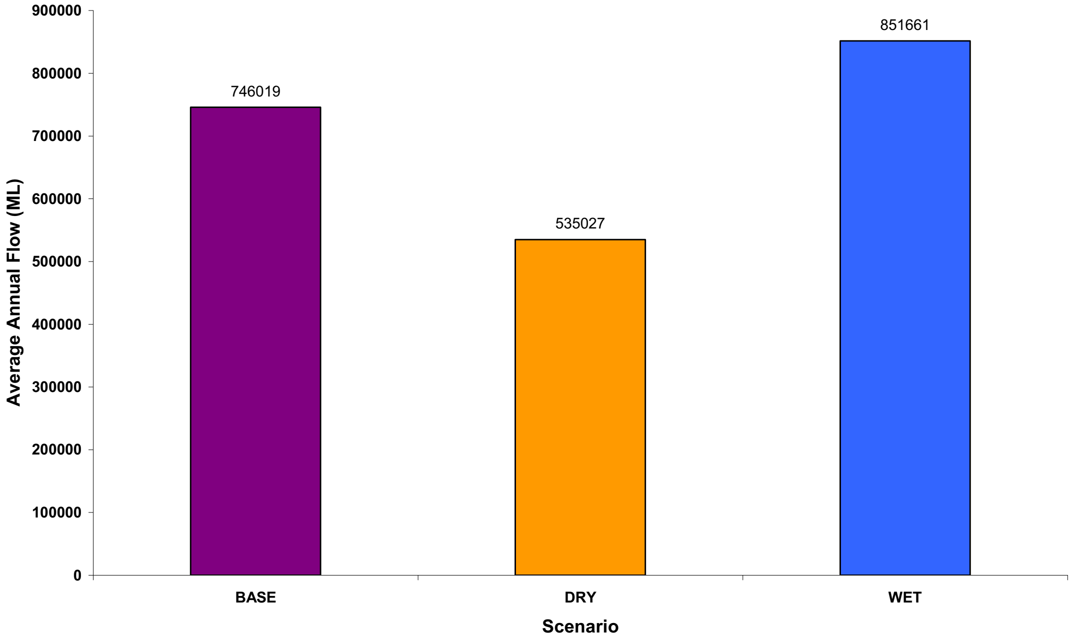

Figure 6. Mean annual streamflow of the Brisbane River downstream of Mt Crosby Weir for the base scenario and the dry and wet climate change scenarios for 2030.

6.2 ANNUAL INFLOWS TO STORAGES

Mean annual simulated inflows into Somerset Dam were 7% higher for the wet climate change scenario and 12% lower for the dry scenario compared to base conditions (Appendix 4). For **Wivenhoe Dam mean annual inflows were 9% higher for the wet climate change scenario and 16% lower for the dry scenario.** For Mt Crosby Weir mean annual inflows were 10% higher for the wet climate change scenario and 20% lower for the dry scenario.

6.3 MONTHLY FLOW CHANGES

Figure 7 shows the average monthly flows of the Brisbane River downstream of Mt Crosby Weir (DMtCW). The highest average flows occur for summer, with the wet scenario having the highest flows and the dry scenario having the lowest flows. Flows decrease during late winter and early spring. Seasonal flows for the Brisbane River DMtCW are shown in Appendix 3.

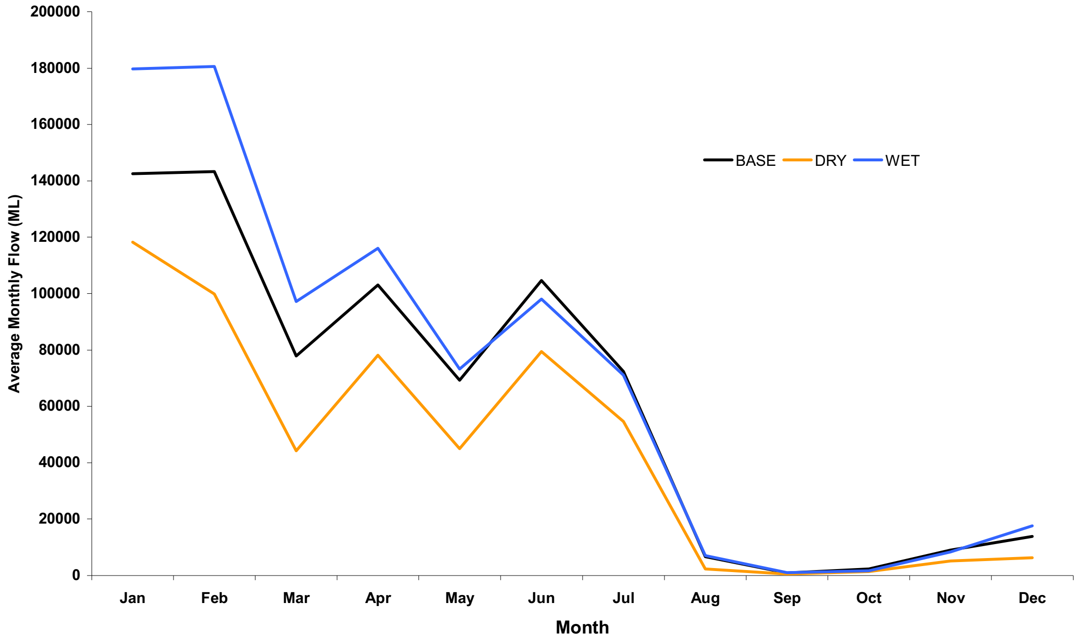

Figure 7. Simulated average monthly flow for the Brisbane River downstream of Mt Crosby Weir for the base, dry and wet scenarios for 2030.

Figure 8 shows the 12 month moving average flows of the Brisbane River DMtCW. The wet and base scenarios have the highest average flows followed by the dry scenario.

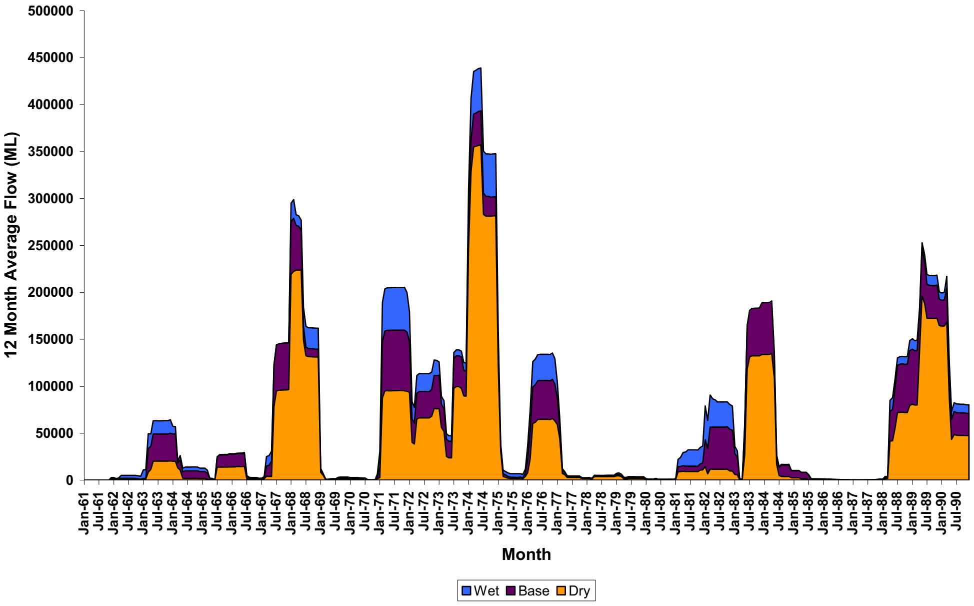

Figure 8. Simulated 12 month moving average flows of the Brisbane River downstream of Mt Crosby Weir for base conditions and under dry and wet climate change scenarios for 2030.

6.4 DAILY FLOW CHANGES

Changes in the frequency of daily flow for the Brisbane River DMtCW for each scenario are shown in Figure 9. The dry/wet scenarios were associated with a decreased/increased frequency of flows for the upper range (~10-50,000 ML/d) compared to the base scenario. **The upper daily flows (60-99 percentile) under the dry scenario were 20-81% lower than the base scenario. For the wet scenario these flows were 13-67% higher than the base scenario.**

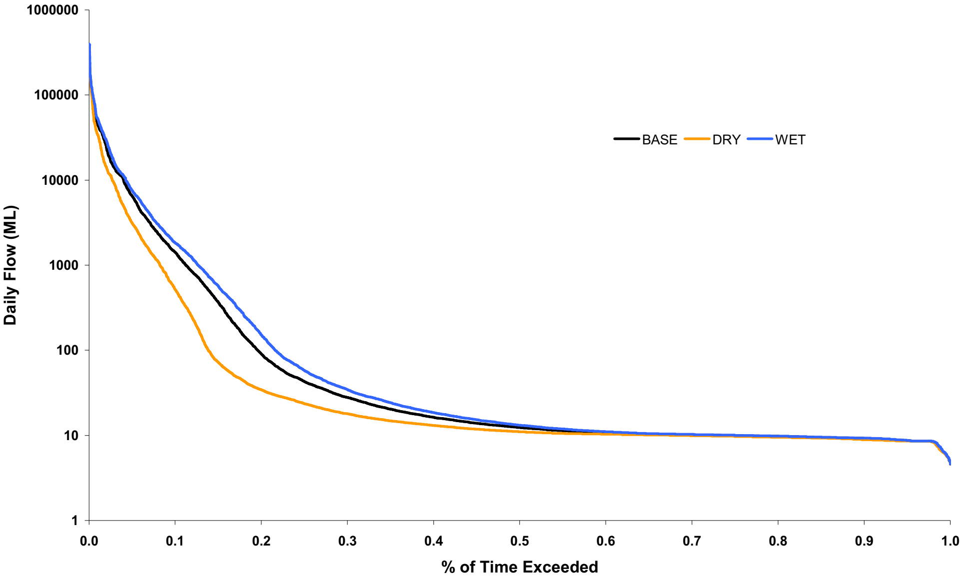

Figure 9. Daily flow exceedance curves for the base, dry and wet climate change scenarios for Brisbane River downstream of Mt Crosby Weir in 2030.

There was no apparent difference in the frequency of extreme high or low daily flows (extreme high >100,000 ML/d, low <10 ML/d) between the base, wet and dry scenarios. The difference in simulated daily flow between the base and dry scenario at the 100th percentile was 2484 ML/day (-1%), and between the base scenario and the wet scenario it was 11059 ML/day (+3%).

6.5 LOW FLOWS

6.5.1 Duration of low flows

There was no apparent change in the duration of low flows (<10.0 ML/day) due to climate change (Figure 10). The longest simulated duration of low flow for the Brisbane River DMtCW for the base, wet and dry scenarios was 31 days (Table 7).

The mean duration of low daily flows (<10.0 ML/day) was 4 days for the base scenario which was not different (P>0.05) from the wet and dry climate change scenarios.

Frequency plots of the duration of low flows show little difference between the base and climate change scenarios (Appendix 3).

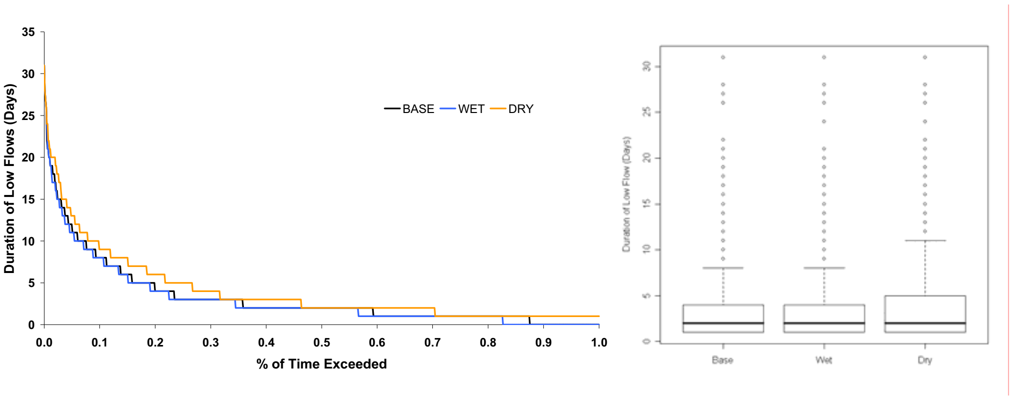

Figure 10. a) Chance of exceeding duration of low flows (<10.0 ML/day) and b) boxplot of duration of low flows for the Brisbane River downstream of Mt Crosby Weir for base, wet and dry scenarios at 2030.

Table 7. Duration of lows flows for the Brisbane River downstream of Mt Crosby Weir for the base, wet and dry climate change scenarios

Probability of exceeding (%)	Duration of low flow (days)		
	Base	Wet	Dry
0	31	31	31
0.2	4	4	6
0.4	2	2	3
0.6	1	1	2
0.8	1	1	1

6.5.2 Frequency of low flows

The mean annual frequency of low daily flows (<10.0 ML/day) at the Brisbane River DMtCW was higher (P<0.01, paired t test) for the dry scenario, and lower for the wet scenario, compared to base (Figure 11). The mean number of days of low flow per year for the base, wet and dry scenarios were 88, 84 and 110 days respectively.

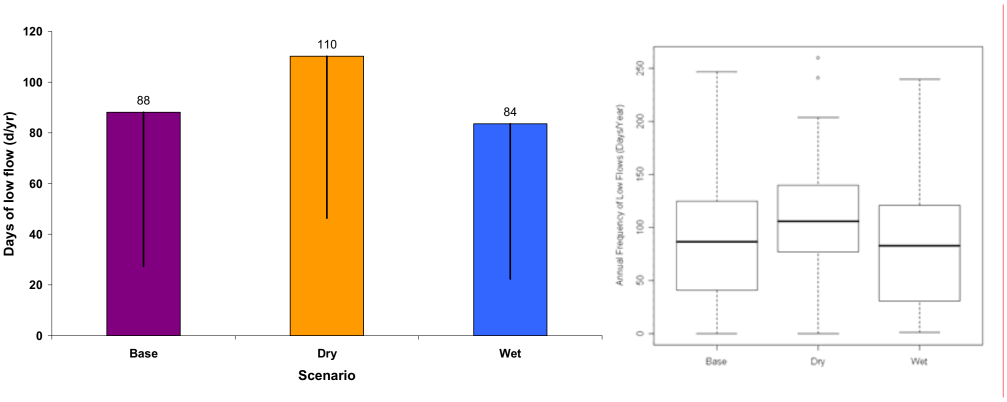

Figure 11. a) Mean number of days per year with low flows <10 ML/d (-SD) and b) boxplot of low flow days per year for the base, dry and wet scenarios in 2030 for the Brisbane River downstream of Mt Crosby Weir.

6.6 HIGH FLOWS

6.6.1 Duration of high flows

There was no apparent change in the duration of high flows (>1450 ML/day) due to climate change (Figure 12a). The longest simulated duration of high flow for the Brisbane River DMtCW for the base, wet and dry scenarios were 85, 85 and 51 days respectively.

The mean duration of high daily flows (>1450 ML/day) was 11 days for the base scenario. There was no difference (P>0.05) between the base scenario and both climate change scenarios. The median duration of high daily flows was 4, 5 and 4 days for the base, wet and dry scenarios respectively.

6.6.2 Frequency of high flows

The mean annual frequency of high daily flows (>1450 ML/day) at the Brisbane River DMtCW was lower (P<0.01, paired t test) for the dry scenario, and higher for the wet scenario, compared to base (Figure 12b). The mean numbers of days of high flow per year for the base, wet and dry scenarios were 36, 41 and 26 days respectively.

In 75% of years high flows were exceeded on 75 days/yr in the base scenario compared to 50 days/yr in the dry scenario. The base and wet scenarios were not different.

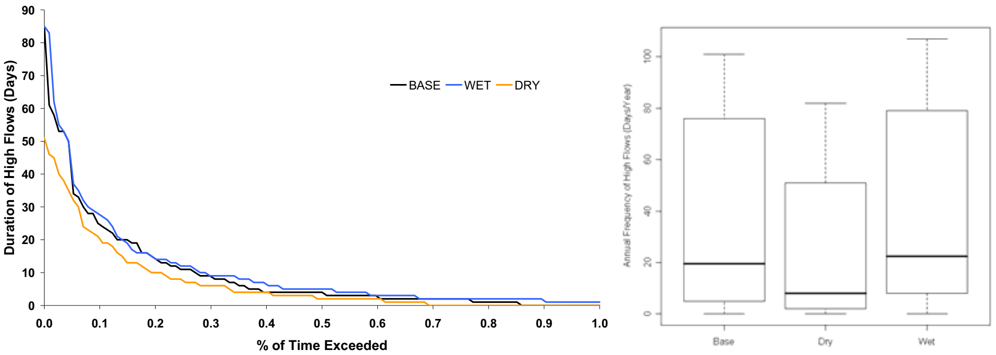

Figure 12. a) Chance of exceeding duration of flows >1450 ML/d and b) number of days per annum of flows >1450 ML/d for the Brisbane River downstream of Mt Crosby Weir for base scenario and the wet and dry climate change scenarios in 2030.

6.7 ENVIRONMENTAL FLOWS

There were no environmental flow requirements for this node of the Brisbane River (flow downstream of Mt Crosby Weir - IQQM node 203).

7 Future water demand

There have been several models of population growth developed for the South East Queensland region. The following information was taken from the South East Queensland Regional Water Supply Strategy, Stage 2 Interim Report (SEQRWSS, Department Natural Resources and Mines, November 2005). It discusses the water supply for the whole of South East Queensland and predicts water demand for the future.

Figure 13 shows the projected increase in demand for water for urban and industrial use. In a scenario where there are no restrictions on water supply in SEQ, water use for urban and industrial demands could reach 675,000 ML/year by 2030, where our current demand for water in SEQ in 2007 is about 500,000 ML/year (NRM 2005). This is an average increase of 35% across SEQ.

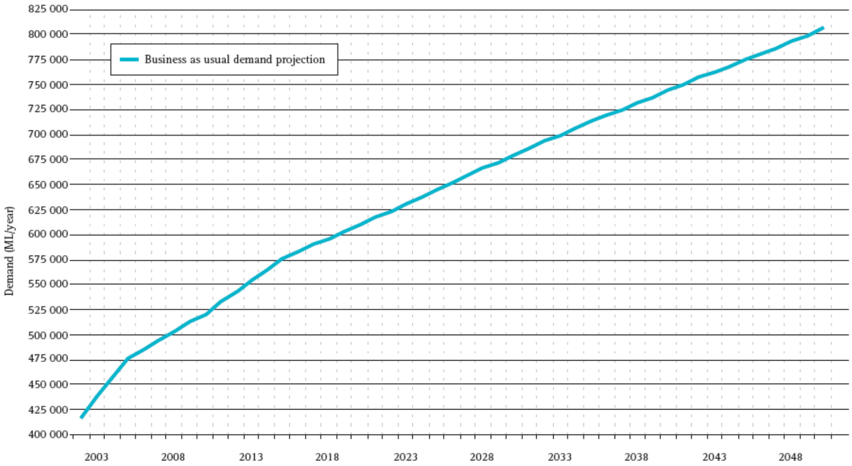

Figure 13. Future water demand for industrial and urban use for South East Queensland. (Source: SEQ Regional Water Supply Strategy - 2nd Interim Report, 2005)

Urban and industrial use contributes to about 71% of the water use in SEQ, the other 29% for power and rural industries (Figure 14). Total water use is approximately 704,200 ML/yr. If the water demand rises by 35% at 2030 a total supply of about 950,700 ML/Year will be needed by the population of SEQ (which includes water for all uses).

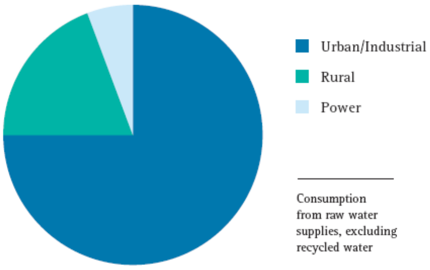

Figure 14. Fractions of water supply used by different sectors in South East Queensland (Source: SEQ Regional Water Supply Strategy - 2nd Interim Report, 2005)

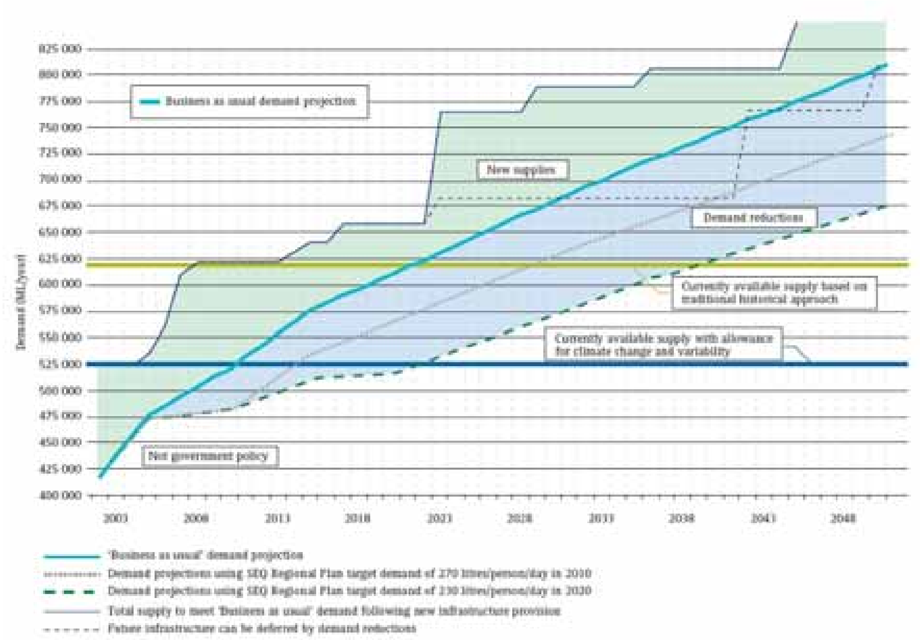

Figure 15. Future water demand for industrial and urban use for South East Queensland with demand reductions and new water supplies. (Source: SEQ Regional Water Supply Strategy - 2nd Interim Report, 2005)

Recent assessments indicate that the region will need additional urban and industrial supplies by about 2021 (Figure 15, Table 8). This is based on a comparison of demand projections and water availability assessed using historical data to determine yield. Some parts of the region will need to be augmented before 2021. As part of the water resource and regional water supply planning activities in South East Queensland, the yields of all storages are being reassessed. The assessment will take account of the environmental flow requirements and the effects of climate variability and change. If yields are reduced due to changes in climate the period existing supplies meet demand may be reduced to 2011 (Table 8). Currently the impact of a preliminary 16 per cent reduction in available supplies below historically determined yields is shown (Figure 15), this being set aside for contingency purposes. This allowance for a reduction in water yield in the water planning process to account for the risk associated with climate variability and climate change is likely to be within the range of reduced water yields reported in this study for the dry scenario. A wet scenario is likely to extend the period SEQ will need additional urban and industrial supplies beyond 2021.

Table 8. Periods that existing supplies will meet demand for different levels of domestic consumption. (Source: SEQ Regional Water Supply Strategy - 2nd Interim Report, 2005)

Domestic consumption (litres/person/day)	Period existing supplies meet demand based on historical record approach	Period existing supplies meet demand allowing for climate variability and change
'Business as usual' 300	2021	2011
Year 2010 target 270	2030	2015
Year 2020 target 230	2040	2022

The domestic consumption targets (see Table 8) could be expected to see the adequacy of existing supplies extended. Assuming that a consumption target of 270 litres per person per day is achievable, supplies could be extended for about eight or nine years (beyond 2021) based on historical supply assessments. An extension of four years (beyond 2011) occurs when a reduction in storage yield is allowed for to address the risk of climate variability and change. The achievability or otherwise of the consumption targets and adjustments to water availability associated with changes in climate are currently being assessed, with the results being incorporated in the final SEQRWSS Stage 2 Report.

8 Conclusions and recommendations

8.1 SUMMARY OF RISK ANALYSIS

In this study we have assessed the likelihood of changes to mean annual flow by perturbing input data to the Upper Brisbane River system 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 nine 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.

Annual rainfall projections range from slightly wetter, to drier than the historical climate. Six of the nine models showed an annual drying trend. Seasonally, changes are uncertain in DJFM and AMJJ but are dominated by decreases in ASON. Changes in potential evaporation are much more certain, always increasing and showing a slight inverse relationship with rainfall.

The dry scenario for 2030 was associated with reduced annual rainfall of 5%, a mean temperature increase of 1.2^{o}C and higher evaporation of 8%. The wet scenario for 2030 was associated with higher annual rainfall of 2%, a mean temperature increase of 0.8^{o}C and higher evaporation of 2%.

Based on the set of scenarios, either increases or decreases in stream flow are possible for the Brisbane River downstream of Mt Crosby Weir depending on which scenario is most closely associated with observed climate in the future. The change in mean annual flow ranged from -28% to +14% by 2030.

The dry/wet scenarios were associated with decreased/increased flows for the upper range (~10-50,000 ML/d) compared to the base scenario. The 60-99 percentile daily flows under the dry scenario were 20-81% lower than the base scenario. For the wet scenario these flows were 13-67% higher than the base scenario. There was no apparent difference in low and high daily flows between the base, wet and dry scenarios.

The mean annual frequency of low daily flows (<10.0 ML/day) at the Brisbane River downstream of Mt Crosby Weir was higher for the dry scenario, and lower for the wet scenario, compared to base. The mean numbers of days of low flow per year for the base, wet and dry scenarios were 88, 84 and 110 days respectively.

The mean annual frequency of high daily flows (>1450 ML/day) at the Brisbane River downstream of Mt Crosby Weir was lower for the dry scenario, and higher for the wet scenario, compared to base. The mean numbers of days of high flow per year for the base, wet and dry scenarios were 36, 41 and 26 days respectively.

The longest simulated duration of low flow (<10.0 ML/day) at the Brisbane River downstream of Mt Crosby Weir for the base scenario was 31 days. There was no difference (P>0.05) from the base scenario for all scenarios.

The mean duration of high daily flows (>1450 ML/day) was 11 days for the base scenario. There was no difference (P>0.05) from the base scenario for all scenarios.

The effects of the dry scenario will be magnified by increased water demand from population and industrial growth in south-east Queensland (SEQ). Demand may rise by 35% by 2030. Water planning processes in SEQ indicate additional urban and industrial supplies will be needed by 2021. However to account for the risk associated with climate variability and climate change a 16% reduction in water yield has been allowed for, reducing the period existing supplies meet demand to 2011. This allowance is likely to be within the range of reduced water yields reported in this study for the dry scenario. A wet scenario is likely to extend the period SEQ will need additional urban and industrial supplies beyond 2021. The capacity to supply sufficient water to SEQ under climate change conditions requires further investigation.

8.2 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.

8.2.1 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).

8.2.2 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.

8.2.3 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.

8.2.4 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.

8.2.5 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.

8.2.6 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; Chiew *et al.* 2005). 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.

8.3 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:

- Complete an analysis of inflows into Wivenhoe and Somerset storages under climate change conditions.
- Complete a full analysis of water availability and demand for the catchment under climate change conditions.
- Include the last 15 years in the historical climate sequence and complete analysis of decadal climate variability and climate change on water yield.
- Assess system vulnerability to water supply and quality to add context to projected changes in catchment water balance.
- Complete an analysis of the impacts of climate change on horticulture and grazing systems and associated natural resources.
- Assess current water strategies in light of possible changes in climate.
- 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.

9 Acknowledgements

Dr Roger Jones provided the scaling factors for the GCM's and emissions scenarios. 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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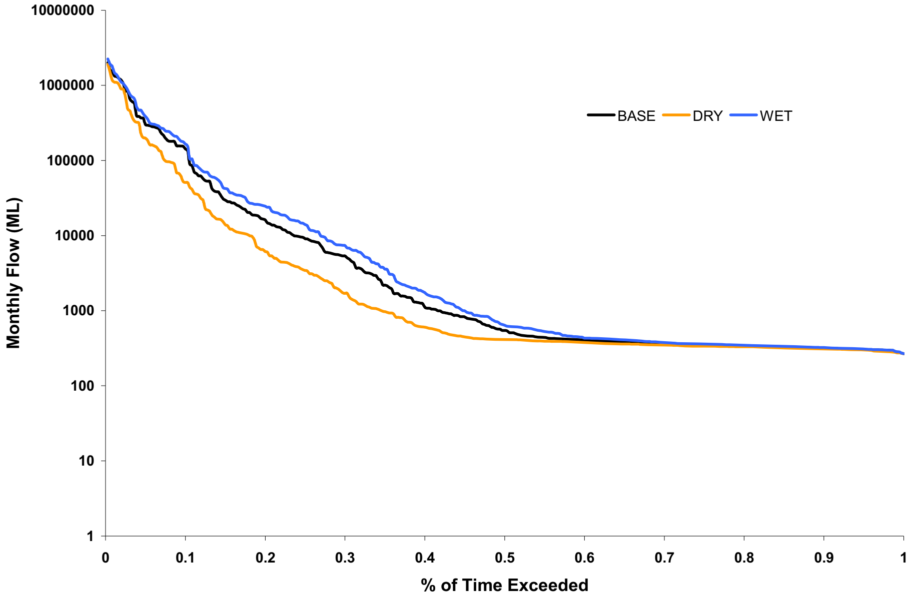
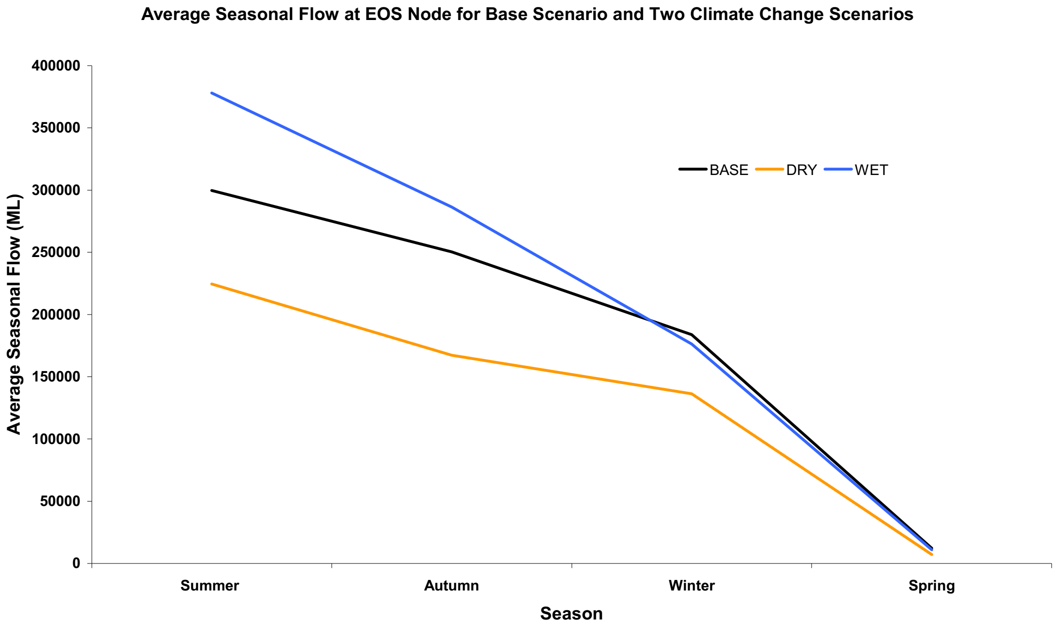
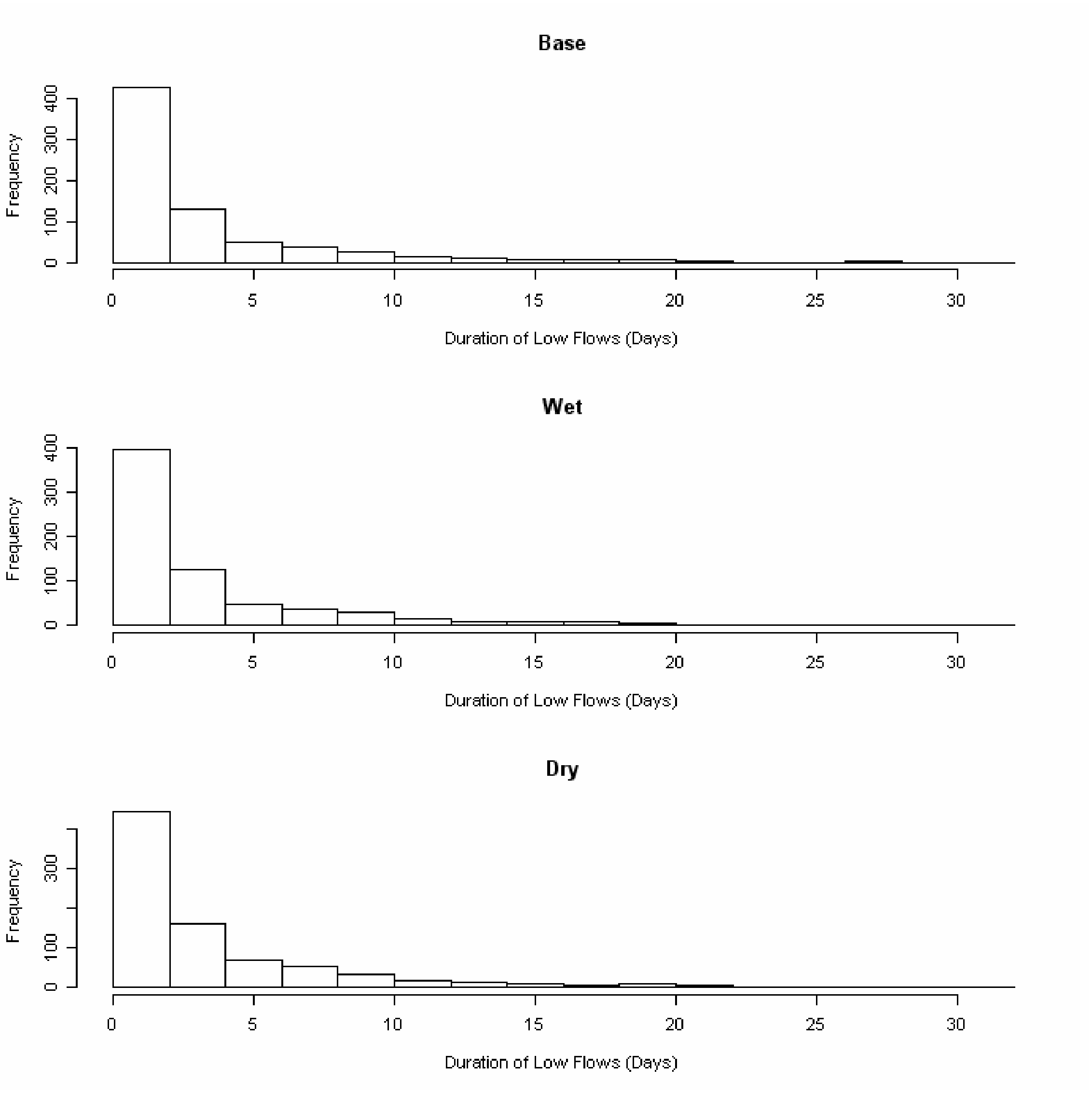
11 Appendix 1 – Exceedance curve for monthly flows for the Brisbane River downstream of the Mt Crosby Weir



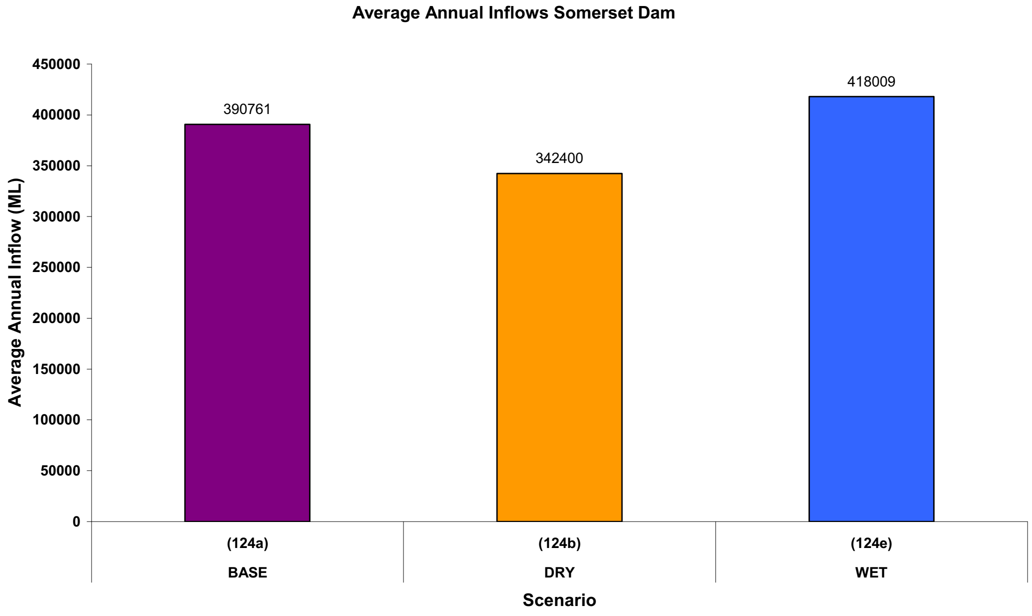
12 Appendix 2 – Average seasonal flows for the Brisbane River downstream of the Mt Crosby Weir

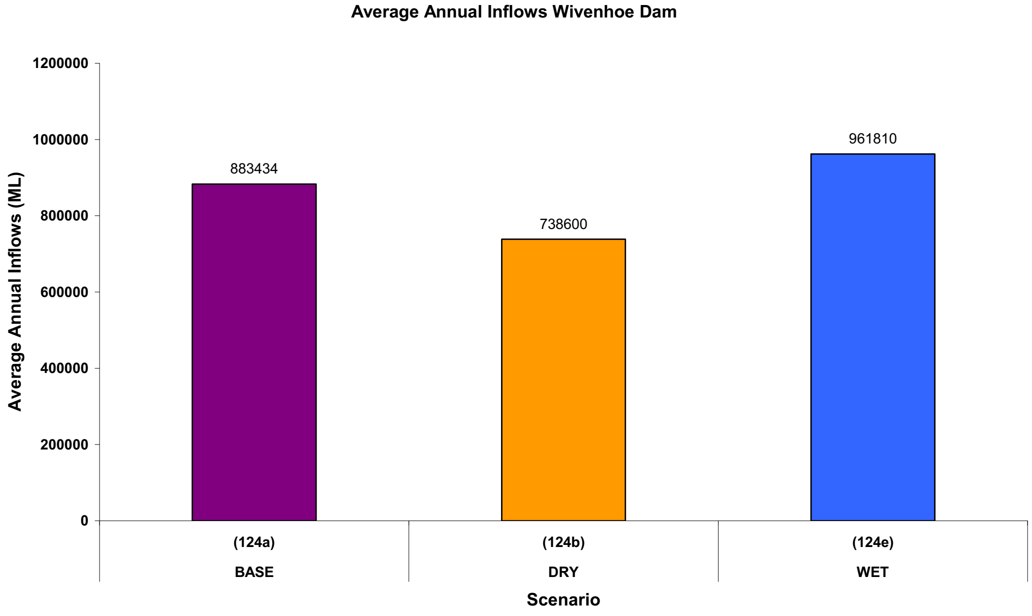


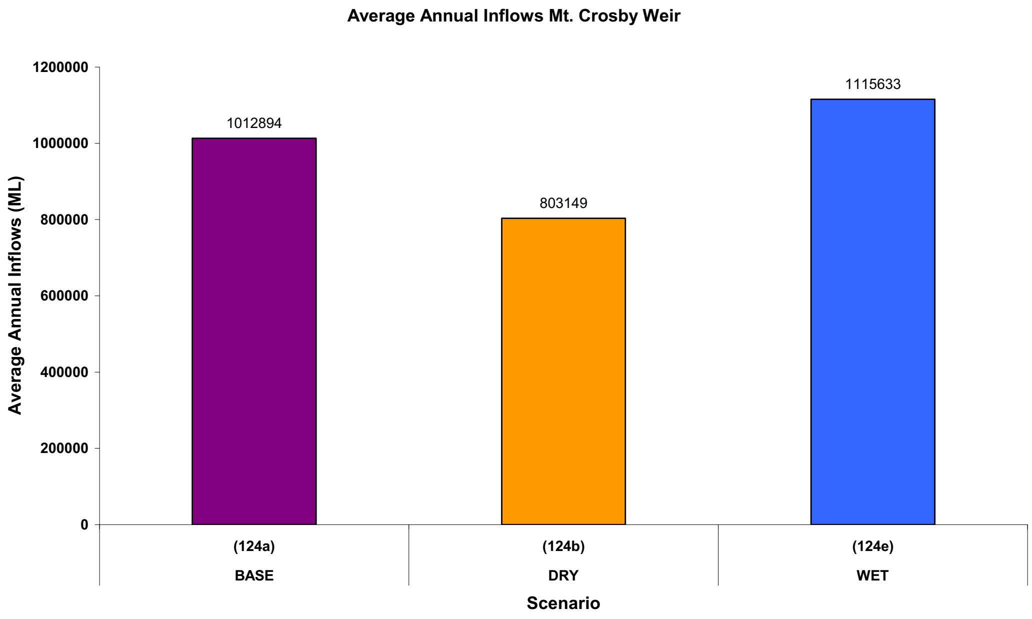
13 Appendix 3 – Frequency plots of low flows for the Brisbane River downstream of the Mt Crosby Weir



14 Appendix 4 – Average annual inflows into major storages

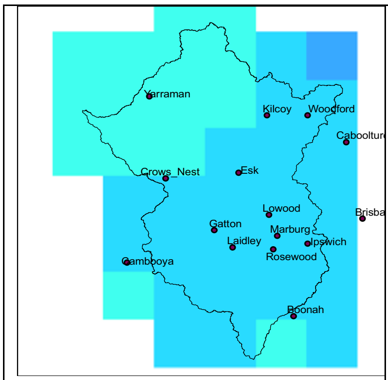




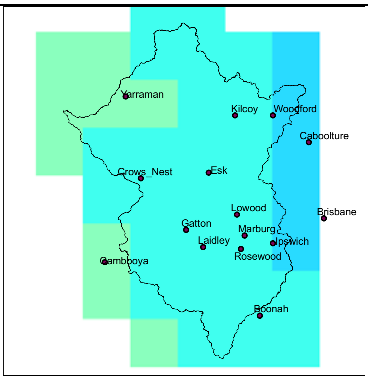

Average Annual Inflows Mt. Crosby Weir
Average Annual Inflows (ML)
1200000
1000000
800000
600000
400000
200000
0
1012894
803149
1115633
(124a)
BASE
(124b)
DRY
(124e)
WET
Scenario

15 Appendix 4 – Maps for wet and dry scenarios for SEQ Western Catchments

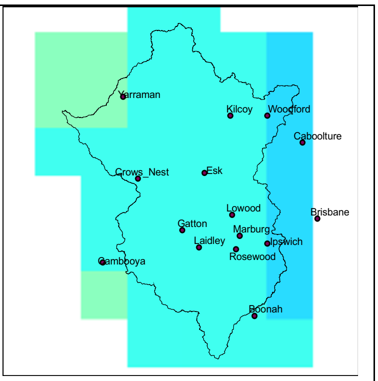
14.1 MINIMUM TEMPERATURE – DRY SCENARIO



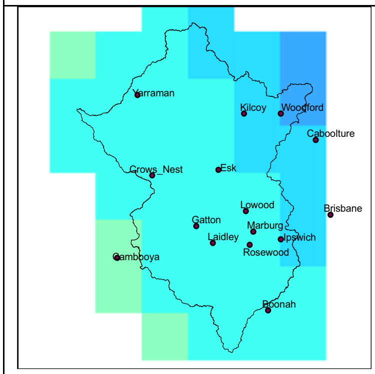
Annual



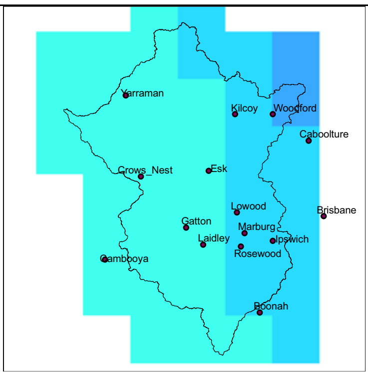
Summer



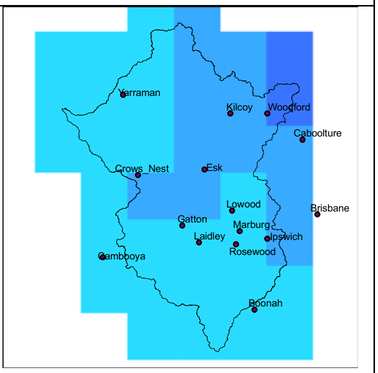
Warm Season



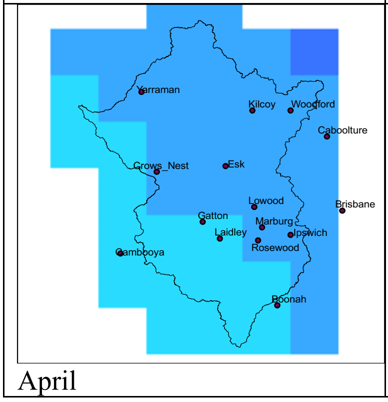
January



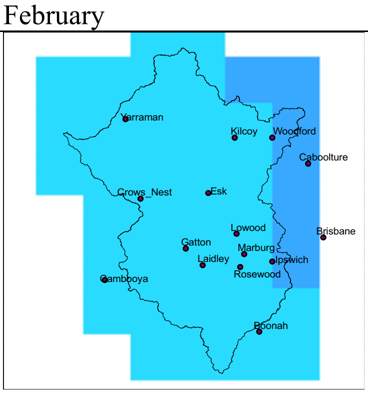
February



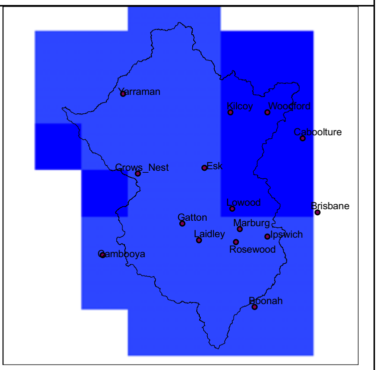
March



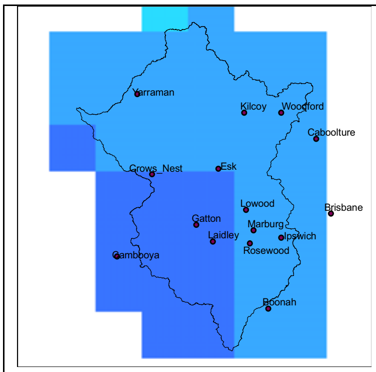
April



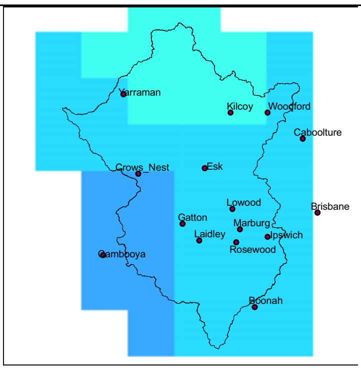
May



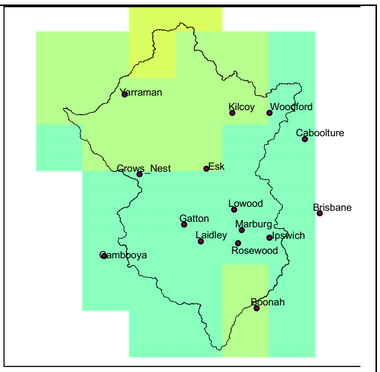
June



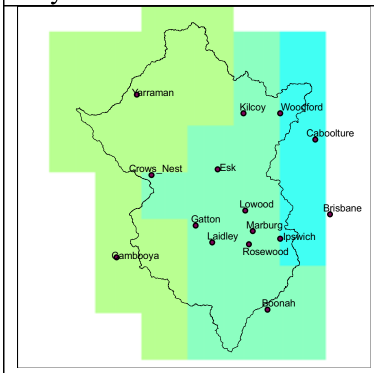
July



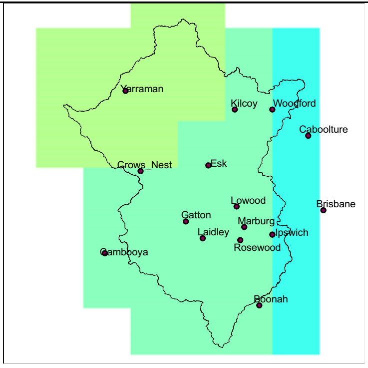
August



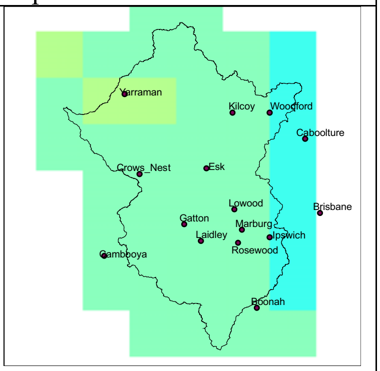
September



October



November



December

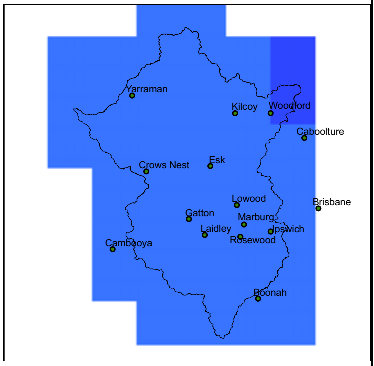
Legend

Temp Change (Degree C)

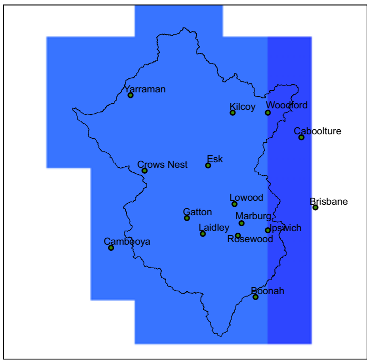
Value

- 🟦 0.6 - 0.7
- 🟦 0.7 - 0.8
- 🟦 0.8 - 0.9
- 🟦 0.9 - 1.0
- 🟦 1.0 - 1.1
- 🟦 1.1 - 1.2
- 🟩 1.2 - 1.3
- 🟩 1.3 - 1.4
- 🟨 1.4 - 1.5
- 🟨 1.5 - 1.6
- 🟨 1.6 - 1.7
- 🟧 1.7 - 1.8
- 🟧 1.8 - 1.9
- 🟥 1.9 - 2.0
- 🟥 2.0 - 2.1

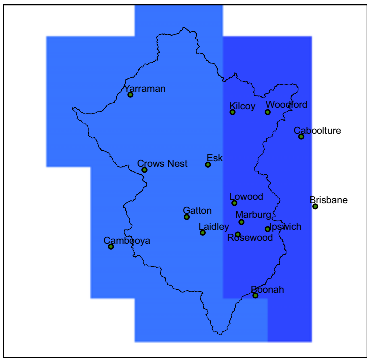
14.2 MINIMUM TEMPERATURE – WET SCENARIO



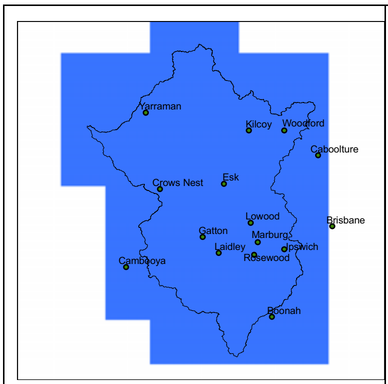
Annual



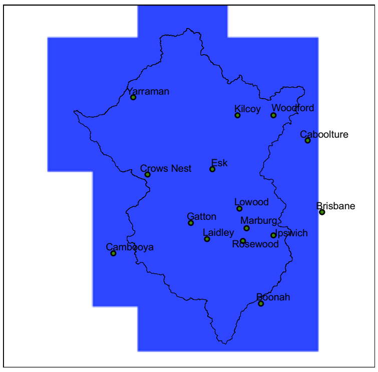
Summer



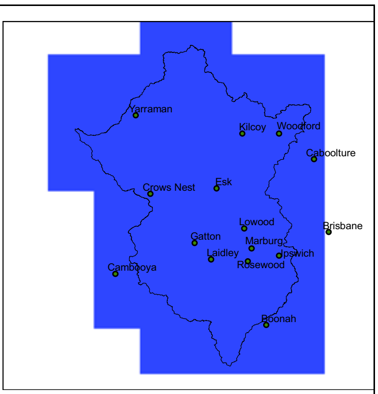
Warm Season



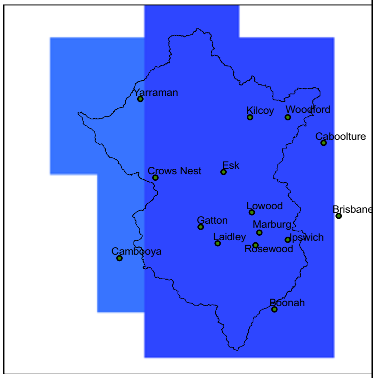
January



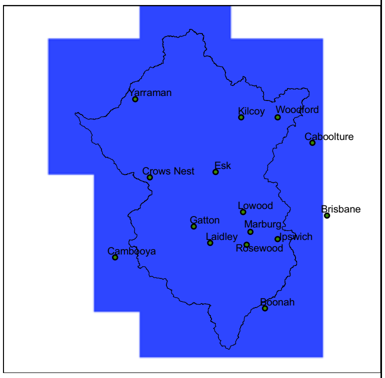
February



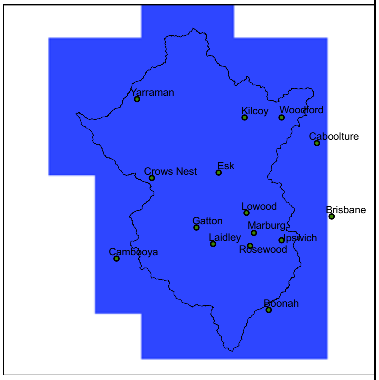
March



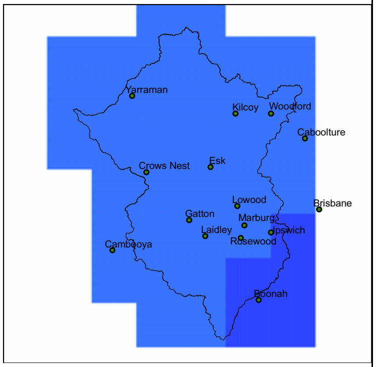
April



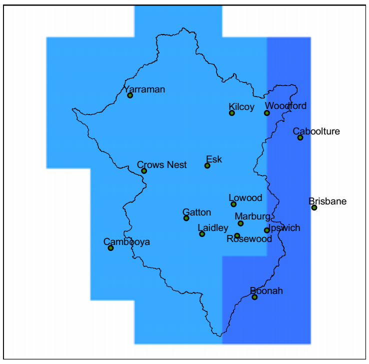
May



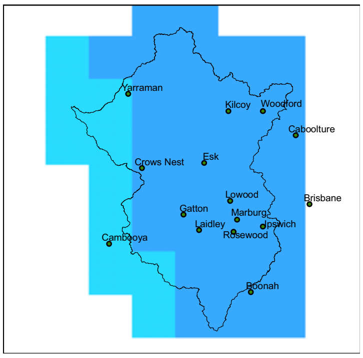
June



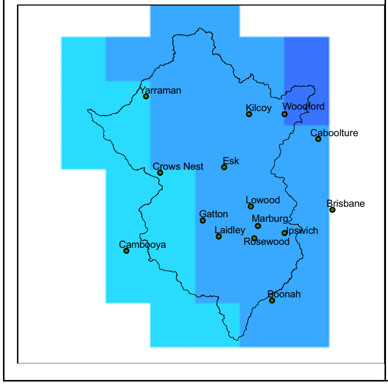
July

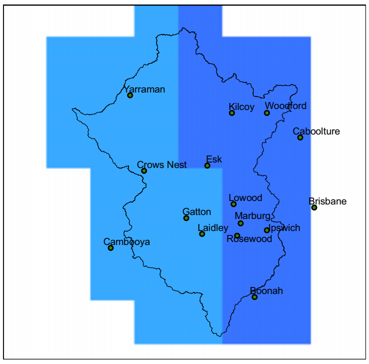


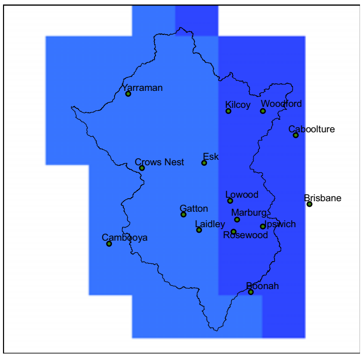
August



September

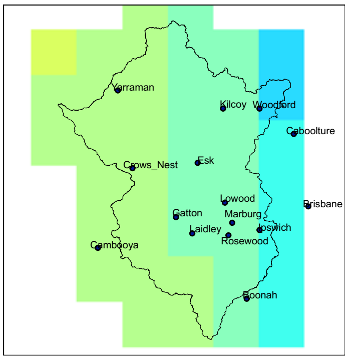




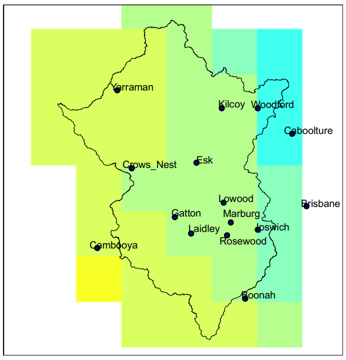


October	November	December
	Legend **Temp Change (Degree C)** **Value** 🟦 0.6 - 0.7 🟦 0.7 - 0.8 🟦 0.8 - 0.9 🟦 0.9 - 1.0 🟦 1.0 - 1.1 🟩 1.1 - 1.2 🟩 1.2 - 1.3 🟩 1.3 - 1.4 🟨 1.4 - 1.5 🟨 1.5 - 1.6 🟨 1.6 - 1.7 🟧 1.7 - 1.8 🟧 1.8 - 1.9 🟥 1.9 - 2.0 🟥 2.0 - 2.1	

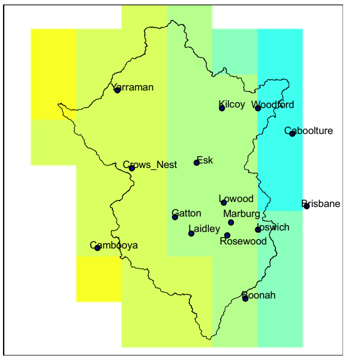
14.3 MAXIMUM TEMPERATURE – DRY SCENARIO



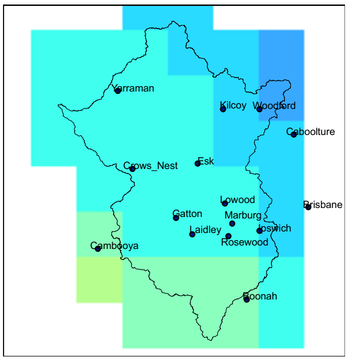
Annual



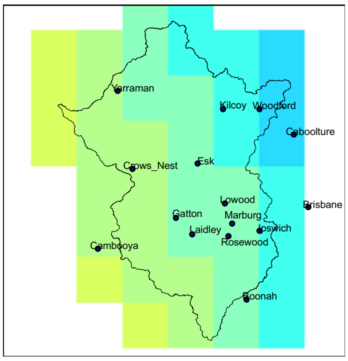
Summer



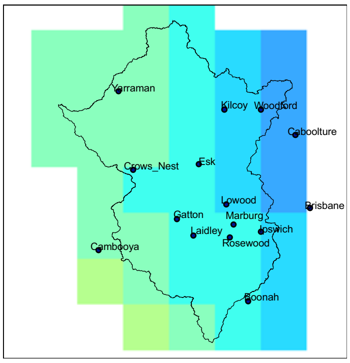
Warm Season



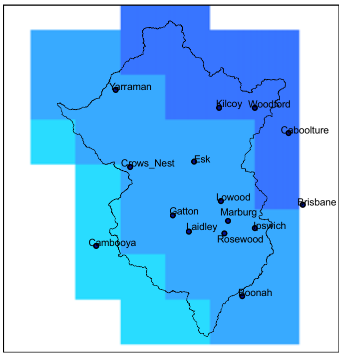
January



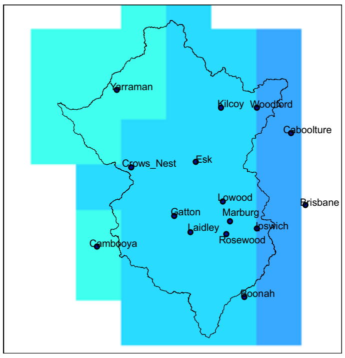
February



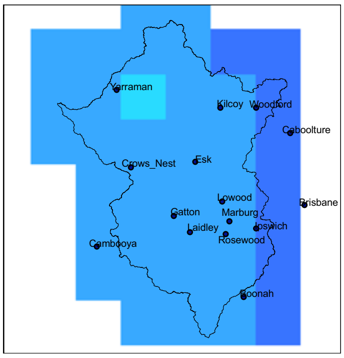
March



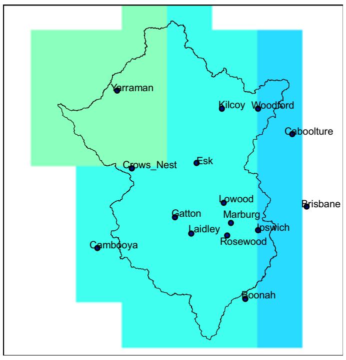
April



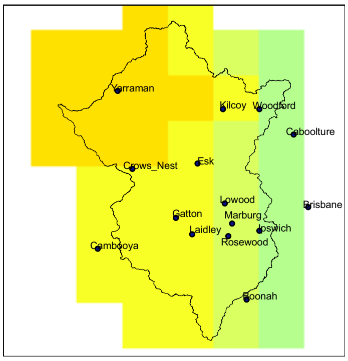
May



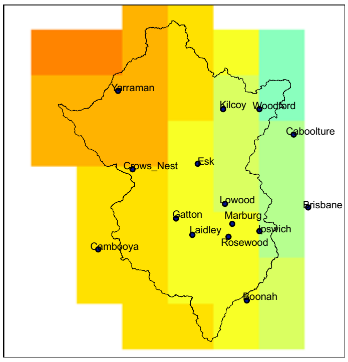
June



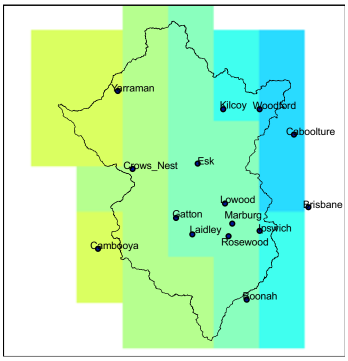
July



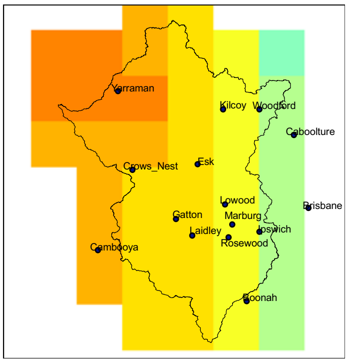
August



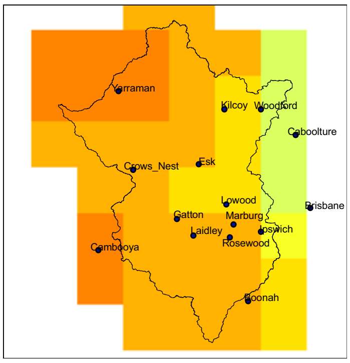
September



October



November



December

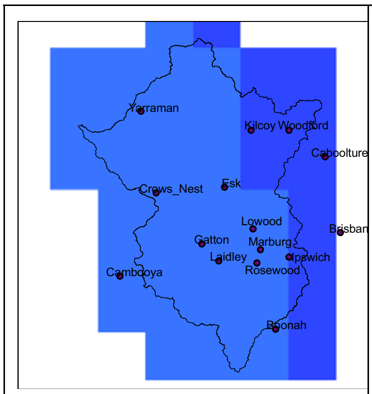
Legend

Temp Change (Degree C)

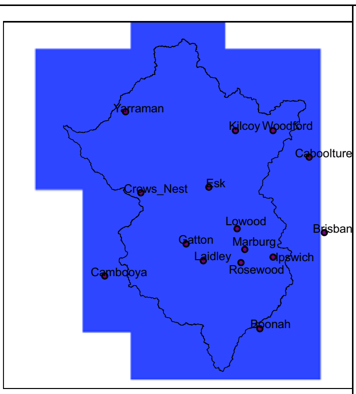
Value

🟦 0.6 - 0.7
🟦 0.7 - 0.8
🟦 0.8 - 0.9
🟦 0.9 - 1.0
🟦 1.0 - 1.1
🟦 1.1 - 1.2
🟩 1.2 - 1.3
🟩 1.3 - 1.4
🟨 1.4 - 1.5
🟨 1.5 - 1.6
🟨 1.6 - 1.7
🟧 1.7 - 1.8
🟧 1.8 - 1.9
🟥 1.9 - 2.0
🟥 2.0 - 2.1

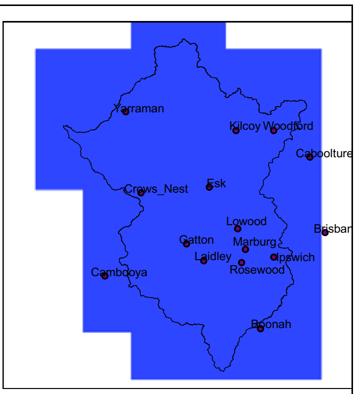
14.4 MAXIMUM TEMPERATURE – WET SCENARIO



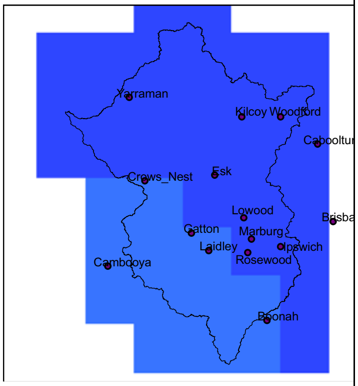
Annual



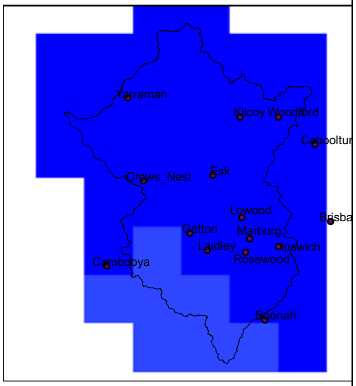
Summer



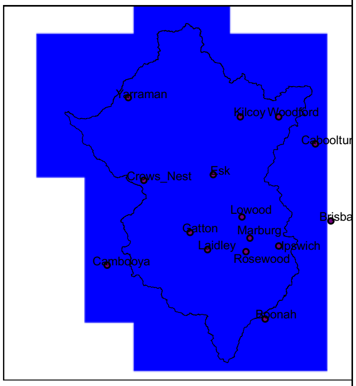
Warm Season



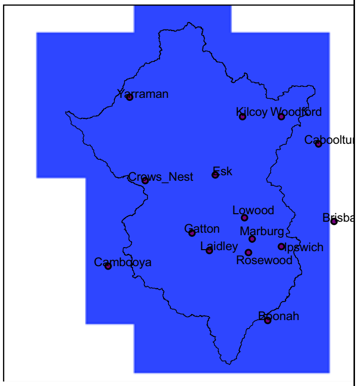
January



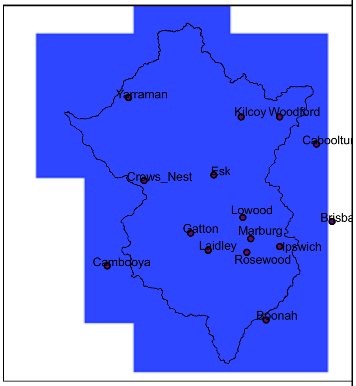
February



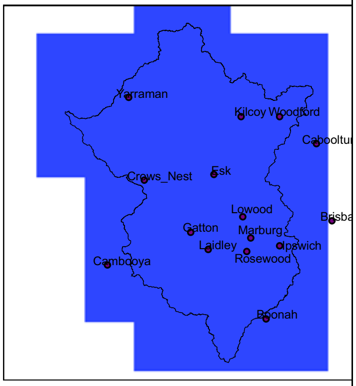
March



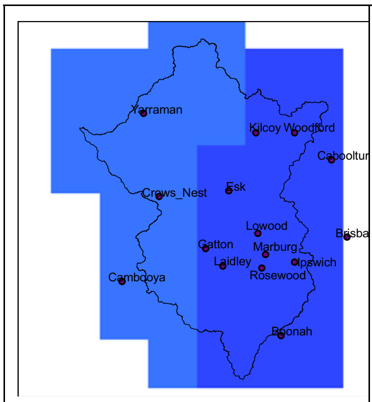
April



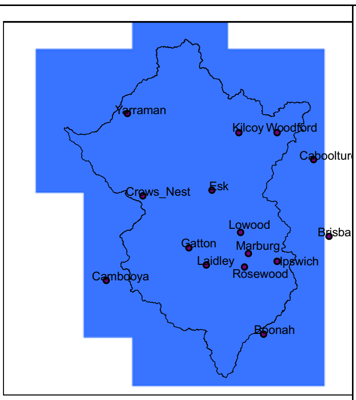
May



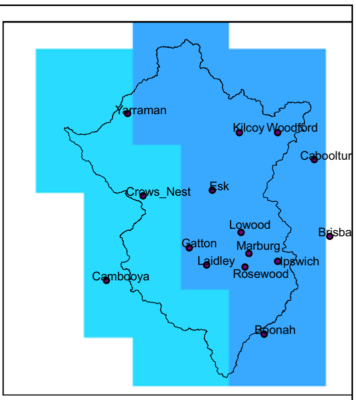
June



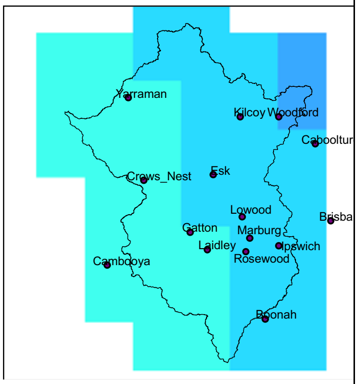
July



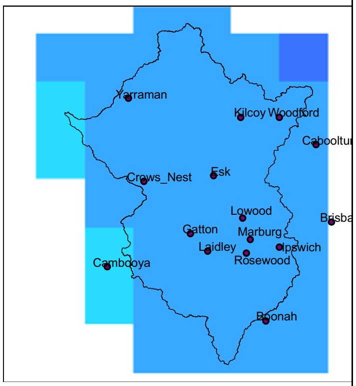
August



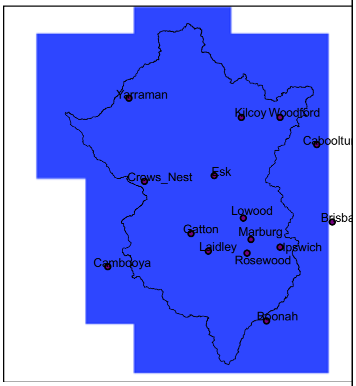
September



October



November



December

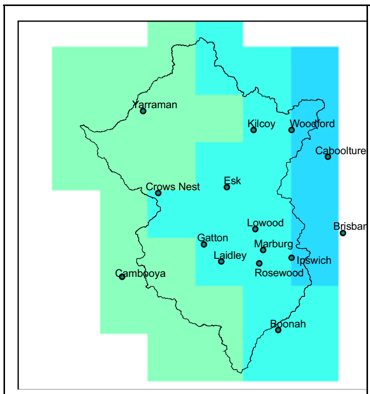
Legend

Temp Change (Degree C)

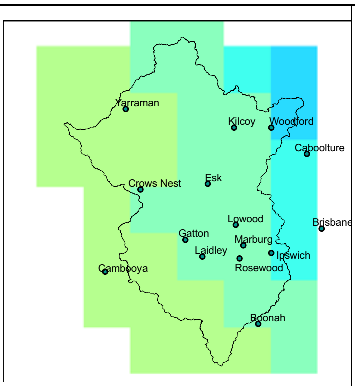
Value

🟦 0.6 - 0.7
🟦 0.7 - 0.8
🟦 0.8 - 0.9
🟦 0.9 - 1.0
🟦 1.0 - 1.1
🟦 1.1 - 1.2
🟩 1.2 - 1.3
🟩 1.3 - 1.4
🟨 1.4 - 1.5
🟨 1.5 - 1.6
🟨 1.6 - 1.7
🟧 1.7 - 1.8
🟧 1.8 - 1.9
🟧 1.9 - 2.0
🟥 2.0 - 2.1

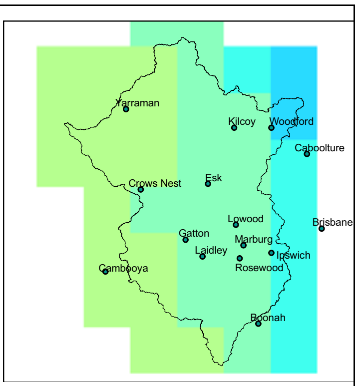
14.5 MEAN TEMPERATURE – DRY SCENARIO



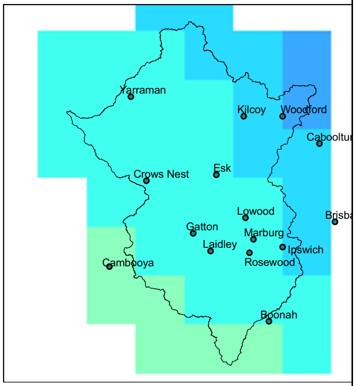
Annual



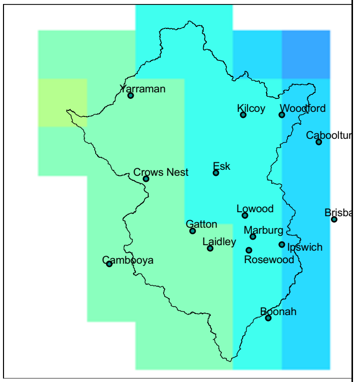
Summer



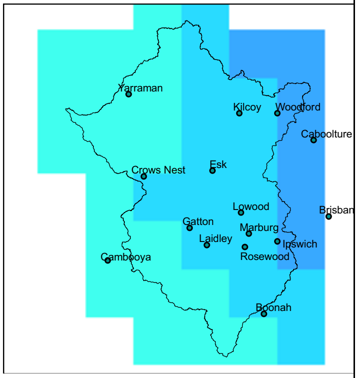
Warm Season



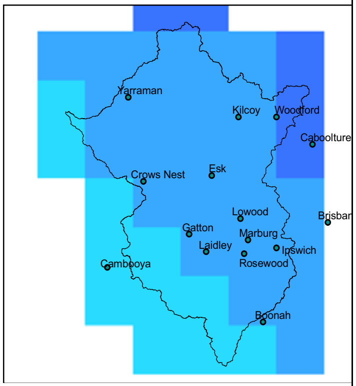
January



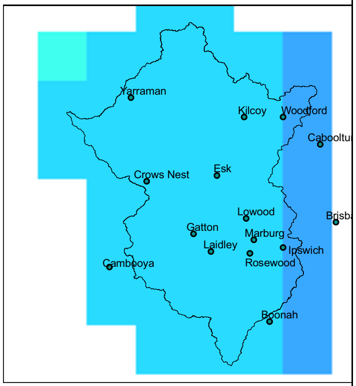
February



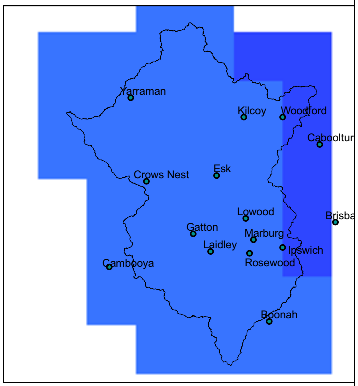
March



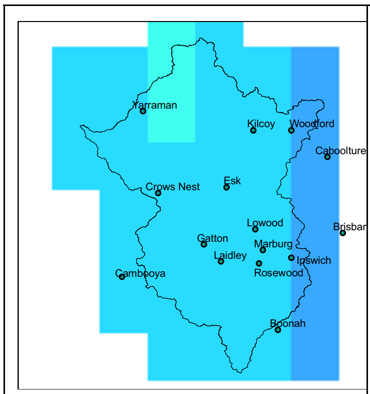
April



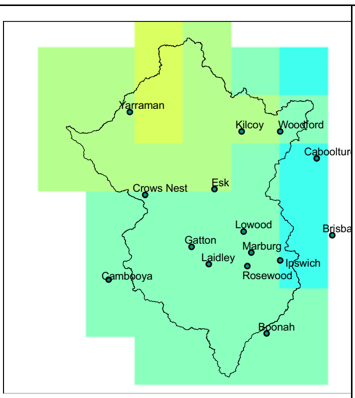
May



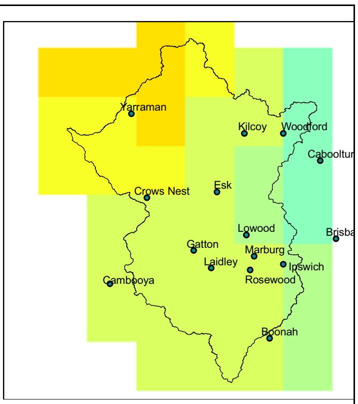
June



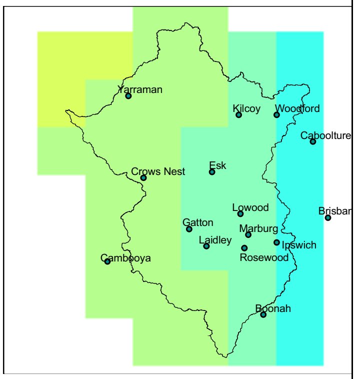
July



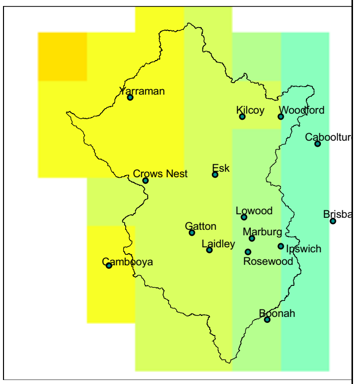
August



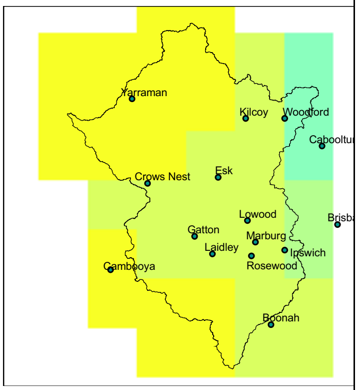
September



October



November



December

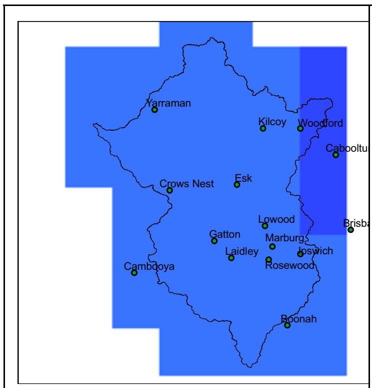
Legend

Temp Change (Degree C)

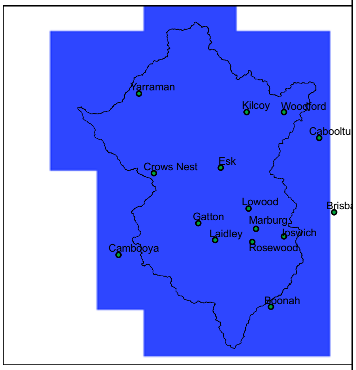
Value

🟦 0.6 - 0.7
🟦 0.7 - 0.8
🟦 0.8 - 0.9
🟦 0.9 - 1.0
🟦 1.0 - 1.1
🟦 1.1 - 1.2
🟩 1.2 - 1.3
🟩 1.3 - 1.4
🟨 1.4 - 1.5
🟨 1.5 - 1.6
🟨 1.6 - 1.7
🟧 1.7 - 1.8
🟧 1.8 - 1.9
🟧 1.9 - 2.0
🟥 2.0 - 2.1

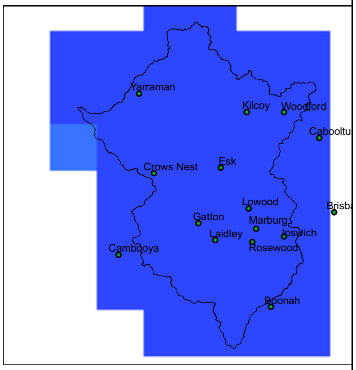
14.6 MEAN TEMPERATURE – WET SCENARIO



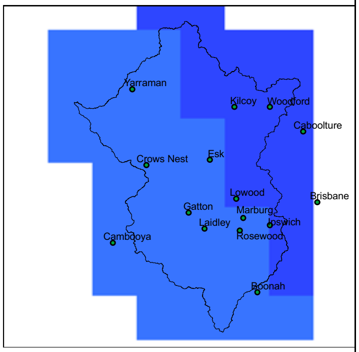
Annual



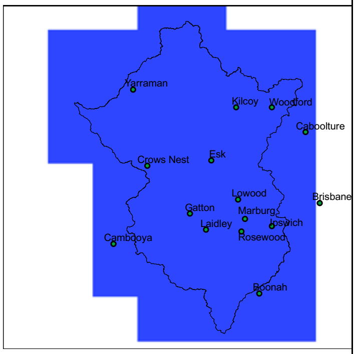
Summer



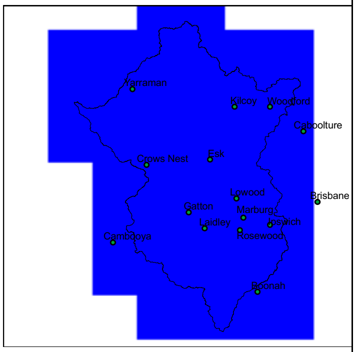
Warm Season



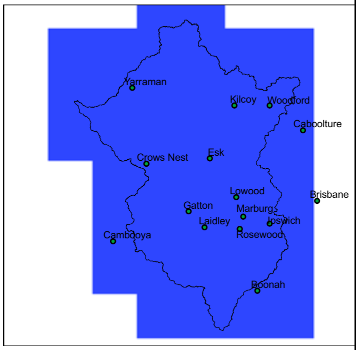
January



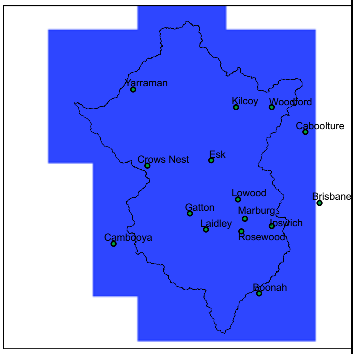
February



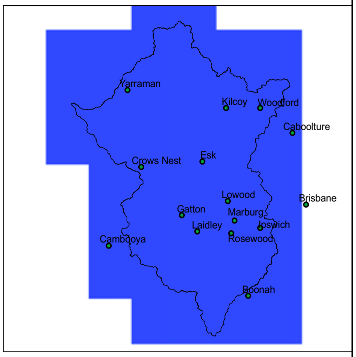
March



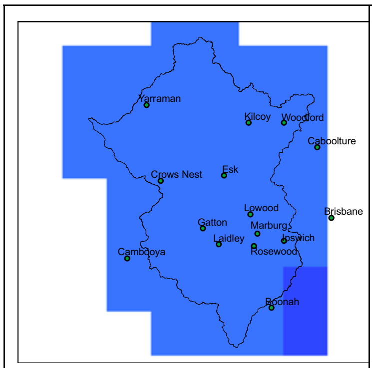
April



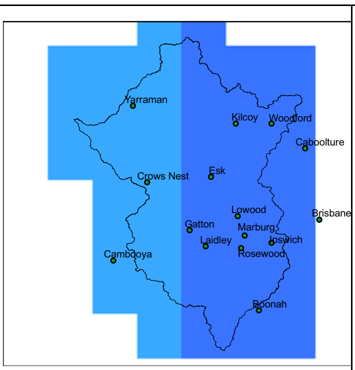
May



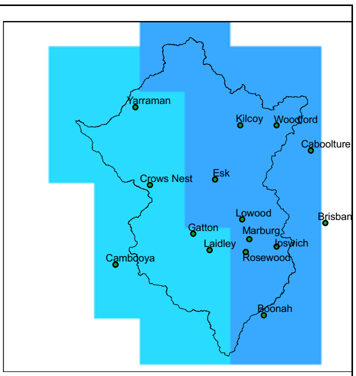
June



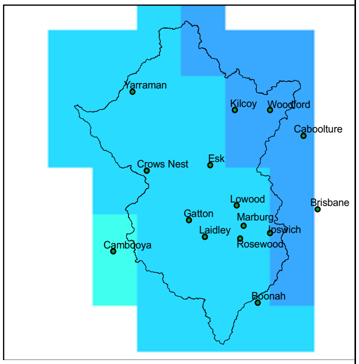
July



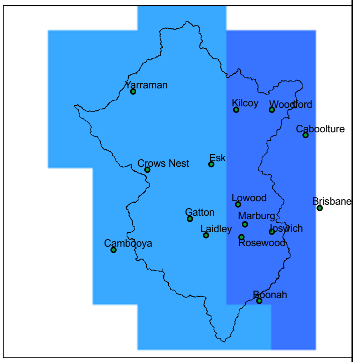
August



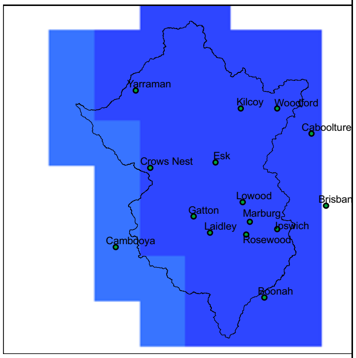
September



October



November



December

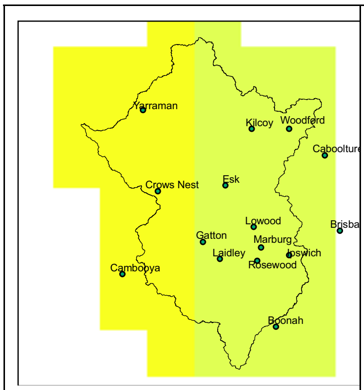
Legend

Temp Change (Degree C)

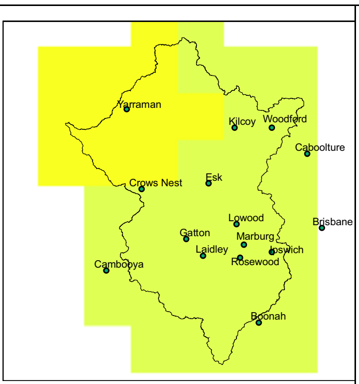
Value

🟦 0.6 - 0.7
🟦 0.7 - 0.8
🟦 0.8 - 0.9
🟦 0.9 - 1.0
🟦 1.0 - 1.1
🟦 1.1 - 1.2
🟩 1.2 - 1.3
🟩 1.3 - 1.4
🟨 1.4 - 1.5
🟨 1.5 - 1.6
🟨 1.6 - 1.7
🟧 1.7 - 1.8
🟧 1.8 - 1.9
🟧 1.9 - 2.0
🟥 2.0 - 2.1

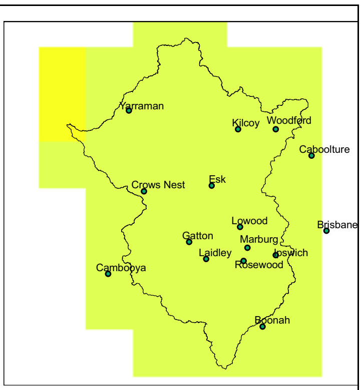
14.7 RAINFALL – DRY SCENARIO



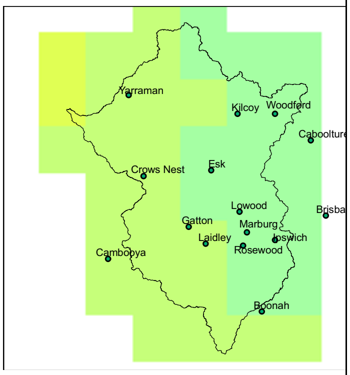
Annual



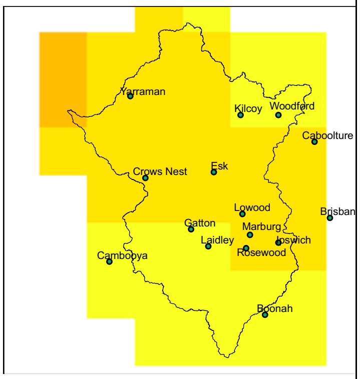
Summer



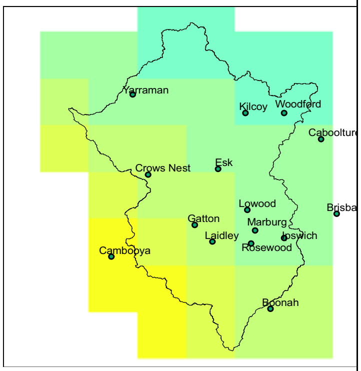
Warm Season



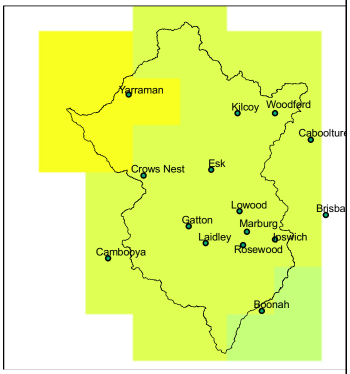
January



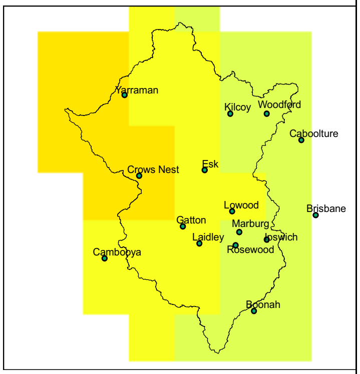
February



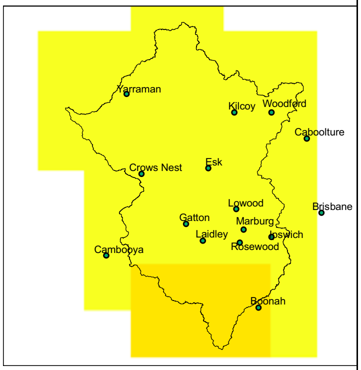
March



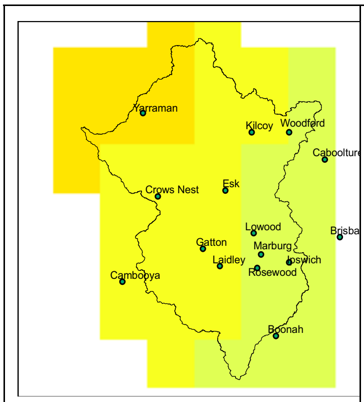
April



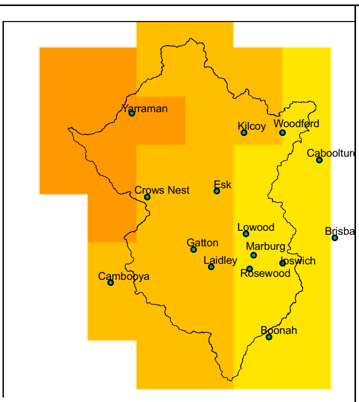
May



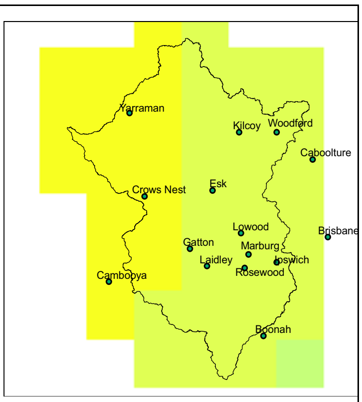
June



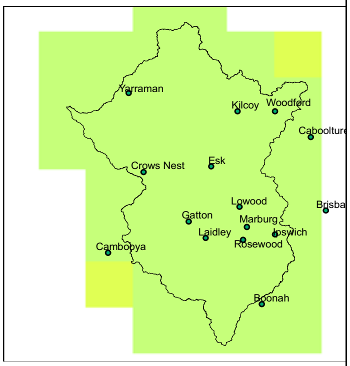
July



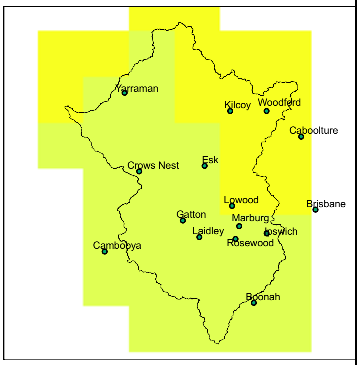
August



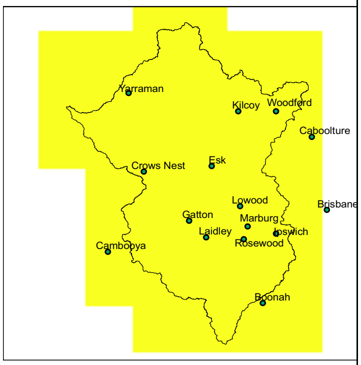
September



October



November



December

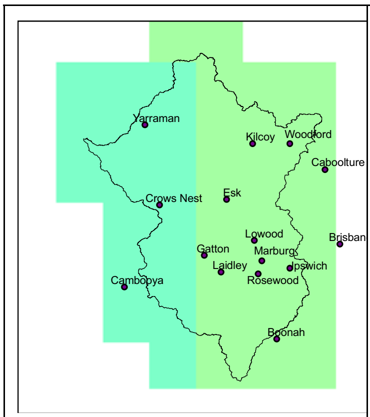
Legend

Rainfall Change (%)

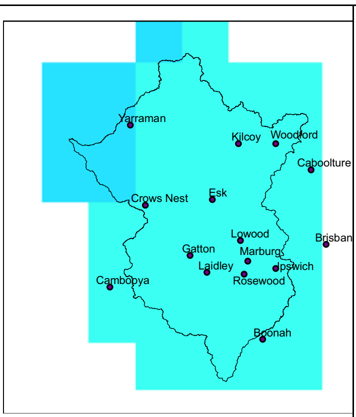
Value

🟥 -25.0 - -20.0
🟥 -20.0 - -17.5
🟧 -17.5 - -15.0
🟧 -15.0 - -12.5
🟧 -12.5 - -10.0
🟨 -10.0 - -7.5
🟨 -7.5 - -5.0
🟨 -5.0 - -2.5
🟩 -2.5 - 0
🟩 0 - 2.5
🟩 2.5 - 5.0
🟦 5.0 - 7.5
🟦 7.5 - 10.0
🟦 10.0 - 12.5
🟦 12.5 - 15.0
🟦 15.0 - 17.5
🟦 17.5 - 20.0
🟦 20.0 - 25.0

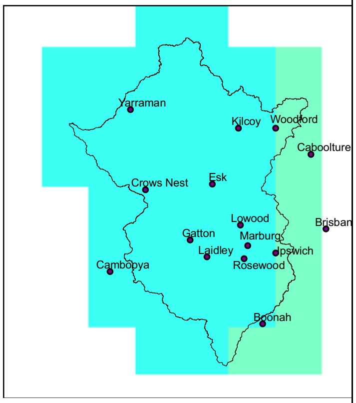
14.8 RAINFALL – WET SCENARIO



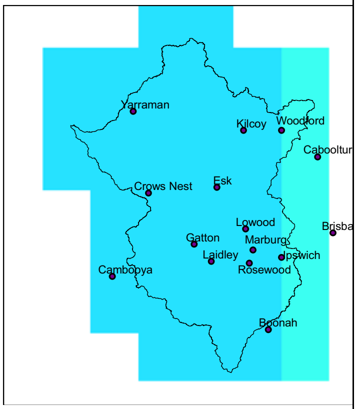
Annual



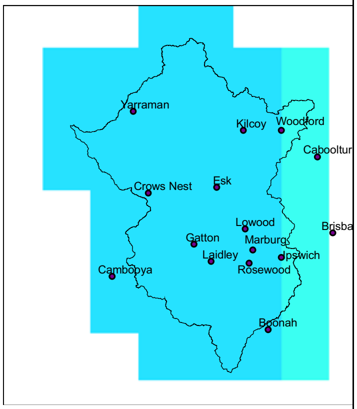
Summer



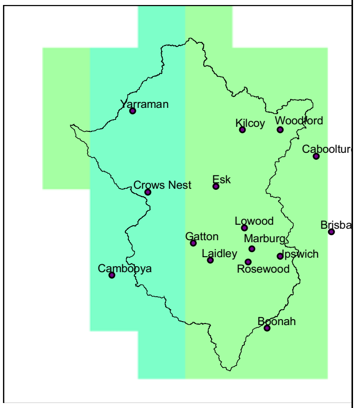
Warm Season



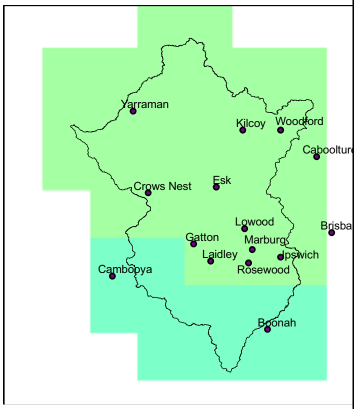
January



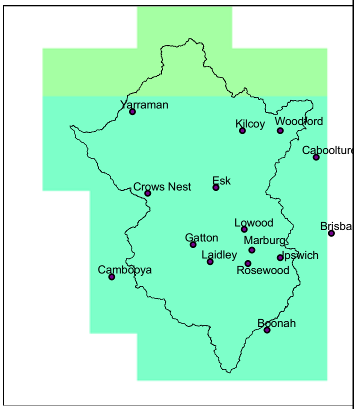
February



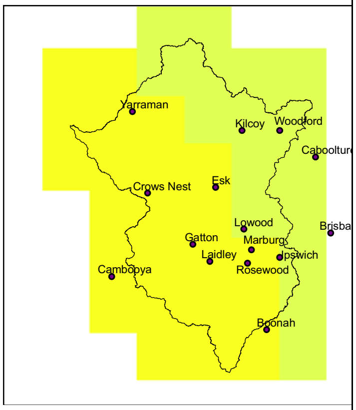
March



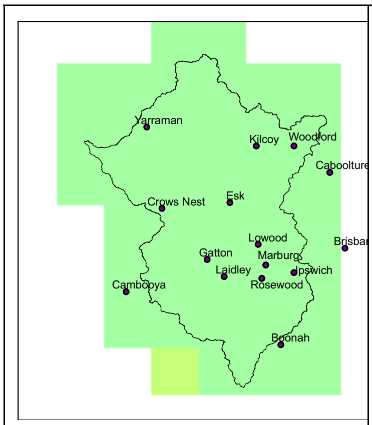
April



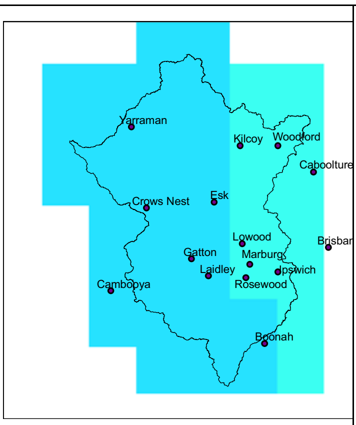
May



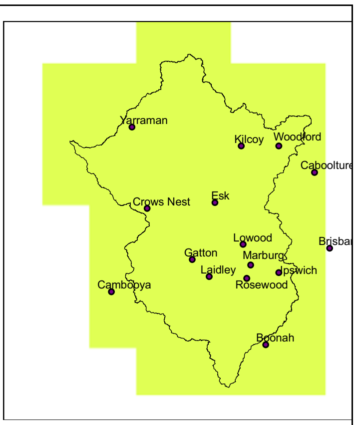
June



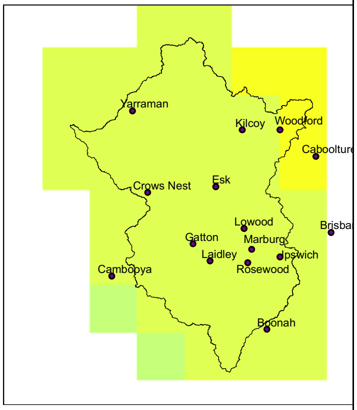
July



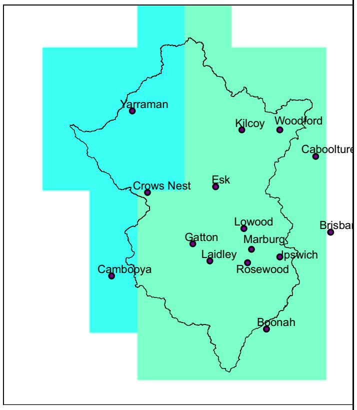
August



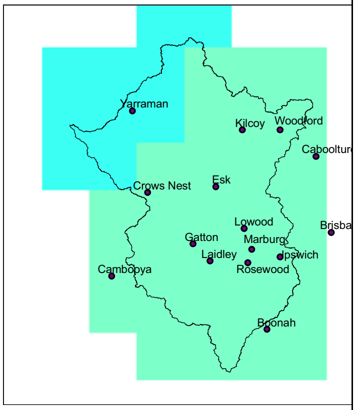
September



October



November



December

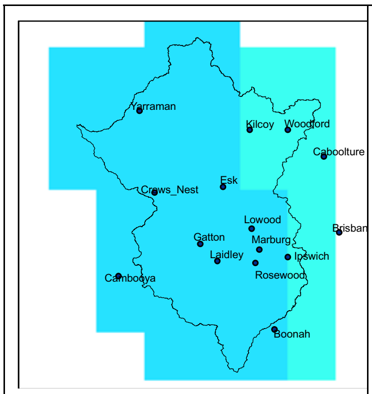
Legend

Rainfall Change (%)

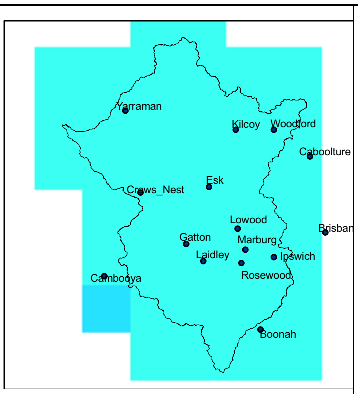
Value

🟥 -25.0 - -20.0
🟥 -20.0 - -17.5
🟧 -17.5 - -15.0
🟧 -15.0 - -12.5
🟧 -12.5 - -10.0
🟨 -10.0 - -7.5
🟨 -7.5 - -5.0
🟨 -5.0 - -2.5
🟩 -2.5 - 0.0
🟩 0.0 - 2.5
🟩 2.5 - 5.0
🟦 5.0 - 7.5
🟦 7.5 - 10.0
🟦 10.0 - 12.5
🟦 12.5 - 15.0
🟦 15.0 - 17.5
🟦 17.5 - 20.0
🟦 20.0 - 25.0

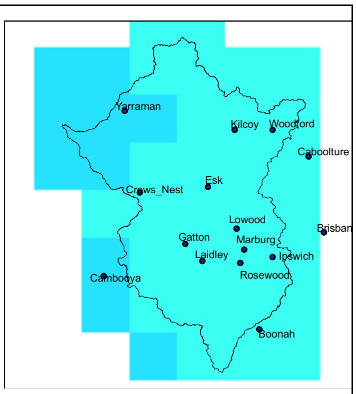
14.9 POTENTIAL EVAPORATION – DRY SCENARIO



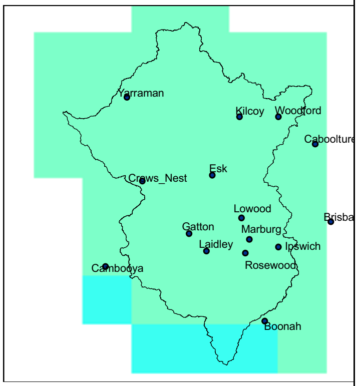
Annual



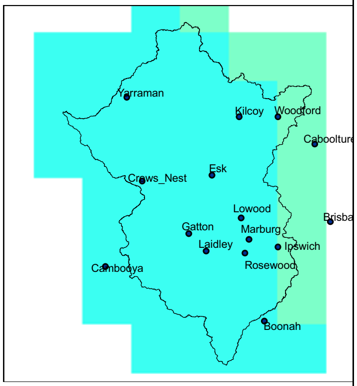
Summer



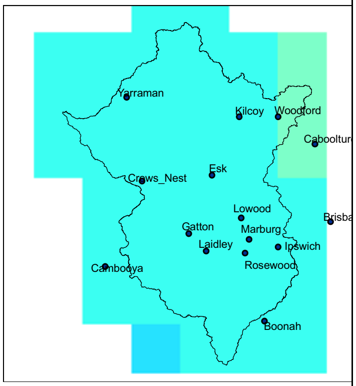
Warm Season



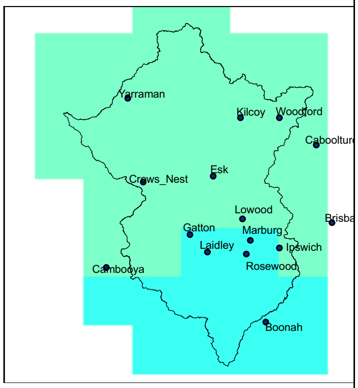
January



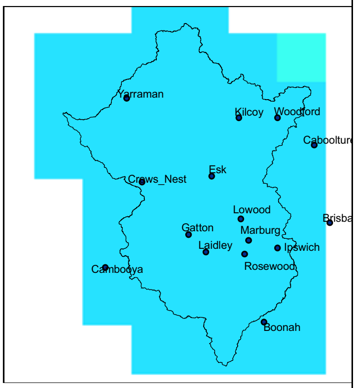
February



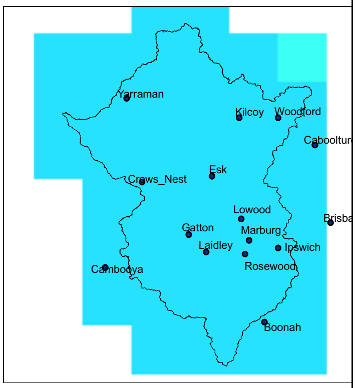
March



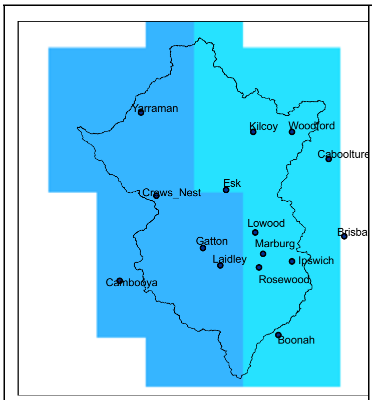
April



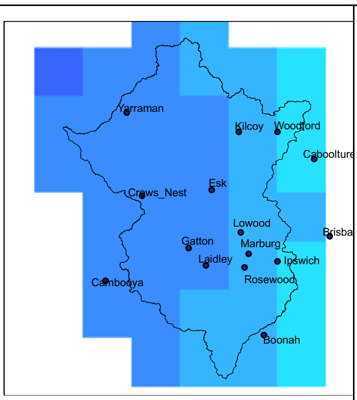
May



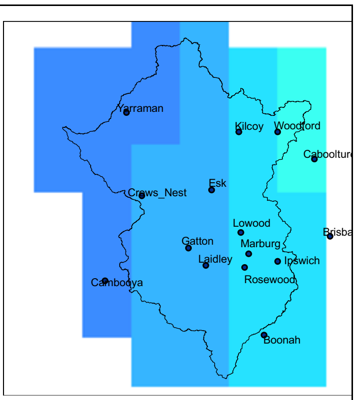
June



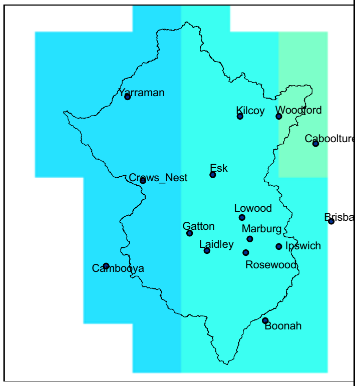
July



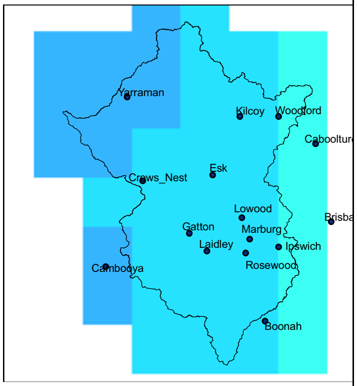
August



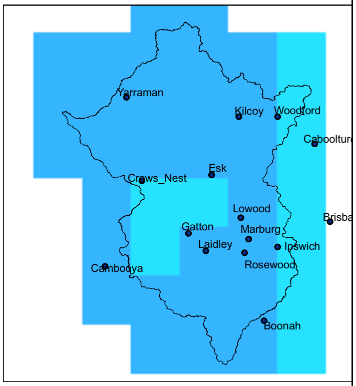
September



October



November



December

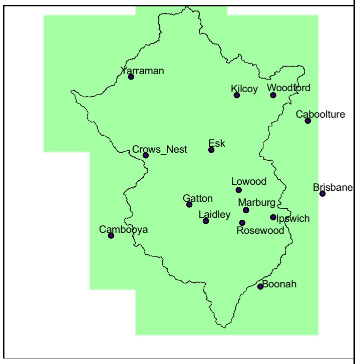
Legend

Evaporation Change (%)

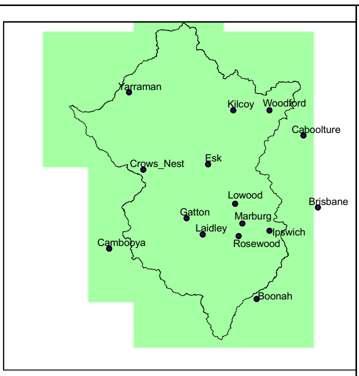
Value

🟥 -25 - -20.0
🟥 -20.0 - -17.5
🟧 -17.5 - -15.0
🟧 -15.0 - -12.5
🟧 -12.5 - -10.0
🟨 -10.0 - -7.50
🟨 -7.50 - -5.00
🟨 -5.00 - -2.50
🟩 -2.50 - 0.00
🟩 0.00 - 2.50
🟩 2.50 - 5.00
🟦 5.00 - 7.50
🟦 7.50 - 10.0
🟦 10.0 - 12.5
🟦 12.5 - 15.0
🟦 15.0 - 17.5
🟦 17.5 - 20.0
🟦 20.0 - 25.0

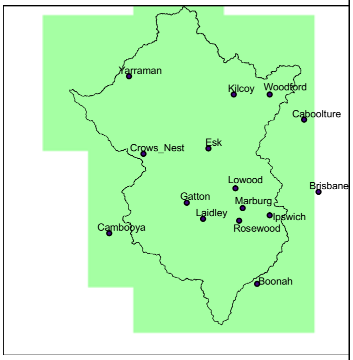
14.10 POTENTIAL EVAPORATION – WET SCENARIO



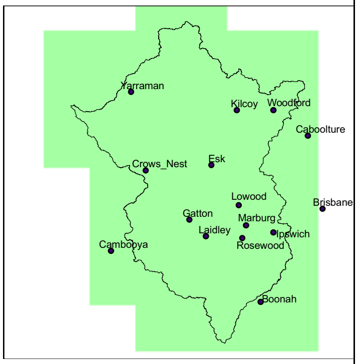
Annual



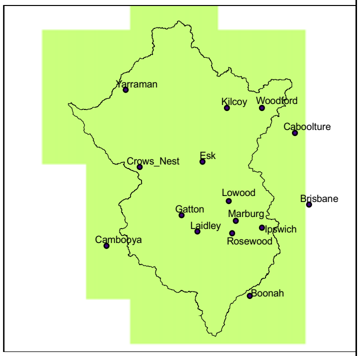
Summer



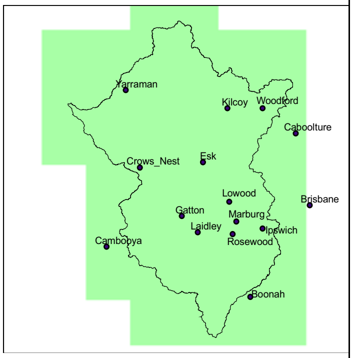
Warm Season



January



February



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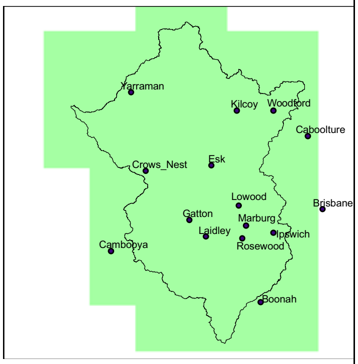

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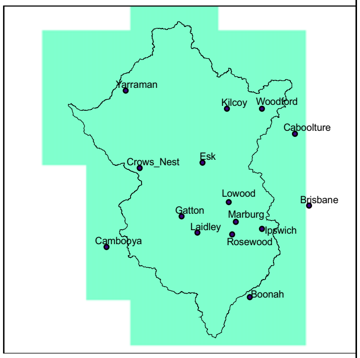

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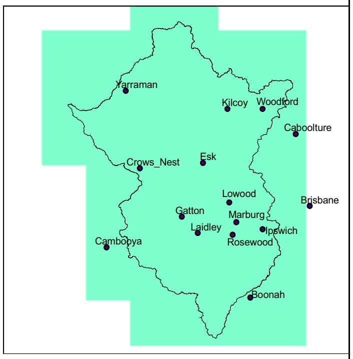

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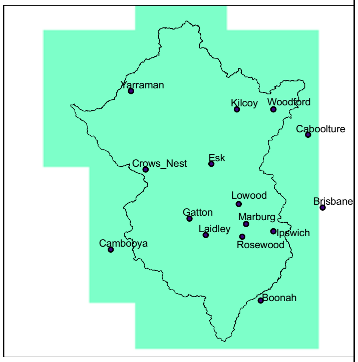

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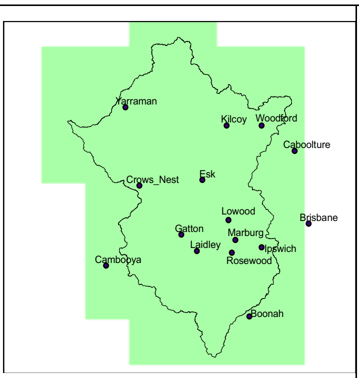

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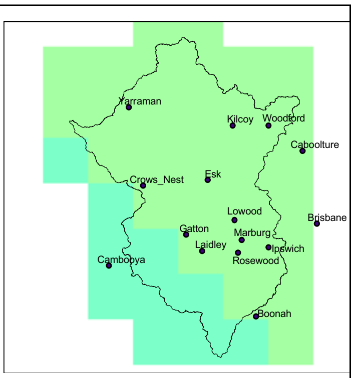

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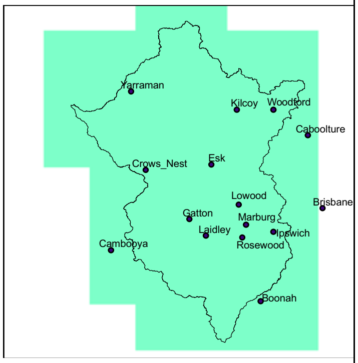

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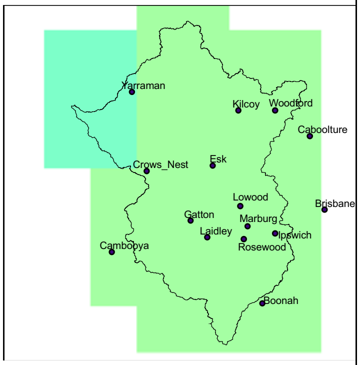
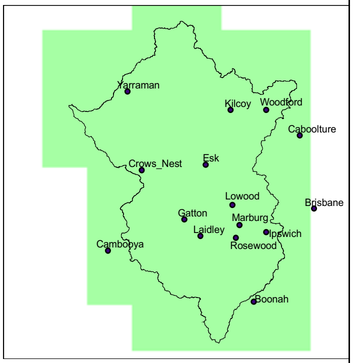


November



December

Legend

Evaporation Change (%)

Value

🟥 -25.0 - -20.0
🟥 -20.0 - -17.5
🟧 -17.5 - -15.0
🟧 -15.0 - -12.5
🟧 -12.5 - -10.0
🟨 -10.0 - -7.50
🟨 -7.50 - -5.00
🟨 -5.00 - -2.50
🟩 -2.50 - 0.00
🟩 0.00 - 2.50
🟩 2.50 - 5.00
🟦 5.00 - 7.50
🟦 7.50 - 10.0
🟦 10.0 - 12.5
🟦 12.5 - 15.0
🟦 15.0 - 17.5
🟦 17.5 - 20.0
🟦 20.0 - 25.0

16 Appendix 5 – Simulated flows downstream of Mt Crosby Weir

Simulated daily 0 to 100 percentile flows for the base, dry and wet climate change scenarios for 2030 downstream of Mt Crosby Weir (IQQM node 203). Percentage change in flow from the base scenario is shown

	Flow (ML/d)			Change in flow (%)	
Percentile	Base	Wet Scenario	Dry Scenario	Wet Scenario	Dry Scenario
100	387885	398944	385401	3	-1
99	48666	54906	36117	13	-26
95	6688	7767	3237	16	-52
92	2449	3071	1135	25	-54
90	1450	1865	534	29	-63
85	369	571	72	55	-81
80	91	151	34	67	-62
75	43	59	24	35	-45
70	28	34	18	25	-36
65	20	24	15	19	-27
60	16	19	13	13	-20
55	14	15	12	10	-15
50	12	13	11	7	-11
45	11	12	11	4	-7
40	11	11	10	3	-5
35	10	11	10	1	-3
30	10	10	10	1	-2
25	10	10	10	1	-2
20	10	10	10	0	-3
15	10	10	9	1	-2
10	9	9	9	0	-3
5	9	9	9	0	-2
0	5	5	5	0	0