Climate Change projections for the Coal River Catchment, Tasmania (Draft Final Report).

Coal River Catchment Climate Change and Hydrological Modelling

Prof Roger Stone, Mr Torben Marcussen and Dr Shahbaz Mushtaq

Australian Centre for Sustainable Catchments, University of Southern Queensland

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Executive summary

This project has selected a subset of recognised, more suitable general circulation models (GCMs) for use in regional studies of climate change for the Coal River Valley region and associated catchment. Additionally, downscaled output from the CSIRO Conformal Cubic Atmospheric Model (CCAM) has been utilised in order to dynamically downscale the results of these (five) defined, more regionally relevant, general circulation models and also following Climate Futures Tasmania's recent report (CFT, 2009). 'Raw output' from the models suggested in the Climate Futures Tasmania report provided a useful data set that could be applied for precipitation, temperature, and hydrological analyses. However, complementary model analyses and associated output, applying a number of additional models and approaches, has also been set up for any ongoing or follow-up needs from this report.

Temperature projections from all five 'more suitable' GCM models utilised and analysed suggest an increase in regional maximum and, especially minimum temperatures, for this catchment over the scenario periods. Outputs from the models selected are generally consistent in suggesting mean maximum temperature over the region is likely to increase by 4% to 6% (1.0°C - 1.2°C) by 2010-2030 (A2 emission scenario). The lower emission scenario, B1 emission scenario, also shows an increase in the maximum temperature, albeit less pronounced compared to the A2 emission scenario. Minimum temperatures are projected to increase by 13% to 16% on a yearly basis and, notably, between 29% and 49% during winter.

Although five, more suitable, climate change models were selected (as per CFT, 2009) due to their capability in reproducing known climate drivers and known local rainfall variability, considerable variations in projected seasonal and monthly rainfall have been identified under the A2 Emission Scenario. Therefore, these model outputs are presented with required caveats. An appraisal of these model outputs of projected rainfall, suggest potential for an increase in rainfall through January-March-April for this region but, conversely, for a potential likely decrease in precipitation for this region for the May-through-November period when the overall outputs are considered.

The combined impacts of increasing temperature, potential increases in evapotranspiration, and possible reduction in winter rainfall may impose a strain on already stretched water resources in the Coal River catchment during that period. Streamflow projections using the approach presented here suggests enhanced summer (January-March) flow but reduced winter (July to September) flow with implications for water storage management and value to growers and producers.

The reduction in rainfall in late autumn through to early summer together with projected increase in minimum temperature has implications for cropping systems in Coal River Catchment, particularly for horticultural crops, but possibly with windows of opportunities for summer cropping systems.

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Background

Climate change poses significance threats to water availability in Australia. Projections from climate change models suggest that rainfall, especially during autumn, winter, and spring in many parts of Australia, is likely to decrease as a result of climate change (Pittock, 2003). This decrease in rainfall will likely be amplified in runoff. Higher temperature and potentially higher evaporation will also lead to reduction in runoff (streamflow) in many seasons in most regions. This likely reduction in runoff requires a significant planning response and potential change in the way water management systems are managed.

Anticipating the impacts of climate change on the availability and rational use of water resources is critical to the development of water management in Tasmania (CSIRO, 2009a). Until recently, climate projections available to the catchment and river basins systems were developed at global and national scales and provided little clarity or certainty around climate change and so could not adequately inform risk management assessments and approaches. This is also the case in Tasmania where most global climate models have only been represented as one or two points of information on the world map, restricting their usefulness in local planning (Climate Futures for Tasmania, 2009). Therefore, more precise assessment, using the most appropriate climate change modelling systems and downscaling systems may provide considerable input and opportunity into strategic planning needs for the region.

Coal River Catchment climate change and hydrological modelling objective

The Coal River Catchment climate change modelling component aims to generate greater understanding of climate change (rainfall, temperature, evapotranspiration, wind flow and radiation) and streamflow (runoff) pattern relevant to farmers in the Coal River Valley Area under a range of future time periods (2040, 2070 and 2100) under various greenhouse gas (GHG) emission scenarios.

Methodology

This project incorporates the world's more suitable climate change and hydrological models that provide appropriate probability distributions of rainfall patterns (monthly, seasonal and yearly) together with run-off/streamflow projections for the Coal River Catchment for specific time horizons.

Modelling approach: Conceptual framework

The modelling strategy of this project is provided in Figure 1. The first steps depicted in the sequence of Figure 1 are those represented in an in-depth understanding of current and historical trends in rainfall, temperature, participation and streamflow. This will be accomplished using descriptive and statistical analysis using historical and current data. The second step in the sequence of Figure 1 is in the development of relevant and appropriate scenarios. The development of these scenarios is based on the key characteristics of historical trends, industry and stakeholders requirements. The third step is the selection of the most appropriate climate change models (selected from a careful analysis of the scientific literature and interaction with key scientists in this field) that are suitable for application to the study area. This is based on the comprehensive review of literature, performance evaluation of major climate change forecast models and applicability of the models in the study area.

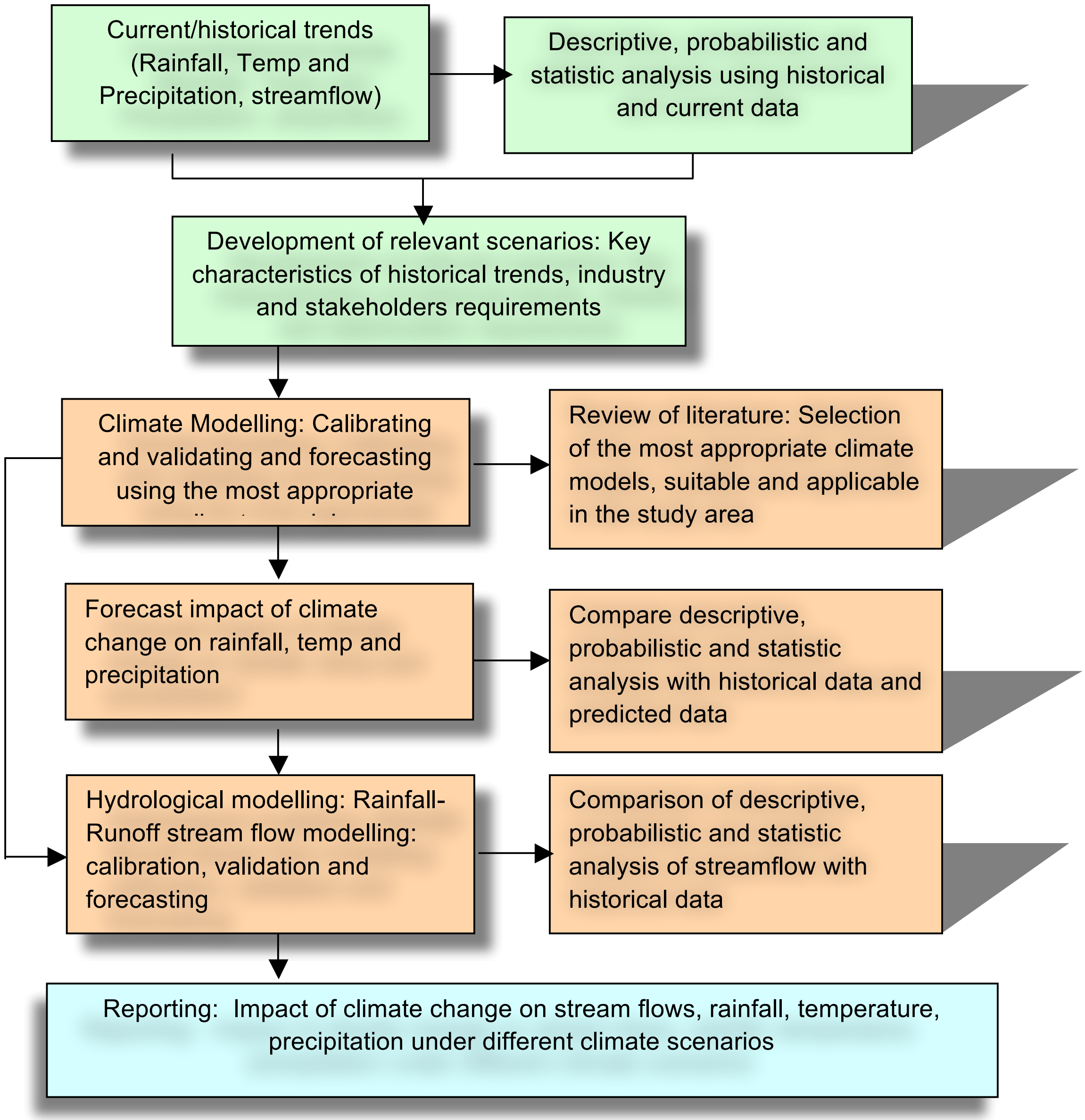


Figure 1. Modelling strategy for evaluating the impact of climate change on water resources in the Coal River Catchment (ACSC, 2009).

Steps 3-4 involve calibration and validation of the most appropriate climate models. These climate projections are compared, in terms of their probability distributions and statistical significance, with relevant historical trends to further identify the prominent climate change trends and patterns. The projected climate data are further integrated into hydrological models in step 5. These models include 'Sacramento' and 'SimHyd', to forecast streamflows in the region. This projected streamflow is compared with historical flows in order to identify key streamflow patterns.

The final step of the modelling strategy is to develop the management and policy implication, and reporting. The adopted approach provides a consistent way of modelling historical runoff in the Coal River Catchment and assessing the potential impacts of climate change and development on future runoff.

Climate modelling

Initially, the project proposed selection of the most appropriate climate change models employing the Suppiah *et al.* (2007a, b) approach to provide projections of regional scale climate outputs for the Coal River Catchment, which would be used as a foundational dataset for use in designing and implementing future water and NRM related investments.

While the Intergovernmental Panel on Climate Change (IPCC) provides outputs compiled from a suite of a large number of climate models (general circulation models (GCMs)) or from a suite of models weighted for their capability in reproducing observed rainfall and temperature patterns across Australia, Suppiah *et al.* (2007a, b) provide a useful approach employing 'demerit points' for certain models as a means of deleting lesser performing models and potentially providing a more useful output for industry. In this approach, a high number of demerit points are allocated for models that do not reproduce known circulation patterns or climate 'drivers', observed rainfall and temperature patterns in Australia as well as a total appraisal of the allocation of demerit points across a wider range of indicators. However, in this instance, as CFT have already developed appropriate downscaling approaches for a number of similar (but not identical) model outputs, it was decided to utilise the approach of Suppiah (2007a) for any follow-up supplementary studies that may be required. The downscaled data available from CFT were then assessed as suitable for integration into hydrological modelling. Additionally, the downscaled data sets were analysed in a larger comprehensive manner for the Coal River Valley Catchment. In addition to CFT detailed climate assessment, the CSIRO Tasmania Sustainable Yields Project also provides critical information on current and likely future climate and water availability (CSIRO, 2009 a,b).

The details of CFT climate modeling are given in (http://www.acecrc.org.au/drawpage.cgi?pid=climate_futures). CFT employed six global climate models/general circulation models from IPCC (Table 1) under 2 SRES emission scenarios — A2 (high) & B1 (low) — to generate climate projections from 1961-2100. The selection of the GCM models are based on optimal performance of GCM models on their ability to reproduce observed variability and known atmospheric and circulation 'drivers' for the region.

Table 1 Selected GCMs for the Coal River Catchment

GCM Model	Description
Hadley Centre (UK)	HADCM3
Geophysical Fluid Dynamics Laboratories (US)	GFDL2.0 -also referred to as GFCM2.0.
Geophysical Fluid Dynamics Laboratories (US)	GFDL2.1 -slightly different structure to GFDL2.0 - also referred to as GFCM2.1
Center for Climate System Research (CCSR), Japan	MIROC 3.2
Max Planck Institute for Meteorology DKRZ	ECHAM5 - also referred to as MPEH5.

Down scaling

CSIRO's Conformal Cubic Atmospheric Model (CCAM) was used to dynamically downscale the results of six global climate models over Tasmania. The CCAM model downscales GCM model outputs by taking into account of Tasmania's complex topography and maritime influences on weather and climate.

The CCAM dynamical downscaling process uses a stretched-grid global model with forcing data taken from a host GCM to generate a fine-scale dynamical model over the area of interest (White et al., 2010; Katzfey et al., 2009). A two stage downscaling process was employed to achieve fine scale resolution. The first stage involved downscaling from the host GCM to a grid with the high resolution face of the cubic conformal grid covering all of Australia at a resolution of approximately 0.5o. The second stage placed the high-resolution face over Tasmania and the Bass Strait islands at an approximate resolution of 0.1 o (White et al., 2010). In addition, in order to better handle extreme events, model outputs were bias adjusted using percentile binning method (Corney et al., 2010).

Hydrological modelling: Rainfall-runoff modelling

Two commonly used 'lumped conceptual rainfall-runoff models', SimHyd and the 'Sacramento Model', were used to simulate and project streamflow for the Coal River Catchment. Both SimHyd and Sacramento models have been used effectively in Australia and internationally (ACSC, 2009; CSIRO, 2008; Chiew et al., 2008; Franz el al., 2003; Peel et al., 2002; Chiew and McMahon, 1993; Chiew and Siriwardena, 2005).

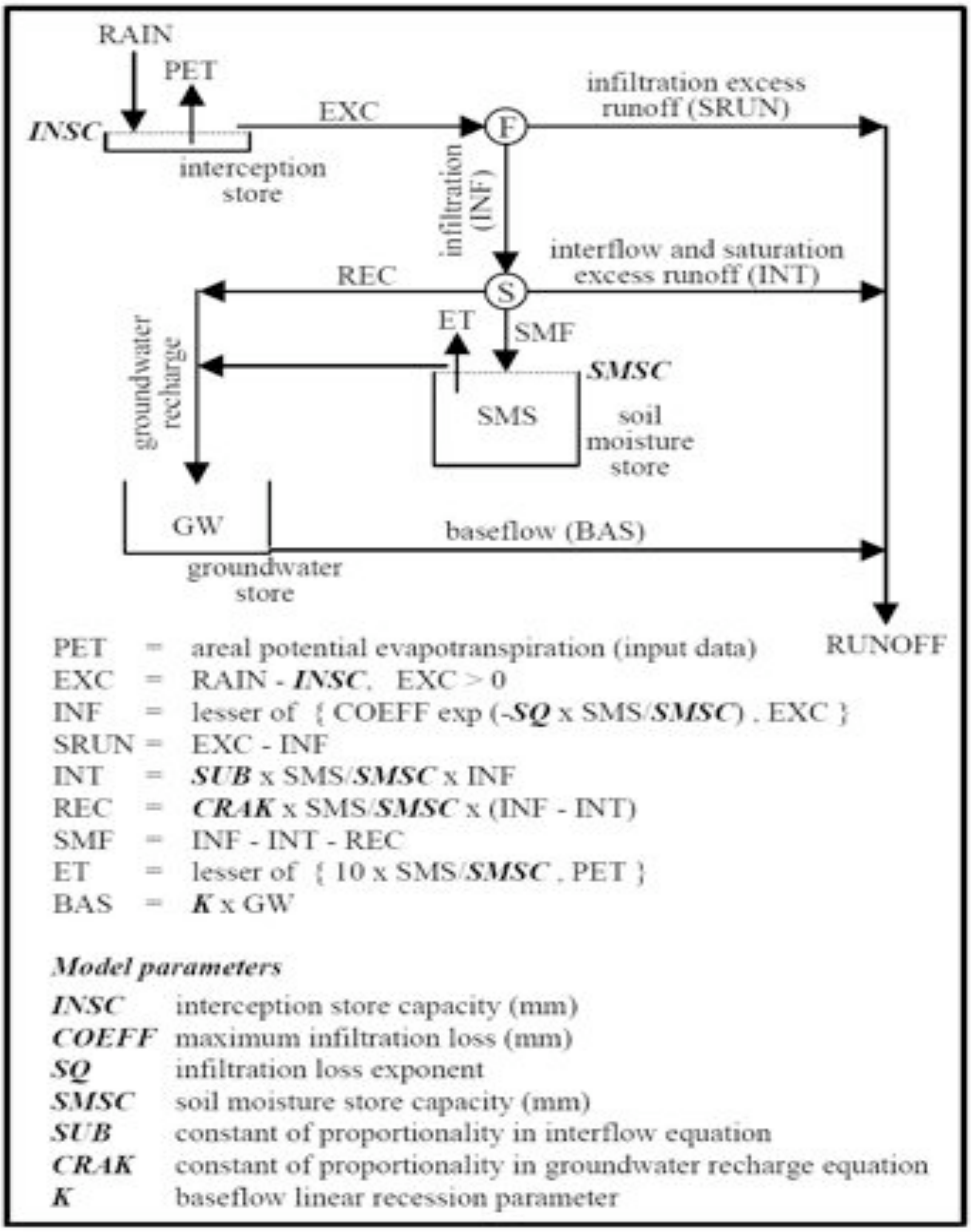
SimHyd, is a simplified version of the daily conceptual rainfall-runoff model HYDROLOG. It is a daily conceptual rainfall-runoff model that estimates daily stream flow from daily rainfall and areal potential evapotranspiration data. The SimHyd model does not only have a simpler structure, fewer parameters, but also have significant advantages of accuracy, flexibility, and ease of use (Peel et al., 2000; 2002)

The structure of SimHyd is shown in Figure 2 with its seven parameters highlighted in bold italics. In SimHyd, daily rainfall first fills the interception store, which is emptied each day by evaporation. The excess rainfall is then subjected to an infiltration function that determines the infiltration capacity. The excess rainfall that exceeds the infiltration capacity becomes infiltration excess runoff. Moisture that infiltrates is subjected to a soil moisture function that diverts the water to the stream (interflow), groundwater store (recharge) and soil moisture store. Interflow is first estimated as a linear function of the soil wetness (soil moisture level divided by soil moisture capacity).

The equation used to simulate interflow therefore attempts to mimic both the interflow and saturation excess runoff processes (with the soil wetness used to reflect parts of the catchment that are saturated from which saturation excess runoff can occur). Groundwater recharge is then estimated, also as a linear function of the soil wetness. The remaining moisture flows into the soil moisture store. In the model calibration, the six parameters in SimHyd are optimised to maximise an objective function that incorporates the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) of monthly runoff and daily flow duration curve. The resulting optimised model parameters are therefore identical for all cells within a calibration catchment.

The Sacramento soil moisture accounting model (Burnash et al., 1973; Burnash, 1995) is a continuous rainfall-runoff model used to forecast daily streamflow from rainfall and evaporation records. The model is deterministic, continuous, and non-linear, having two soil layers, an upper and a lower zone.

Each layer includes tension and free water storages, which interact to generate soil moisture states and five runoff components. Rainfall first fills the upper zone tension water storage. The rainfall volume exceeding the tension water capacity, UZTWM, generates the excess rainfall. This excess rainfall goes into the free water storage tank from which it can percolate to the lower zone or flow out as interflow. After satisfying the percolation demand and interflow withdrawal, any water in excess of the UZFWM will form surface runoff.



PET = areal potential evapotranspiration (input data)
EXC = RAIN - ***INSC***, EXC > 0
INF = lesser of { COEFF exp (-***SQ*** x SMS/***SMSC***) , EXC }
SRUN = EXC - INF
INT = ***SUB*** x SMS/***SMSC*** x INF
REC = ***CRAK*** x SMS/***SMSC*** x (INF - INT)
SMF = INF - INT - REC
ET = lesser of { 10 x SMS/***SMSC*** , PET }
BAS = ***K*** x GW

Model parameters

INSC	interception store capacity (mm)
COEFF	maximum infiltration loss (mm)
SQ	infiltration loss exponent
SMSC	soil moisture store capacity (mm)
SUB	constant of proportionality in interflow equation
CRAK	constant of proportionality in groundwater recharge equation
K	baseflow linear recession parameter

Figure 2. Structure of the conceptual rainfall-runoff model SIMHYD (Source: Peel et al. 2000)

The rate of this generated runoff depends on the capacity of the lower zone tension water, LZTWM, and free water, LZFSM and LZFPM storages. The surface runoff generated from each of the free water storages depends on the depletion coefficients in the upper zone, UZK and the lower zone LZSK and LZPK. The percolation rate to the lower zone is a nonlinear function of upper zone and lower zone storages and is controlled by two parameters, ZPERC, which is the maximum rate of the percolation and REXP, which is an exponent that defines the shape of the percolation curve. As mentioned above, the lower zone water is divided among three tanks, consisting of free and tension components. The parameter PFREE is the fraction of the lower zone water going to the free water storages. Fig. 3 shows a schematic of the SAC-SMA model.

The Sacramento model has 17 parameters, but in the application here, only 13 parameters are optimised (ADIMP, LZFPM, LZFSM, LZPK, LZSK, LZTWM, PFREE, REXP, SARVA, IZFWM, UZK, UZTWM, ZPERC) plus one unit hydrograph parameter, with the other four parameters set to default values (PCTIM=0, RSERV=0.3, SIDE=0, SSOUT=0).

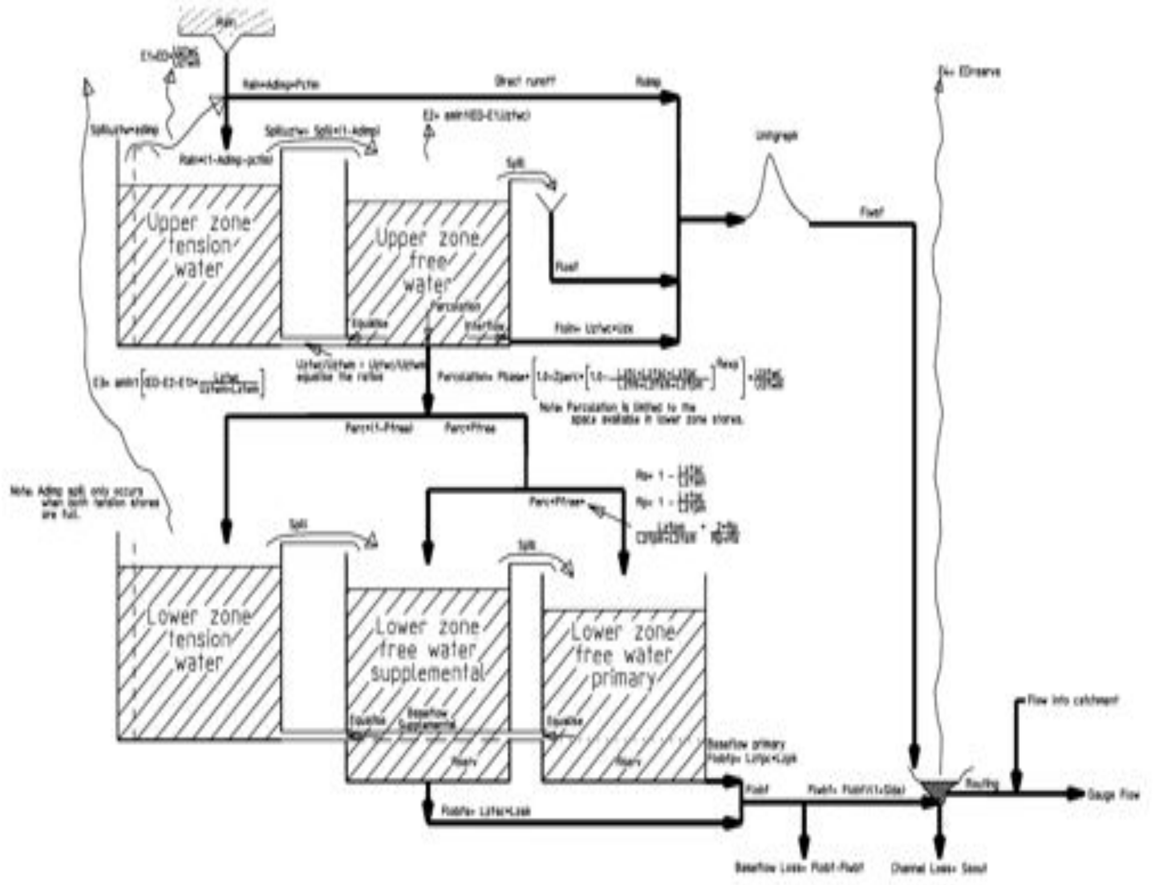


Figure 3. Structure of conceptual Sacramento soil moisture accounting model

Calibration and cross validation

The calibration is conducted to assess whether Sacramento and SimHyd can be calibrated successfully. The cross validation is conducted to assess whether the calibrated parameter values can be used to successfully estimate streamflow for an independent test period that is not used to calibrate the model.

Sacramento and SimHyd run on a daily time step but they are calibrated against monthly streamflow. The entire recorded monthly runoff record is used to calibrate models. The models parameters are optimized to reduce an objective function defined as the sum of squared differences between the estimated and recorded monthly streamflows (Equation 1).

$$OBJ = \sum_{i=1}^{n} \left(EST_i - REC_i\right)^2 \tag{1}$$

where OBJ is the objective function, EST is the estimated monthly streamflow, REC is the recorded monthly streamflow and n is the number of months of recorded monthly streamflow. Since the calibrated model is to be used for streamflow record extension, extra effort is made to ensure that the calibrated model is able to reproduce some of the basic summary statistics of the recorded streamflow.

Assessing model performance

The performance of the model was assessed by measuring the coefficient of efficiency (E). The coefficient of efficiency describes the proportion of recorded streamflow variance that is described by the model (Nash & Sutcliffe, 1970). The coefficient of efficiency was estimated by the Equation 2.

$$E = \frac{\sum \left(REC_i - \overline{REC}\right)^2 - \sum_{i=1}^{n} \left(EST_i - REC_i\right)^2}{\sum_{i=1}^{n} \left(REC_i - \overline{REC}\right)^2} \tag{2}$$

where $\overline{REC}$ is the mean recorded streamflow. The coefficient of efficiency is related to the objective function described in Equation 1, in that a low value of the objective function will produce a high value of E and vice versa. If the model exactly reproduced all the recorded monthly streamflow then E would equal 1. The coefficient of efficiency is a dimensionless number, unlike the objective function and is therefore useful for comparisons of model performance across catchments.

Available Simulations and Data

The study area has been determined to be between longitudes 145. 43 and latitude -42.4, -42.6 The Coal River Catchment has about 8 streamflow gauging sites, however currently four stream gauging sites are operational. The historical streamflow data for the current following current gauging sites (Table 2) were collected from Water Information System in Tasmania (WIST).

Table 2 Stream flow monitoring sites in the Coal River catchment

Site	Site Name	Area (km^2)	Start record	End record
3203	Coal River at Baden	53	13/07/1971	Current
3206	Coal River downstream Craigbourne Dam	247	20/10/1986	Current
3208	Coal River at Richmond	536	07/06/1989	Current
3209	White Kangaroo Rt upstream Coal River	110	08/05/1990	Current

The CFT project has analysed more than 140 climate variables for each grid cell (including rainfall, minimum and maximum temperature, evaporation, radiation, wind). The project has generated more than 75 terabytes of modelling output, which consists of recorded data 6 hourly, with 6 minute data available for 15 sites.

The CFT climate and hydrological models outputs are available for this proposed project. The key output includes:

- Bias-adjusted Australian Water Availability Project gridded observation dataset
- 14 km (0.1° grid) - 6 models x 2 scenarios
- 60 km (0.5° grid) - 6 models x 2 scenarios
- Ensemble (0.1° grid) - 1 model, 1 scenario x 3 runs
- Downscaled global pressure observations

Study area and its characteristics

The Coal River catchment (Figure 4) is located in the southeast of the state and occupies an area of approximately 630 km^2. It is bordered by the Little Swanport and Prosser River catchments in the east, the Jordan River catchment in the west, and the Macquarie River catchment in the north (DPIWE, 2003).

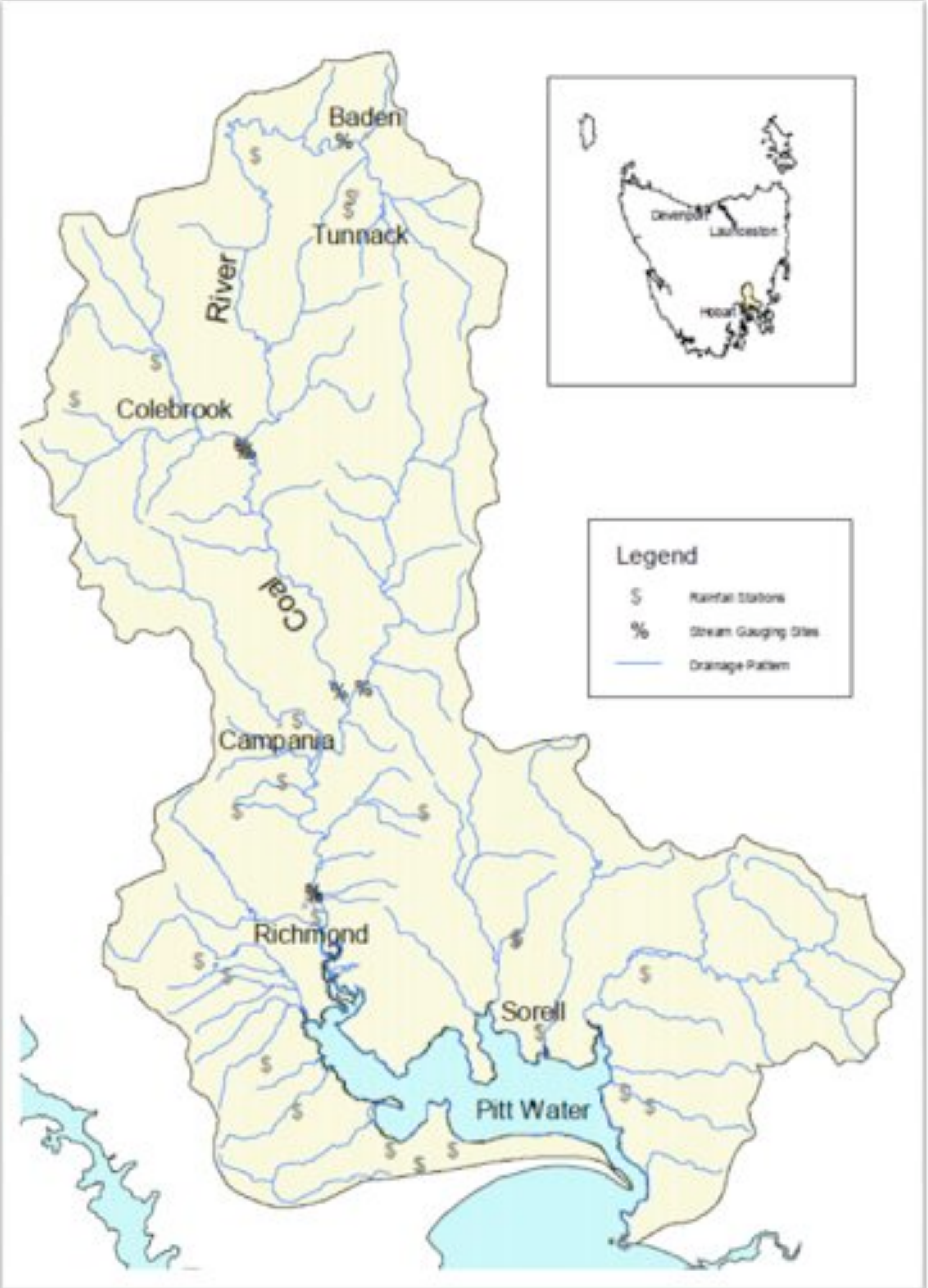


Figure 4. Location and hydrological set up of the Coal River catchment. Source: (DPIWE, 2003).

The geological history of the Coal catchment has a major influence on the soil types and where they occur as well as the present day topography and landforms as rock type strongly influences erosion, drainage and consequently land use activities (DPIWE, 2003).

Land Use

The key industry in the catchment is agriculture. The area has a very favourable climate for the production of cool temperate crops. The development of the South East Irrigation Scheme (SEIS) has allowed a wider range of crops to be grown with minimum risks compared with dryland conditions. Land use is dominated by cereal (21%), vegetables (27%) and fruits (including stone fruit) (24%) (Table 3). The current value of production is estimated at $83.06 million (Coal River Products Association, 2008). However, the value of production is expected to increase by 40% ($33.25m) as a result of an expected increase in cropped areas. The Coal River Valley Product Association expects that over the next five years the area of intensive crops is projected to increase by 88% to 5,290 hectares. The main increases in terms of absolute area are peas, cereals, poppies and other.

Table 3. Land use pattern in the Coal River Catchment

Crop	Area (ha)	Percent
Cereals	600	21.3%
Peas	479	17.0%
Stone Fruit	382	13.6%
Grapes	300	10.7%
Fresh Veg	280	10.0%
Fat Lamb	170	6.0%
Poppies	140	5.0%
Lucerne	137	4.9%
Seed Crops	104	3.7%
Olives	95	3.4%
Other	91	3.2%
Walnuts	36	1.3%
TOTAL	2,814	100%

Source: Coal River Products Association, 2008.

Agricultural activities in the region are critically dependent on water for irrigation. Water resources in the Coal River catchment are heavily dependent upon highly variable rainfall and groundwater baseflow

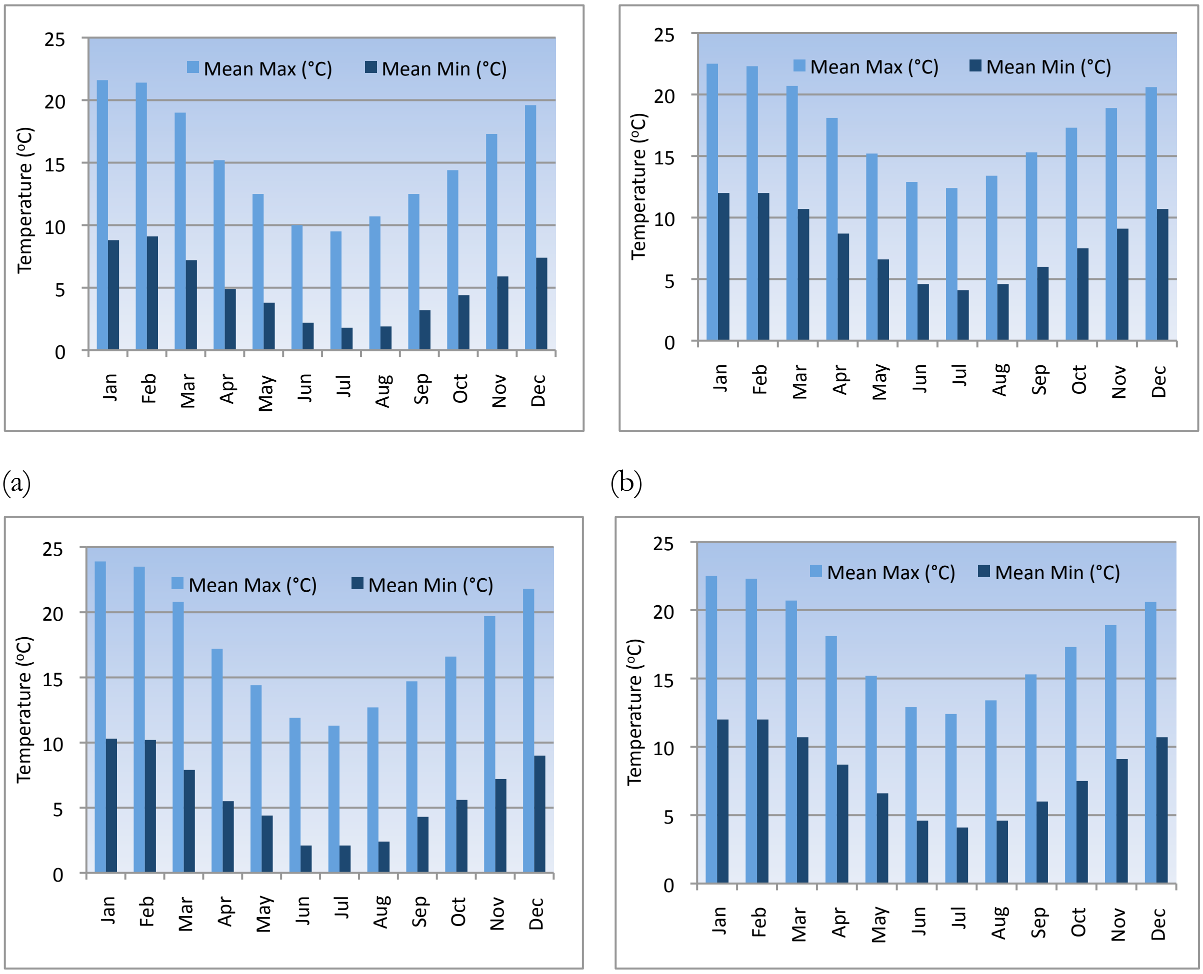
(DPIWE, 2003). Traditionally in-stream and off-stream farm dams have provided the major irrigation and stock water supply over the drier summer period. However, demand for water has increased over the past 10 years with the increase in cropped area. To overcome the demand and shortage of water, and to ensure reliability of flows, the Craigbourne Dam was constructed in 1986 as part of the South-East Irrigation Scheme (SEIS). Originally built to hold 12,500 ML of water, the Dam was designed to release 5,400 ML per annum which, at 65% efficiency, would make available 3,500 ML of water to be pumped onto farms in the district. Davies et al (2002) observed that Craigbourne Dam has substantially altered the seasonality of flow, changes in the timing and magnitude of both high and low flows have occurred, primarily in response to storage and delivery of irrigation flows. There has also been a reduction in flood size, frequency and duration (DPIWE, 2003). Despite this Craigbourne Dam levels remains crucially low during summer seasons, affecting the reliability of water supply (Coal River Products Association, 2008). The situation in the medium and longer term could be exacerbated if more general climate change projections for this latitude region of reduced rainfall, higher temperatures and increased evapotranspiration are realised.

Temperature

The Coal River Catchment has variable temperature with average daily maximum and minimum temperature ranges between 17.5ºC and 5.1ºC (Table 4). January is the hottest month in summer with average daily maximum and minimum temperatures of 24°C and 9°C whereas July is the coldest month in winter with daily maximum and minimum temperatures of 10°C and 1.5°C (Figure 5). The hottest maximum daily recorded was 40.1ºC (in Richmond) whereas the lowest daily temperature was -7.1ºC (in Colebrook). These relatively cooler temperatures provide a suitable climate for the production of cool temperate crops.

Table 4 Long term mean max and mean min temperature at selected rainfall stations at Coal River Catchment.

	Tunnack	Richmond	Colebrook	Campania
Mean Max (°C)	15.3	17.5	17.4	17.5
Mean Min (°C)	5.1	8	6	8
Mean Rain (mm)	582	497	427	497
Median Rain (mm)	594	482	426	482
Mean Rain Days	162	140	148	140



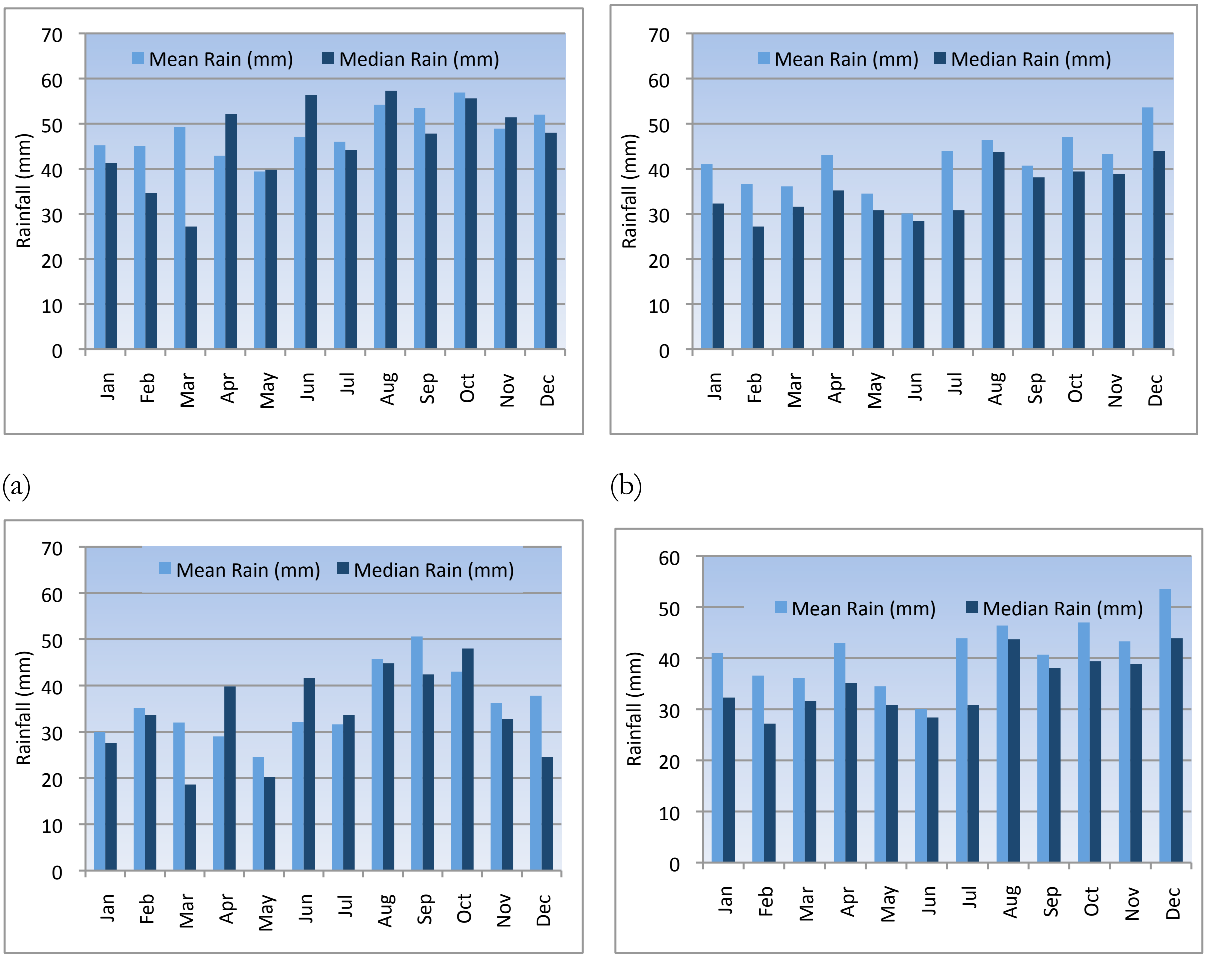
(a) (b)

(c) (d)

Figure 5. Long term monthly mean max and mean min temperature at selected rainfall stations at Coal River Catchment: (a) Tunnack, (b) Richmond, (c) Colebrook, and (d) Campania

Rainfall Patterns

The Coal River catchment is one of the driest catchments in Tasmania in that it receives the lowest rainfall of any region in Tasmania. The distribution of rainfall mainly depends by the topography and prevalence or otherwise of westerly winds, with higher rainfall occurring around the upland areas in the north, west and east of the catchment (DPIWE, 2003). The region has a mean number of raindays of 147.5, with a mean annual rainfall close to 598 mm, varying from 565 mm in Colebrook in Central parts of the catchment to 672 mm in upland areas in the north around Tunnack (Table 4). There is no dominant annual rainfall season; however the core summer season and the August-September receives relatively more rainfall than other periods. On the average, monthly rainfall varies between 55 mm and 30 mm (Figure 6).



(a) (b)

(c) (d)

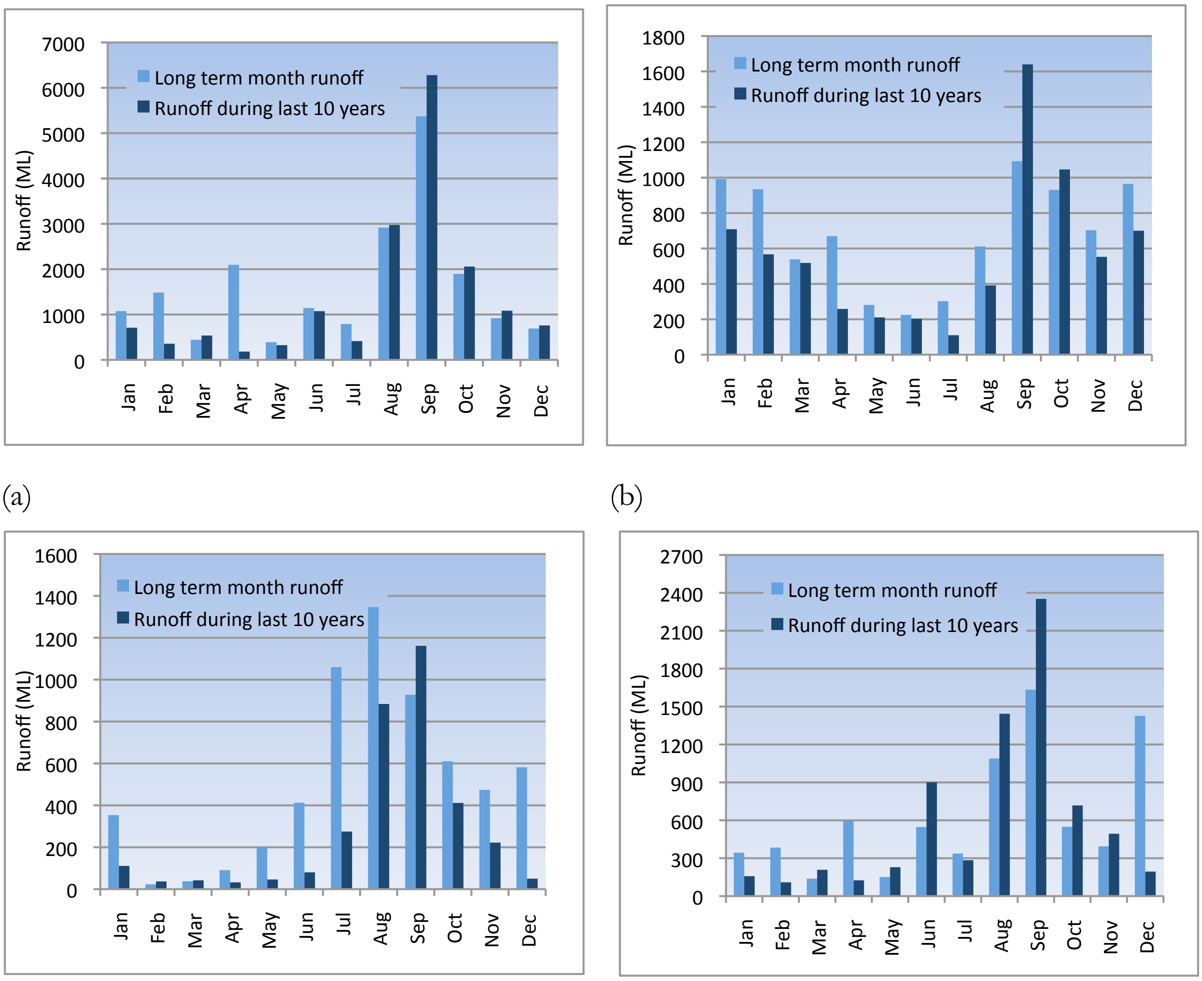
Figure 6. Long term monthly mean and median rainfall at selected rainfall stations within the Coal River Catchment: (a) Tunnack, (b) Richmond, (c) Colebrook, and (d) Campania

Water Resources

The Coal River rises in the hills south east of Tunnack in south east Tasmania at some 580m altitude and discharges into Pittwater to the south of Richmond. The river is approximately 80 km long and has a catchment area of 780 km^2 (DPIWE, 2003; Davies et al., 2002). Historical records indicate that stream flow was generally highly dependent on rainfall resulting from easterly winds bringing moist air over the catchment. Daley (1999) compared annual rainfall with indicative annual flows for the catchment and found that during periods of high rainfall and flood conditions, river flows corresponded well with rainfall, regardless of whether the river was dammed or not. However, during lower rainfall periods and especially after 1987 with the advent of the irrigation scheme, this relationship is not as high.

The Coal River now has a highly regulated flow regime, mainly due to the presence of Craigbourne Dam. The number of registered instream and offstream dams in the Coal River catchment is approximately 300, with a potential capacity of 35,500 ML, including Craigbourne Dam (Davies et al., 2002).

On an annual basis most rainfall events occur during the months of August to October, and hence the annual flow pattern is winter to spring dominated (Figure 7). Over the last 10 years the riverflow pattern has slightly shifted to late winter and early spring, following rainfall shifts with relatively higher runoff, while there is decrease in runoff is observed during summer.



(a) (b)

(c) (d)

Figure 7. Long term monthly runoff at selected streamflow gauge stations at Coal River: (a) Richmond; (b) Craigbourne; (c) Baden; and (d) White Kangaroo

Modelling Results

Runoff Model Performance

Sacramento and SimHyd are calibrated and verified using observed streamflow data from a total of 3 catchments. Sacramento and SimHyd run on a daily time step, however, they are calibrated against monthly runoff. This removes the need for routing and errors associated with routing (Chiew and Siriwardena, 2005). The parameters in the model are optimised to minimise an objective function defined as the sum of squares of the difference between the modelled and recorded monthly runoffs.

The Nash-Sutcliffe coefficient of efficiency (E) is used here as a measure of the model performance. The E value describes the agreement between all the modelled and recorded monthly runoffs, with E=1.0 indicating that all the modelled monthly runoffs are the same as the recorded runoffs. In general, E values greater than 0.6 suggest a reasonable modelling of runoff and E values greater than 0.8 suggest a good modelling of runoff for catchment yield studies (Peel et al. 2000; Chiew and McMahon, 1993).

Figure 8 and 9 compares the modelled and observed monthly runoff and the modelled and observed daily flow duration curves Coal River at Baden (3203). The results indicate that both the Sacramento and SimHyd models can reproduce reasonably satisfactorily the observed monthly runoff series (Nash-Sutcliffe coefficient of efficiency (E) is over 80%).

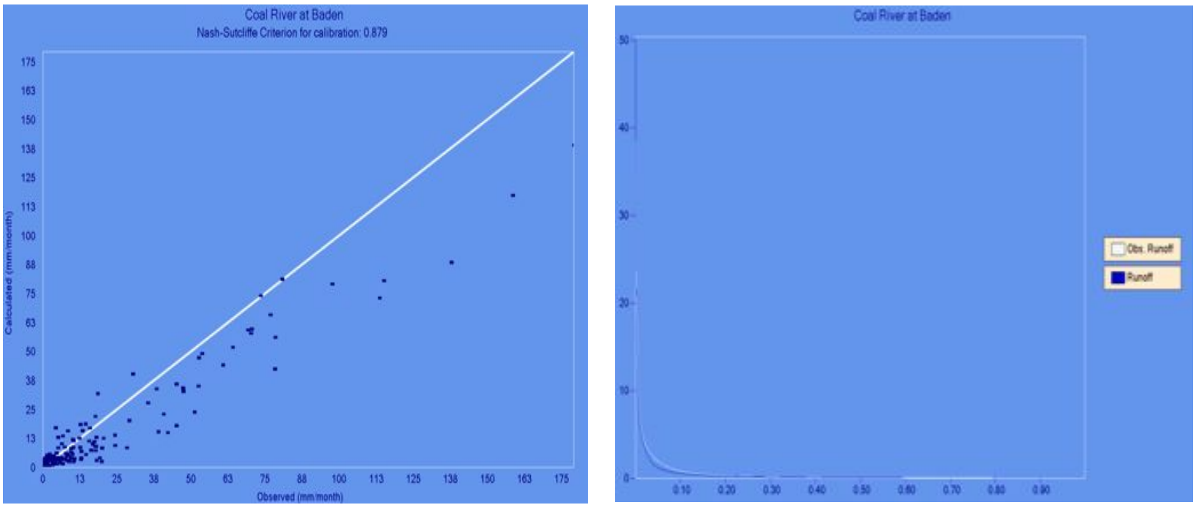


Figure 8. Modelled and observed monthly runoff and daily flow duration curve for Coal River at Baden (3203) using Sacramento Model

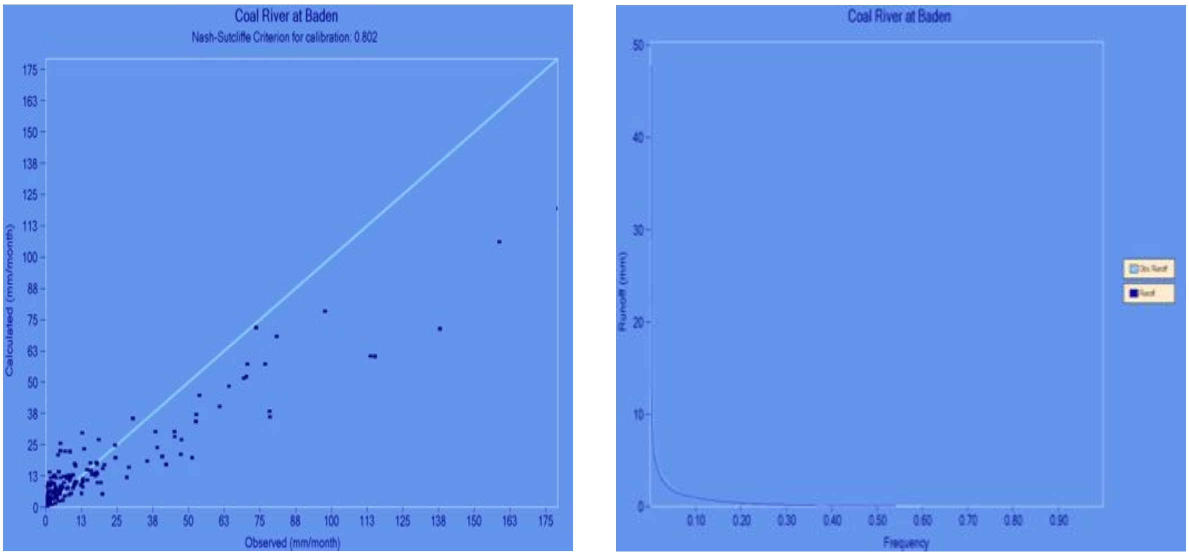


Figure 9. Modelled and observed monthly runoff and daily flow duration curve for Coal River at Baden (3203) using SimHyd Model

The calibration results (E) for Coal River at Richmond for SimHyd and Sacramento models were 55.0 and 56.4, respectively, and 51.9 and 67.5 for Coal River at downstream Craigbourne Dam.

Temperature

All Five GCM models utilised and analysed suggest an increase in regional maximum and minimum temperatures (Table 5 and 6) over the scenario periods.

Outputs from the models are generally consistent in suggesting the mean maximum temperature of the region is likely to increase by 4% to 6% (1.0°C - 1.2°C) by 2010-2030, by 9% to 11% (2.0°C-2.2°C) by 2040-2069, and by 16% to 18% (3.5°C or slightly above) by 2100 under A2 emission scenario. The B1 emission scenario also shows an increase in the maximum temperature, however, understandably, less significant compared with the A2 emission scenario. For the period 2070-2100, the B1 emission indicates about 11% (2.2°C) increase in mean maximum temperature.

Mean minimum temperatures are projected (using this method) to increase by between 12% and 17% on a yearly basis, depending on the model being utilised. However, mean winter temperature increases range from between 29% and 49%, depending on model output applied (A2 Scenarios).

In terms of seasonal temperature change, the models analysed indicate that although mean winter and summer temperature is shown to increase overall, mean winter month values are shown to be have a higher rate of increase. A monthly breakdown of temperature change also suggests an increase in temperature for almost all months (Appendix 1).

Table 5 Seasonal and yearly maximum temperature changes under A2 and B1scenarios (all percentage values shown as positive ("+")).

	A2 summary					B1 summary				
2010 - 2039	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	3%	4%	5%	3%	**4%**	1%	6%	5%	2%	**3%**
gfdlcm20	4%	7%	7%	3%	**5%**	5%	6%	4%	2%	**4%**
gfdlcm21	4%	7%	7%	6%	**6%**	5%	6%	8%	6%	**6%**
miroc3_2_medres	4%	6%	6%	7%	**6%**					
ukhadcm3	2%	6%	8%	5%	**5%**	1%	6%	7%	4%	**4%**
2040 - 2069	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	7%	11%	14%	10%	**10%**	6%	9%	10%	6%	**7%**
gfdlcm20	8%	12%	11%	8%	**9%**	9%	9%	11%	5%	**8%**
gfdlcm21	8%	12%	13%	10%	**10%**	6%	10%	11%	9%	**8%**
miroc3_2_medres	9%	11%	13%	11%	**11%**					
ukhadcm3	7%	15%	18%	10%	**11%**	3%	8%	10%	6%	**6%**
2070 - 2099	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	12%	20%	21%	16%	**16%**	8%	14%	13%	11%	**11%**
gfdlcm20	14%	19%	21%	15%	**16%**	10%	12%	15%	8%	**11%**
gfdlcm21	12%	19%	22%	17%	**16%**	6%	11%	12%	10%	**10%**
miroc3_2_medres	14%	21%	22%	18%	**18%**					
ukhadcm3	11%	23%	26%	18%	**18%**	7%	12%	15%	11%	**10%**

Table 6 Seasonal and yearly minimum temperature changes under A2 and B1scenarios

	A2 summary					B1 summary				
2010 - 2039	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	11%	13%	31%	11%	**13%**	7%	17%	28%	9%	**12%**
gfdlcm20	8%	22%	29%	6%	**12%**	7%	21%	19%	8%	**11%**
gfdlcm21	10%	22%	41%	14%	**16%**	10%	22%	40%	15%	**16%**
miroc3_2_medres	11%	19%	33%	17%	**16%**	**n/a**				
ukhadcm3	9%	21%	49%	14%	**17%**	6%	20%	38%	12%	**13%**
2040 - 2069	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	19%	32%	76%	24%	**28%**	16%	29%	52%	18%	**23%**
gfdlcm20	17%	39%	52%	18%	**25%**	15%	28%	44%	14%	**20%**
gfdlcm21	19%	40%	72%	26%	**30%**	14%	32%	63%	23%	**25%**
miroc3_2_medres	22%	38%	68%	27%	**31%**	**n/a**				
ukhadcm3	24%	50%	101%	33%	**38%**	13%	26%	57%	20%	**21%**
2070 - 2099	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	33%	66%	117%	40%	**49%**	20%	45%	72%	27%	**32%**
gfdlcm20	30%	65%	98%	37%	**45%**	21%	40%	75%	23%	**30%**

gfdlcm21	30%	65%	125%	43%	**49%**	16%	38%	72%	24%	**28%**
miroc3_2_medres	35%	68%	130%	45%	**53%**	**n/a**				
ukhadcm3	34%	80%	158%	49%	**59%**	19%	45%	87%	29%	**33%**

Precipitation:

Overall there is some discrepancy between model outputs in terms of projected changes in precipitation, even though only five models have been selected for application. For example, a (slight) majority of the climate models selected suggest an overall decrease in mean annual rainfall for the period of 2010-2039 under the A2 emission scenario (Table 7). However, interestingly, for the longer term (2040-2069 and 2070-2100), a majority of the selected climate models suggest a subsequent increase in annual rainfall for those later periods. The ECHAM and UKHADCM model outputs suggest an increase in overall annual rainfall, with a range of 5% to 16%, under both A2 and B1 emission scenarios for all future time periods, while GFDL2.0, GFDL2.1, and MIROC3.2 model output suggest a decrease in overall mean rainfall, with a range of -1% to -9%, under both A2 and B1 emission scenarios for all future time periods. GFDL2.1 outputs a decrease of rainfall for the 2010-2039 for about -1% to -2% but with a 'general' increase in rainfall for 2040-2069 and 2070-2100 under both A2 and B1 emission scenarios.

More detailed monthly summary outputs appear to provide more useful information (see below). Under the A2 emission scenario, the models selected suggest an increase of between 3% and 23% in 'summer rainfall' (in this case, defined as 'January to March') while for late autumn through winter and early spring the model outputs suggest a decrease in precipitation of between 1% and 15%. Interestingly, all models selected suggest an increase in April precipitation.

Table 7 Seasonal and annual rainfall changes under A2 and B1scenario

	A2 summary					B1 summary				
2010 – 2039	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	Yearly
echam5	23%	4%	-1%	-3%	**5%**	23%	2%	14%	9%	**12%**
gfdlcm20	-9%	-4%	-10%	6%	**-4%**	-16%	-11%	-10%	11%	**-6%**
gfdlcm21	3%	1%	-6%	-4%	**-2%**	-5%	14%	-1%	-10%	**-1%**
miroc3_2_medres	12%	-5%	-5%	-15%	**-4%**	**n/a**				
ukhadcm3	17%	16%	-5%	5%	**7%**	8%	18%	5%	-1%	**7%**
2040 – 2069	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	16%	8%	2%	-3%	**5%**	21%	11%	2%	1%	**8%**
gfdlcm20	3%	-5%	-6%	3%	**-1%**	-17%	-4%	-18%	12%	**-7%**
gfdlcm21	0%	0%	-2%	5%	**1%**	12%	-7%	0%	8%	**3%**
miroc3_2_medres	2%	-8%	-7%	-17%	**-8%**	**n/a**				
ukhadcm3	24%	37%	-2%	8%	**16%**	11%	7%	-3%	1%	**3%**
2070 – 2099	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	30%	4%	-3%	-7%	**4%**	15%	-7%	-1%	-6%	**-1%**

gfdlcm20	-12%	-3%	-17%	12%	**-5%**	-1%	-11%	-12%	12%	**-3%**
gfdlcm21	5%	9%	5%	-9%	**2%**	5%	-10%	3%	-3%	**-1%**
miroc3_2_medres	-10%	5%	-9%	-19%	**-9%**					
ukhadcm3	33%	26%	1%	3%	**15%**	16%	12%	-2%	1%	**6%**

A breakdown of seasonal and monthly projected rainfall may provide further detailed insight into potential climate change impacts on rainfall in this region and subsequently on water resources. Considerable variations in seasonal and monthly rainfall are suggested in the projected rainfall. The details of monthly rainfall changes are presented in Appendix 1. Generally, the climate model outputs under the A2 Emissions Scenario and as applied here suggest:

- For summer, the model outputs provided here suggest potential for a general increase in rainfall through the January-March period for the Catchment with some potential for this to continue through April - but not a high chance of this outcome continuing beyond April. In this respect, 3 out of five models selected suggest an increase in January rainfall, 2 out of the five selected suggest an increase in February rainfall, and four out of the five models selected suggest an increase in March rainfall for this catchment.

- For April, five out of the five models selected (all models selected) suggest an increase in precipitation, continuing the more likely suggested projected patterns for 'summer'. Conversely, for May only two of the five models selected suggest an increase in precipitation.

- Using the approach outlined here with its limitations, the June to August period is generally projected as a period of a likely decrease in rainfall in this catchment. Additional analyses suggest the period, generally from May through to November, as mostly a period of likely reduced rainfall. As an example in detail, for the month of June while none of the models indicate much variation in either direction (negative or positive), for July all of the models indicate a likely decrease in precipitation (ie five out of five models suggest a decrease in precipitation), and for August three out of the five models suggest a decrease in precipitation. .

- For the spring/early summer period (for all months in this period), most model outputs suggest a decrease in rainfall over this period as follows: September - two out of the five models suggest a small increase in precipitation but only by a small amount, while three out of the five models suggest a substantial decrease in precipitation; October – two out of the five models suggest just a very modest increase in precipitation while three out of five models suggest a substantial decrease; November – two out of the five models suggest a modest increase while three out of five models suggest a substantial decrease in precipitation; December – a mixed outcome with two models suggesting an increase in precipitation and two models suggesting a decrease (one model no change).

Under the B1 Emission Scenario, in general, most model outputs suggest a decrease in precipitation in most months of the year with the exception of March, April, August and November. The UK Hadley Centre model selected here (HADCM3) more consistently favoured higher rainfall likelihood than other model outputs. Conversely, the US GFDL 2.0 model more consistently favoured lower rainfall likelihood. As there are but four models suitable for analysis under this emission scenario the tabular results are not summarised here but available in the Appendix.

Overall, the combined impacts of increasing temperature (and potential increases in evapotranspiration) and reduction in winter rainfall may impose a strain on water resources in the Coal River catchment. The reduction in rainfall in late autumn through to early summer has implications on the cropping system in Coal River Catchment, particularly to horticultural crops, with windows of opportunities through summer cropping systems.

Radiation

Table 8. Seasonal and annual radiation changes under A2 and B1scenario.

	A2 summary					B1 summary				
2010 – 2039	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	-1%	-1%	1%	-1%	**-1%**	-2%	0%	-1%	-1%	**-1%**
gfdlcm20	2%	-1%	2%	0%	**1%**	4%	-2%	0%	-1%	**1%**
gfdlcm21	0%	-1%	0%	1%	**0%**	1%	-2%	1%	2%	**1%**
miroc3_2_medres	-3%	1%	0%	2%	**0%**					
ukhadcm3	-1%	1%	0%	0%	**0%**	-3%	0%	-1%	0%	**-1%**
2040 - 2069	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	-2%	0%	0%	1%	**0%**	-2%	-2%	1%	-1%	**-1%**
gfdlcm20	1%	-2%	0%	2%	**1%**	4%	-1%	3%	-1%	**1%**
gfdlcm21	0%	-1%	-1%	1%	**0%**	-1%	1%	-2%	1%	**0%**
miroc3_2_medres	-2%	-2%	1%	3%	**0%**					
ukhadcm3	-4%	-1%	0%	-1%	**-2%**	-3%	0%	1%	-1%	**-1%**
2070 - 2099	JFM	AMJ	JAS	OND	**Yearly**	JFM	AMJ	JAS	OND	**Yearly**
echam5	-2%	-2%	-1%	0%	**-1%**	-1%	-1%	0%	1%	**0%**
gfdlcm20	1%	-3%	1%	1%	**1%**	2%	-1%	2%	-1%	**1%**
gfdlcm21	-1%	-3%	-2%	3%	**0%**	-1%	-2%	-2%	2%	**0%**
miroc3_2_medres	-3%	-3%	-2%	2%	**-1%**					
ukhadcm3	-4%	-1%	-1%	1%	-1%	-2%	-1%	1%	1%	0%

Streamflow

Table 9 Seasonal and yearly streamflow changes under A2 and B1scenario

Streamflow Summary (A2)

2010 - 2039	JFM	AMJ	JAS	OND	Yearly
echam5	+49%	+25%	-1%	-18%	+5%
gfdlcm20	-23%	-10%	-20%	+11%	-14%
gfdlcm21	+18%	+20%	-11%	-18%	-3%
miroc3_2_medres	+50%	-10%	-14%	-37%	-12%
ukhadcm3	+52%	+54%	-4%	+2%	+15%

2040 - 2069	JFM	AMJ	JAS	OND	Yearly
echam5	+77%	+28%	+2%	-9%	+12%
gfdlcm20	+1%	-20%	-16%	+9%	-13%
gfdlcm21	+29%	+11%	-11%	+12%	+1%
miroc3_2_medres	+8%	-22%	-19%	-53%	-24%
ukhadcm3	+32%	+128%	+6%	-7%	+35%

2070 - 2099	JFM	AMJ	JAS	OND	Yearly
echam5	+149%	+29%	-7%	-20%	+10%
gfdlcm20	-32%	-19%	-36%	+34%	-23%
gfdlcm21	+1%	+32%	+8%	-34%	+7%
miroc3_2_medres	0%	-11%	-20%	-44%	-20%
ukhadcm3	+174%	+74%	+8%	-6%	+35%

Streamflow Summary (B1)

2010 - 2039	JFM	AMJ	JAS	OND	Yearly
echam5	+101%	+23%	+25%	+32%	+30%
gfdlcm20	-44%	-38%	-25%	+10%	-26%
gfdlcm21	-3%	+43%	-1%	-34%	+5%
ukhadcm3	-31%	+50%	+14%	-8%	+15%

2040 - 2069	JFM	AMJ	JAS	OND	Yearly
echam5	+70%	+46%	+7%	+15%	+22%
gfdlcm20	-25%	-20%	-34%	+16%	-24%
gfdlcm21	+44%	+1%	-3%	+19%	+5%
ukhadcm3	+17%	+18%	-3%	-14%	+1%

2070 - 2099	JFM	AMJ	JAS	OND	Yearly
echam5	+54%	-3%	-6%	-36%	-7%
gfdlcm20	+41%	-29%	-28%	+6%	-19%
gfdlcm21	-27%	-22%	0%	-24%	-11%
ukhadcm3	+48%	+35%	0%	-11%	+10%

Detailed integration of climate model projections with hydrological modelling (that incorporates temperature, rainfall and evapotranspiration inputs) suggests a mixed outcome for annual streamflow for this region. However, it is notable that under the A2 scenario for 2010-2039 that summer flow is projected to generally be enhanced while winter flow is projected to be reduced. Outputs for autumn and spring tend to indicate more mixed results. This outcome will be further tested using a number of additional model outputs (as applied in other regions of eastern Australia) as well as more detailed monthly assessments made.

Summary and Conclusions

Climate projections relevant to catchment and river basins systems have largely hitherto been developed at global and national scales and may provide less than optimal clarity regarding certain aspects of likely climate change needed for policy decisions for industry or government. In this project, output from the CSIRO Conformal Cubic Atmospheric Model (CCAM) was provided to the research team to dynamically downscale the results of five defined more relevant global climate models over Tasmania (CFT, 2009). 'Raw output' from the models suggested in the Climate Futures Tasmania report (CFT, 2009) provided the prime data set to be applied for hydrological and additional temperature/rainfall analyses in this instance. Nevertheless, it is suggested complementary model output applying a number of additional models and approaches should be set up to be ongoing from this report to provide comparison results as may be necessary for future studies. (This aspect has now been developed should further analyses be required).

In this report, it is noted that temperature projections from all five GCM models utilised and analysed suggest an increase in regional maximum and minimum temperatures for this catchment over the scenario periods. Outputs from the models selected are generally consistent in suggesting a mean maximum temperature of the region is likely to increase by 4% to 6% (1.0ºC - 1.2°C) by 2010-2030. The B1 emission scenario also shows an increase in the maximum temperature, albeit less pronounced compared to the A2 emission scenario. Minimum temperatures are projected to increase by 13% to 16% on a yearly basis and between 29% and 49% during winter.

A breakdown of seasonal and monthly projected rainfall provided further detailed insight into potential climate change impacts on rainfall in this region and subsequently on water resources. Although, five more suitable climate change models were selected due to their capability in reproducing known climate drivers and known local rainfall variability, considerable variations in seasonal and monthly rainfall are suggested in the projected rainfall under the A2 Emission Scenario. Nevertheless, these model outputs are presented with caveats needed to be borne in mind. These model outputs suggest potential for an increase in rainfall through January-March-April but, conversely, for a potential likely decrease in precipitation for the May through November period when the overall outputs are considered.

Under the B1 Emission Scenario, in general, most models outputs suggest a decrease in precipitation in most months of the year with the exception of March, April, August and November. The UK Hadley Centre model selected in this study (HADCM3) consistently favoured higher rainfall likelihood than other model outputs. Conversely, the US GFDL 2.0 model consistently favoured lower rainfall likelihood. As there are but four models suitable for analyses under this B1 Emission Scenario, considerable care needs to be taken in assessment of the results.

Considerable effort was made to develop streamflow projections based on the core model outputs and integration with hydrological models. While annual streamflow results (2010-2039) suggest a mixed outcome depending on models selected, it is noteworthy that under (the possibly more likely) A2 scenario that four out of five models suggest a considerable increase in core summer streamflow for this region and all models selected suggest a decrease in core winter streamflow. Autumn and spring flow show mixed results, although more detailed monthly results may provide more useful information here. Projected changes for the longer term indicate more mixed results. Further investigation using additional relevant models combined with monthly projections may provide enhanced information for this requirement.

It is suggested that, overall, the combined impacts of increasing temperature (and potential increases in evapotranspiration) and possible reduction, especially in winter rainfall may impose a strain on already stretched water resources in the Coal River catchment at that time of the year. Potential enhanced streamflow over summer months for this region (possibly associated with enhanced east-coast low pressure development under climate change) may allow enhanced water resource management systems to be introduced. The reduction in rainfall but generally increase in minimum temperatures in late autumn through to early summer has implication for horticultural crop management systems.

It is suggested further analyses, applying other or additional suitable models (and which have been applied in other Australian regions) should be applied outside of the context of the outputs required for the timing of the issuing of this report but which would be provided as an extra report summary in the near future if considered a suitable approach. Selection of the more suitable climate projection models for this type of study is critical in determining the outcomes for variables such as projected streamflow and rainfall for a comparatively small region.

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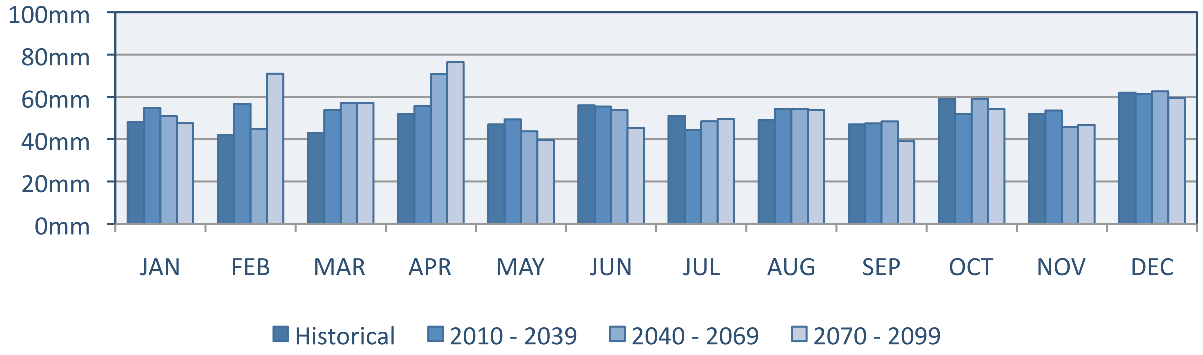
Appendix

ECHAM5

Max Planck Institute for Meteorology, Germany

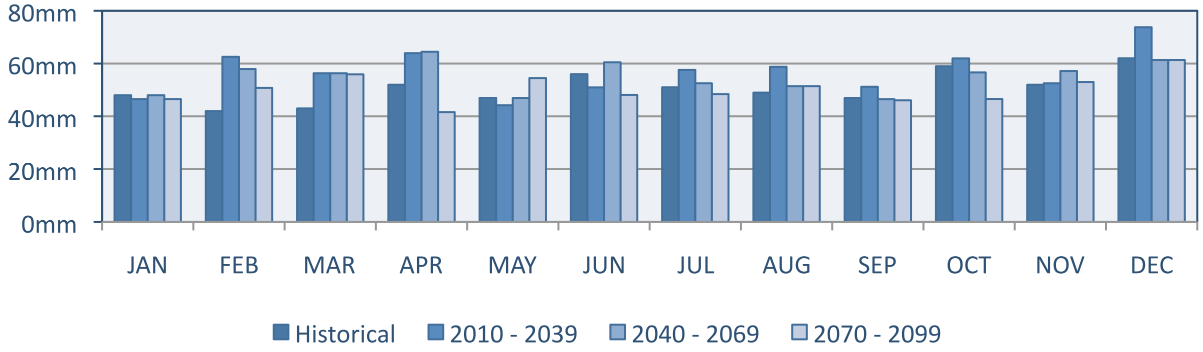
ECHAM5 is a fifth-generation atmospheric general circulation model developed at the Max Planck Institute of Meteorology (MPIM). It is a coupled model consisting of atmospheric, oceanic, and land surface components.

Average Monthly Rainfall (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	+14%	+35%	+25%	+7%	+5%	-1%	-13%	+11%	+1%	-12%	+3%	-1%
2040 - 2069	+6%	+7%	+33%	+36%	-7%	-4%	-5%	+11%	+3%	0%	-12%	+1%
2070 - 2099	-1%	+69%	+33%	+47%	-16%	-19%	-3%	+10%	-17%	-8%	-10%	-4%

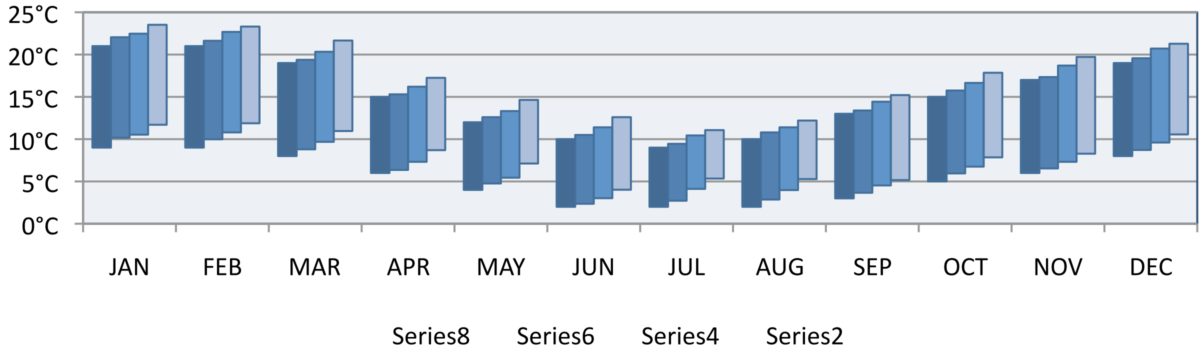
Average Monthly Rainfall (B1 Scenario)



B1	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**

2010 - 2039	-3%	+49%	+31%	+23%	-6%	-9%	+13%	+20%	+9%	+5%	+1%	+19%
2040 - 2069	0%	+38%	+31%	+24%	0%	+8%	+3%	+5%	-1%	-4%	+10%	-1%
2070 - 2099	-3%	+21%	+30%	-20%	+16%	-14%	-5%	+5%	-2%	-21%	+2%	-1%

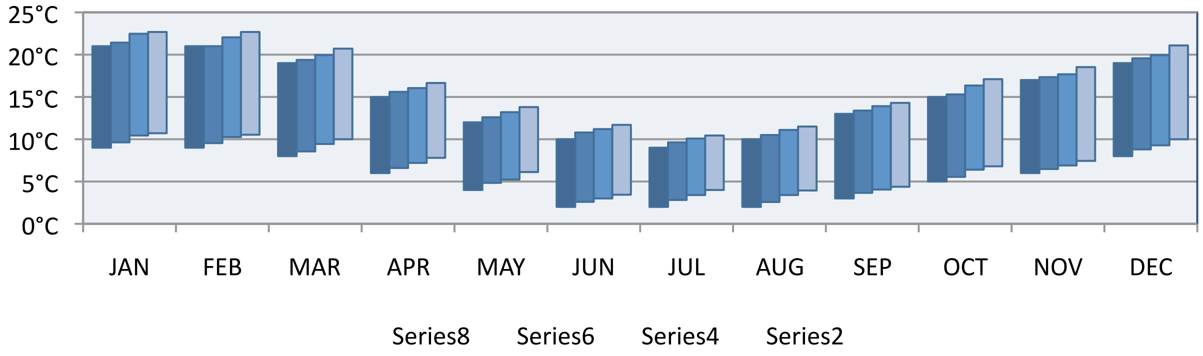
Average Monthly Temperature (A2 Scenario)



TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+13%	+11%	+10%	+6%	+19%	+18%	+36%	+43%	+22%	+19%	+9%	+9%
2040 - 2069	+17%	+20%	+21%	+22%	+36%	+51%	+106%	+99%	+51%	+35%	+22%	+20%
2070 - 2099	+30%	+32%	+37%	+45%	+78%	+101%	+167%	+164%	+72%	+57%	+38%	+32%

TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+5%	+3%	+2%	+2%	+5%	+5%	+5%	+8%	+3%	+5%	+2%	+3%
2040 - 2069	+7%	+8%	+7%	+8%	+11%	+14%	+16%	+14%	+11%	+11%	+10%	+9%
2070 - 2099	+12%	+11%	+14%	+15%	+22%	+26%	+23%	+22%	+17%	+19%	+16%	+12%

Average Monthly Temperature (B1 Scenario)

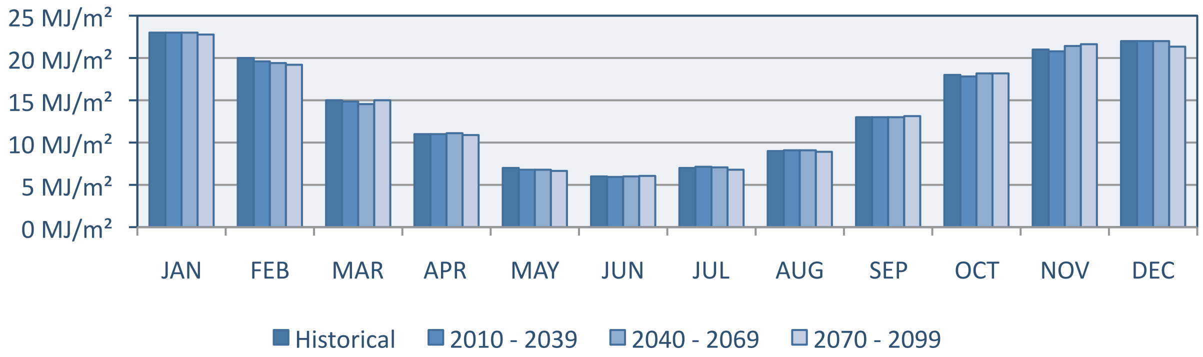


TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+7%	+6%	+7%	+10%	+21%	+30%	+41%	+29%	+22%	+11%	+8%	+10%
2040 - 2069	+16%	+14%	+18%	+20%	+31%	+50%	+70%	+70%	+35%	+28%	+15%	+16%

2070 - 2099	+19%	+17%	+25%	+30%	+53%	+72%	+100%	+97%	+46%	+36%	+24%	+25%

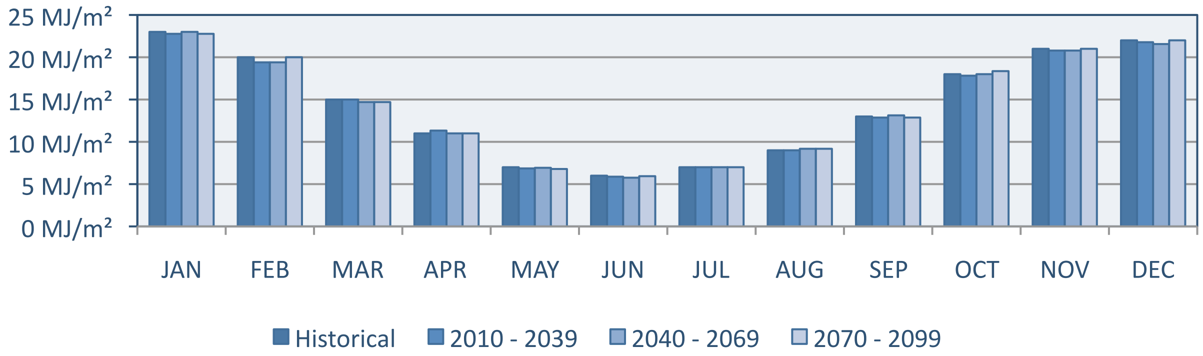
TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+2%	0%	+2%	+4%	+5%	+8%	+7%	+5%	+3%	+2%	+2%	+3%
2040 - 2069	+7%	+5%	+5%	+7%	+10%	+12%	+12%	+11%	+7%	+9%	+4%	+5%
2070 - 2099	+8%	+8%	+9%	+11%	+15%	+17%	+16%	+15%	+10%	+14%	+9%	+11%

Average Monthly Radiation (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	0%	-2%	-1%	0%	-3%	-1%	+2%	+1%	0%	-1%	-1%	0%
2040 - 2069	0%	-3%	-3%	+1%	-3%	0%	+1%	+1%	0%	+1%	+2%	0%
2070 - 2099	-1%	-4%	0%	-1%	-5%	+1%	-3%	-1%	+1%	+1%	+3%	-3%

Average Monthly Radiation (B1 Scenario)



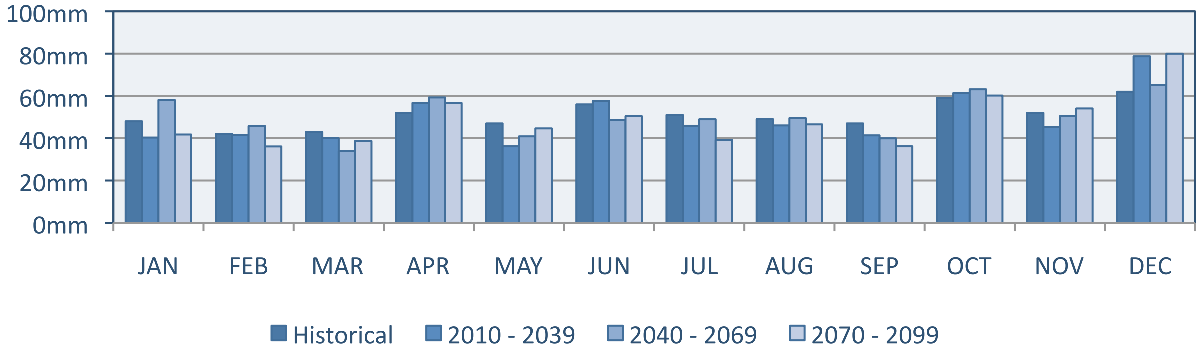
B1	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	-1%	-3%	0%	+3%	-2%	-2%	0%	0%	-1%	-1%	-1%	-1%
2040 - 2069	0%	-3%	-2%	0%	-1%	-4%	0%	+2%	+1%	0%	-1%	-2%
2070 - 2099	-1%	0%	-2%	0%	-3%	-1%	0%	+2%	-1%	+2%	0%	0%

GFDL CM2.0

Geophysical Fluid Dynamics Laboratory, NOAA

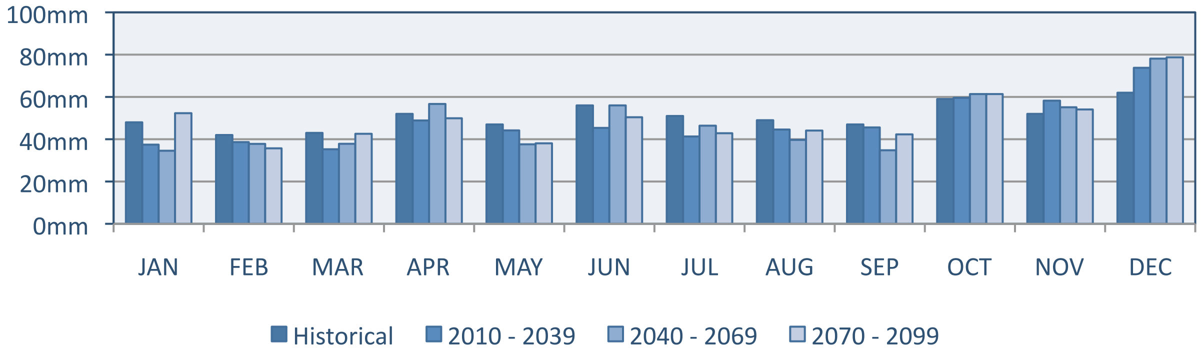
The GFDL CM2.0 is a coupled atmosphere, land, and ocean model, developed by the Geophysical Fluid Dynamics Lab. GFDL 2.0 is a grid point model with a horizontal resolution of 2° latitude x 2.5° longitude for atmosphere and land components. The ocean component has a horizontal resolution of 1° latitude x 1° longitude.

Average Monthly Rainfall (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	-16%	-1%	-7%	+9%	-23%	+3%	-10%	-6%	-12%	+4%	-13%	+27%
2040 - 2069	+21%	+9%	-21%	+14%	-13%	-13%	-4%	+1%	-15%	+7%	-3%	+5%
2070 - 2099	-13%	-14%	-10%	+9%	-5%	-10%	-23%	-5%	-23%	+2%	+4%	+29%

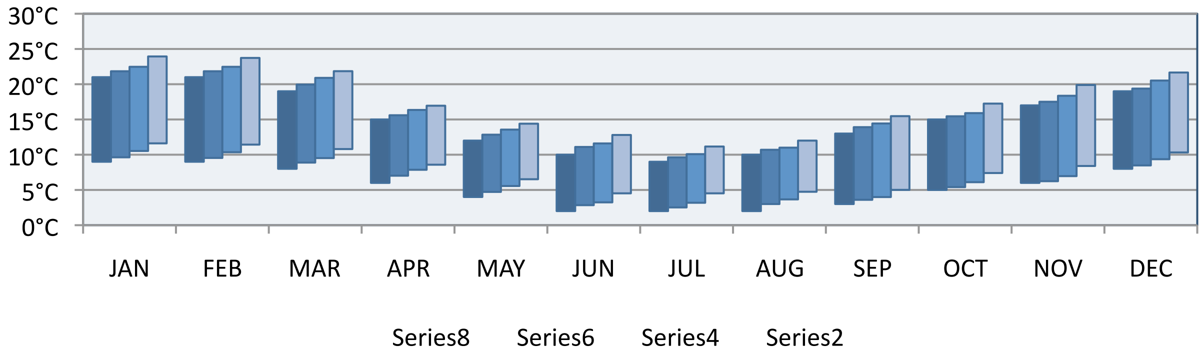
Average Monthly Rainfall (B1 Scenario)



B1	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	-22%	-8%	-18%	-6%	-6%	-19%	-19%	-9%	-3%	+1%	+12%	+19%
2040 - 2069	-28%	-10%	-12%	+9%	-20%	0%	-9%	-19%	-26%	+4%	+6%	+26%

2070 - 2099	+9%	-15%	-1%	-4%	-19%	-10%	-16%	-10%	-10%	+4%	+4%	+27%

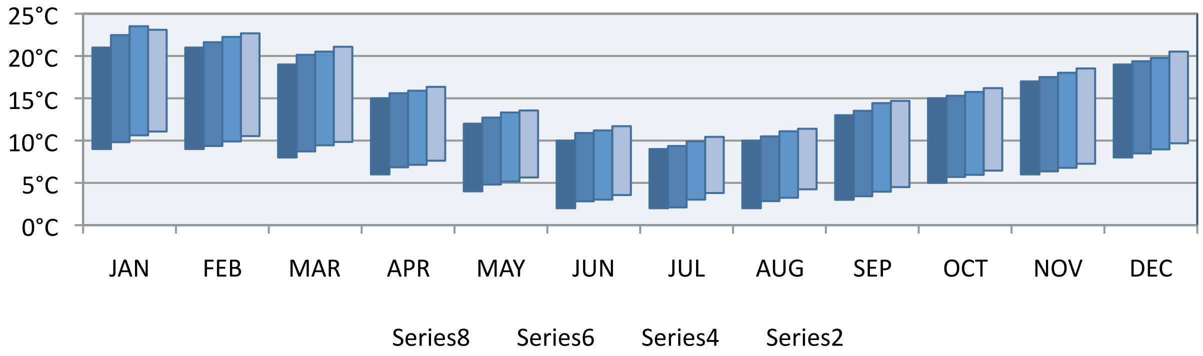
Average Monthly Temperature (A2 Scenario)



TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+7%	+6%	+11%	+17%	+18%	+42%	+26%	+50%	+20%	+8%	+4%	+6%
2040 - 2069	+17%	+15%	+19%	+31%	+39%	+62%	+59%	+83%	+33%	+22%	+16%	+17%
2070 - 2099	+29%	+27%	+35%	+43%	+63%	+126%	+126%	+137%	+67%	+48%	+40%	+29%

TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+4%	+4%	+5%	+4%	+7%	+11%	+7%	+7%	+7%	+3%	+3%	+2%
2040 - 2069	+7%	+7%	+10%	+9%	+13%	+16%	+12%	+10%	+11%	+6%	+8%	+8%
2070 - 2099	+14%	+13%	+15%	+13%	+20%	+28%	+24%	+20%	+19%	+15%	+17%	+14%

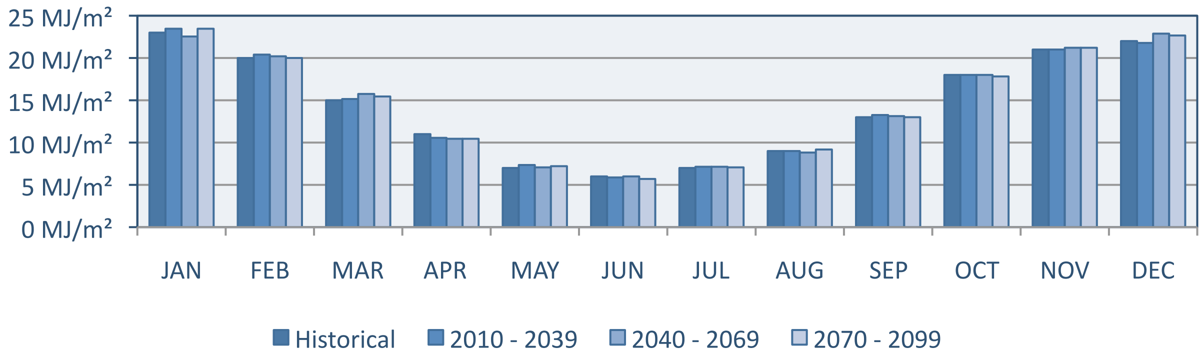
Average Monthly Temperature (B1 Scenario)



TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+9%	+4%	+9%	+14%	+20%	+41%	+5%	+42%	+14%	+14%	+6%	+6%
2040 - 2069	+18%	+10%	+18%	+19%	+29%	+51%	+51%	+62%	+32%	+19%	+13%	+12%
2070 - 2099	+23%	+17%	+23%	+27%	+41%	+78%	+90%	+112%	+50%	+29%	+21%	+21%

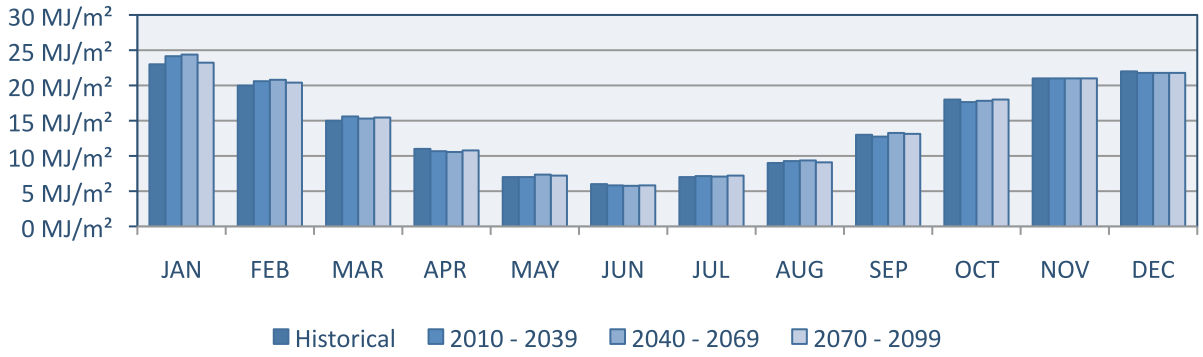
TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+7%	+3%	+6%	+4%	+6%	+9%	+4%	+5%	+4%	+2%	+3%	+2%
2040 - 2069	+12%	+6%	+8%	+6%	+11%	+12%	+10%	+11%	+11%	+5%	+6%	+4%
2070 - 2099	+10%	+8%	+11%	+9%	+13%	+17%	+16%	+14%	+13%	+8%	+9%	+8%

Average Monthly Radiation (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	+2%	+2%	+1%	-4%	+5%	-2%	+2%	0%	+2%	0%	0%	-1%
2040 - 2069	-2%	+1%	+5%	-5%	+1%	0%	+2%	-2%	+1%	0%	+1%	+4%
2070 - 2099	+2%	0%	+3%	-5%	+3%	-5%	+1%	+2%	0%	-1%	+1%	+3%

Average Monthly Radiation (B1 Scenario)



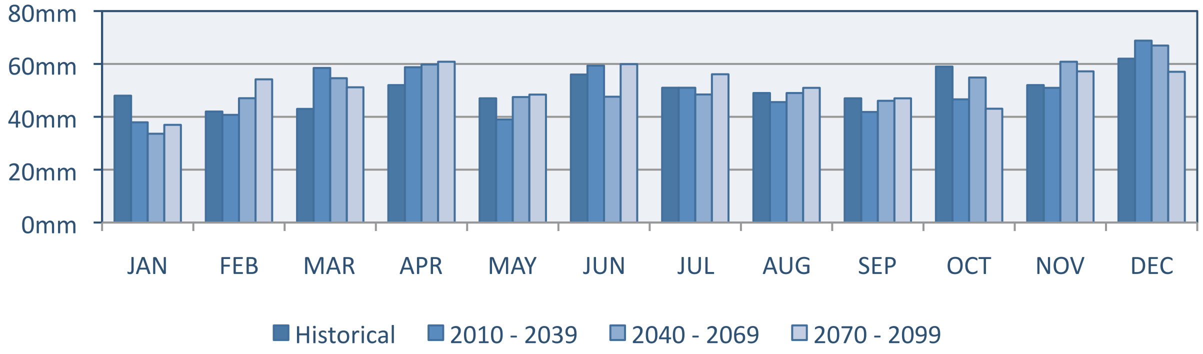
B1	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	+5%	+3%	+4%	-3%	0%	-3%	+2%	+3%	-2%	-2%	0%	-1%
2040 - 2069	+6%	+4%	+2%	-4%	+5%	-4%	+1%	+4%	+2%	-1%	0%	-1%
2070 - 2099	+1%	+2%	+3%	-2%	+3%	-3%	+3%	+1%	+1%	0%	0%	-1%

GFDL CM2.1

Geophysical Fluid Dynamics Laboratory, NOAA

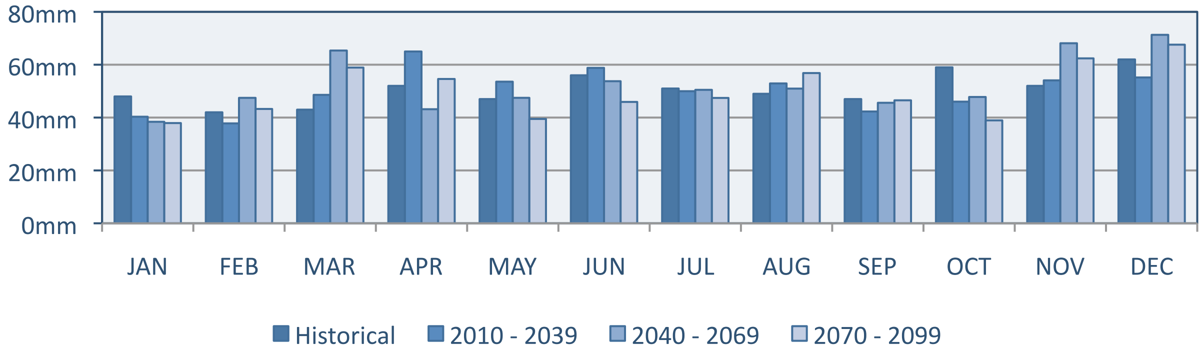
The GFDL CM2.1 is a coupled atmosphere, land, and ocean model developed by the Geophysical Fluid Dynamics Lab. GFDL 2.1 is a grid point model with a horizontal resolution of 2° latitude x 2.5° longitude for atmosphere and land components. The ocean component has a horizontal resolution of 1° latitude x 1° longitude.

Average Monthly Rainfall (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	-21%	-3%	+36%	+13%	-17%	+6%	0%	-7%	-11%	-21%	-2%	+11%
2040 - 2069	-30%	+12%	+27%	+15%	+1%	-15%	-5%	0%	-2%	-7%	+17%	+8%
2070 - 2099	-23%	+29%	+19%	+17%	+3%	+7%	+10%	+4%	0%	-27%	+10%	-8%

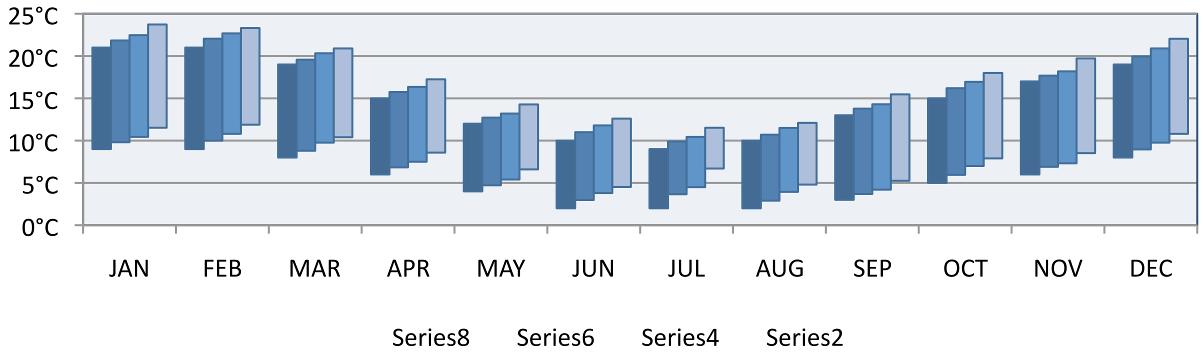
Average Monthly Rainfall (B1 Scenario)



B1	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	-16%	-10%	+13%	+25%	+14%	+5%	-2%	+8%	-10%	-22%	+4%	-11%

2040 - 2069	-20%	+13%	+52%	-17%	+1%	-4%	-1%	+4%	-3%	-19%	+31%	+15%
2070 - 2099	-21%	+3%	+37%	+5%	-16%	-18%	-7%	+16%	-1%	-34%	+20%	+9%

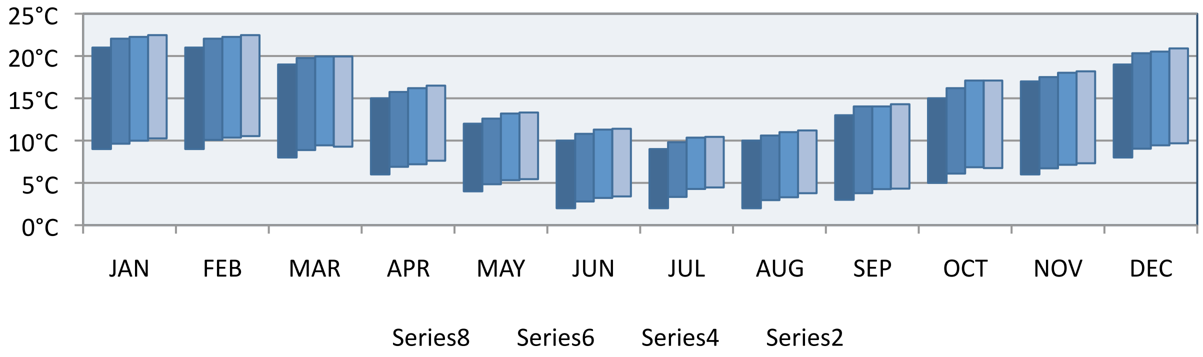
Average Monthly Temperature (A2 Scenario)



TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+9%	+11%	+10%	+14%	+18%	+49%	+83%	+45%	+23%	+19%	+15%	+12%
2040 - 2069	+16%	+20%	+22%	+25%	+35%	+90%	+125%	+97%	+40%	+40%	+22%	+22%
2070 - 2099	+28%	+32%	+30%	+43%	+65%	+126%	+235%	+140%	+75%	+58%	+42%	+35%

TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+4%	+5%	+3%	+5%	+6%	+10%	+10%	+7%	+6%	+8%	+4%	+5%
2040 - 2069	+7%	+8%	+7%	+9%	+10%	+18%	+16%	+15%	+10%	+13%	+7%	+10%
2070 - 2099	+13%	+11%	+10%	+15%	+19%	+26%	+28%	+21%	+19%	+20%	+16%	+16%

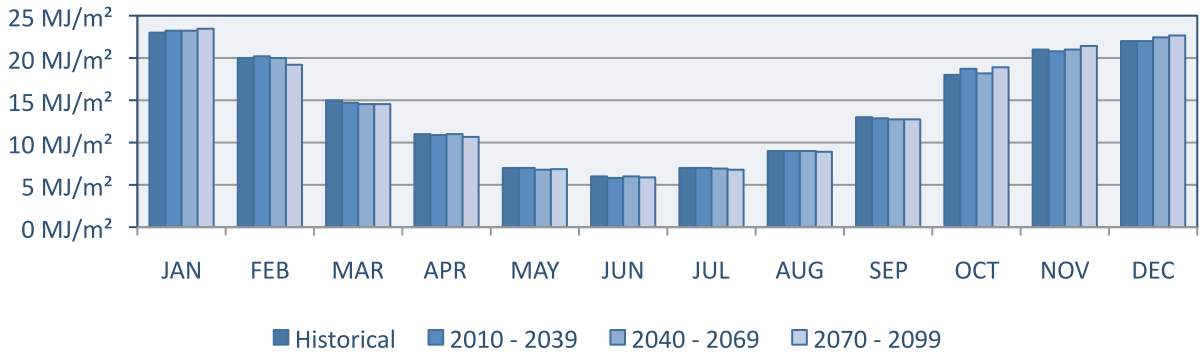
Average Monthly Temperature (B1 Scenario)



TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+7%	+12%	+11%	+15%	+21%	+40%	+67%	+48%	+26%	+22%	+12%	+13%
2040 - 2069	+11%	+15%	+18%	+20%	+33%	+61%	+114%	+65%	+42%	+37%	+19%	+18%
2070 - 2099	+14%	+17%	+16%	+27%	+36%	+70%	+123%	+89%	+44%	+35%	+22%	+21%

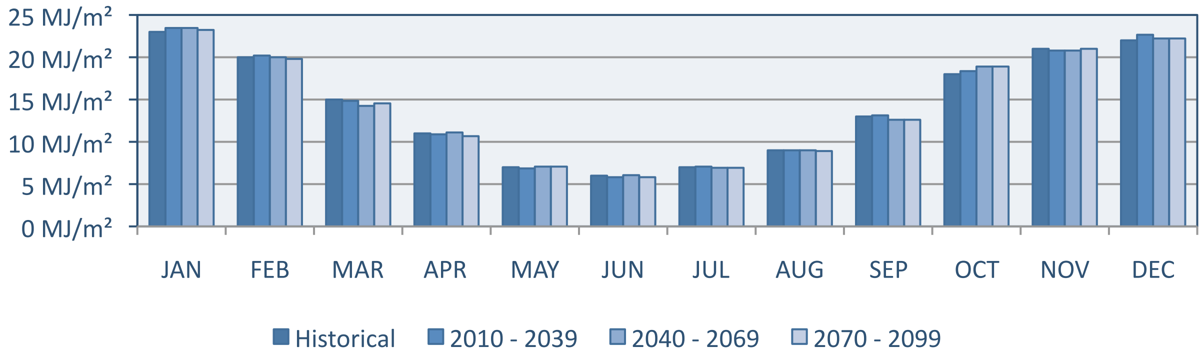
TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+5%	+5%	+4%	+5%	+5%	+8%	+9%	+6%	+8%	+8%	+3%	+7%
2040 - 2069	+6%	+6%	+5%	+8%	+10%	+13%	+15%	+10%	+8%	+14%	+6%	+8%
2070 - 2099	+7%	+7%	+5%	+10%	+11%	+14%	+16%	+12%	+10%	+14%	+7%	+10%

Average Monthly Radiation (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	+1%	+1%	-2%	-1%	0%	-3%	0%	0%	-1%	+4%	-1%	0%
2040 - 2069	+1%	0%	-3%	0%	-3%	0%	-1%	0%	-2%	+1%	0%	+2%
2070 - 2099	+2%	-4%	-3%	-3%	-2%	-2%	-3%	-1%	-2%	+5%	+2%	+3%

Average Monthly Radiation (B1 Scenario)



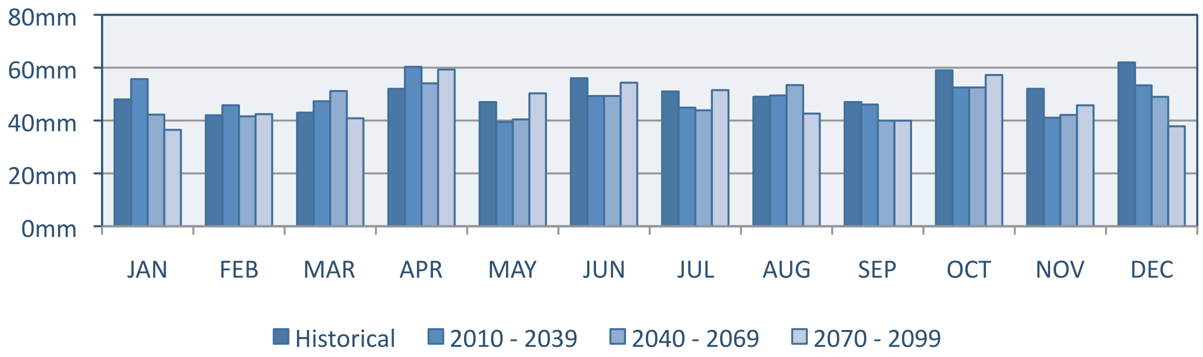
A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	+2%	+1%	-1%	-1%	-2%	-3%	+1%	0%	+1%	+2%	-1%	+3%
2040 - 2069	+2%	0%	-5%	+1%	+1%	+1%	-1%	0%	-3%	+5%	-1%	+1%
2070 - 2099	+1%	-1%	-3%	-3%	+1%	-3%	-1%	-1%	-3%	+5%	0%	+1%

MIROC3.2 MEDRES

Center for Climate System Research - University of Tokyo

The Model for Interdisciplinary Research on Climate (MIROC) is a coupled general circulation model consisting of five components: atmosphere, land, sea ice, river, and ocean. The atmospheric component of the climate model is the CCSR/NIES/FRCGC AGCM version 5.7.

Average Monthly Rainfall (A2 Scenario)

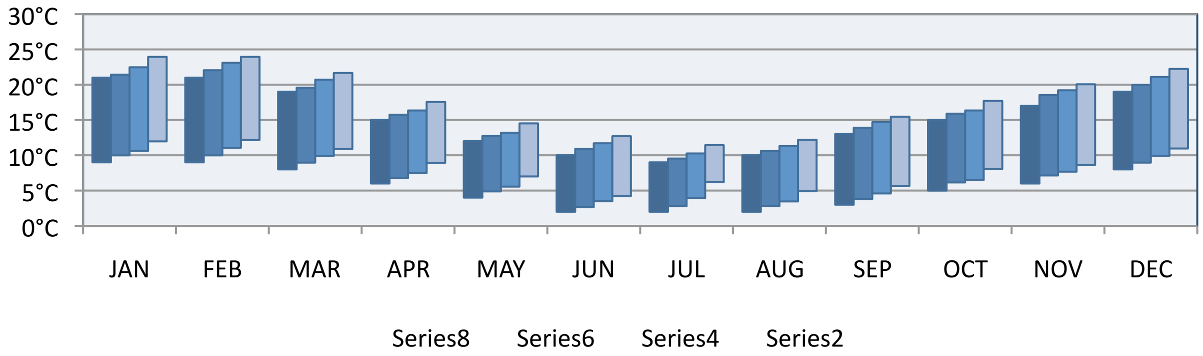


A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	+16%	+9%	+10%	+16%	-16%	-12%	-12%	+1%	-2%	-11%	-21%	-14%
2040 - 2069	-12%	-1%	+19%	+4%	-14%	-12%	-14%	+9%	-15%	-11%	-19%	-21%
2070 - 2099	-24%	+1%	-5%	+14%	+7%	-3%	+1%	-13%	-15%	-3%	-12%	-39%

Average Monthly Rainfall (B1 Scenario)

Data not available

Average Monthly Temperature (A2 Scenario)



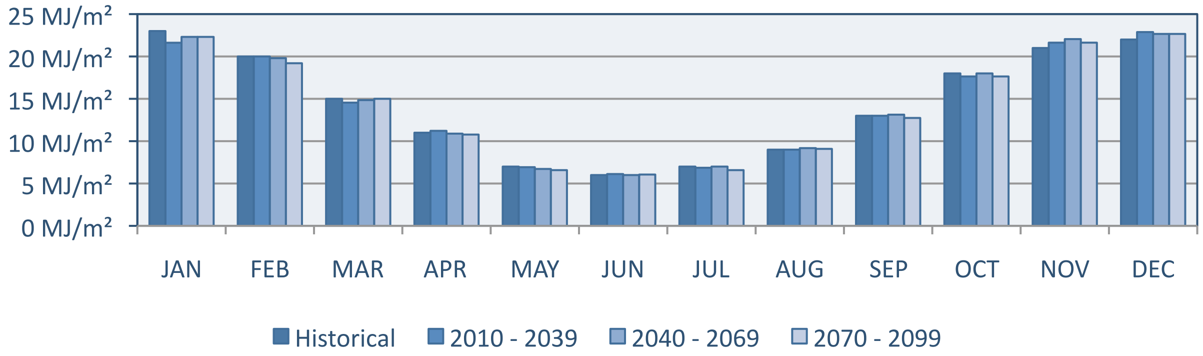
TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+11%	+11%	+12%	+13%	+22%	+33%	+39%	+40%	+27%	+23%	+19%	+12%
2040 - 2069	+18%	+23%	+24%	+25%	+39%	+74%	+96%	+73%	+53%	+30%	+28%	+24%
2070 - 2099	+33%	+35%	+36%	+49%	+75%	+110%	+209%	+145%	+89%	+61%	+44%	+37%

TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+2%	+5%	+3%	+5%	+6%	+9%	+6%	+6%	+7%	+6%	+9%	+5%
2040 - 2069	+7%	+10%	+9%	+9%	+10%	+17%	+14%	+13%	+13%	+9%	+13%	+11%
2070 - 2099	+14%	+14%	+14%	+17%	+21%	+27%	+27%	+22%	+19%	+18%	+18%	+17%

Average Monthly Temperature (B1 Scenario)

Data not available

Average Monthly Radiation (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	-6%	0%	-3%	+2%	-1%	+2%	-2%	0%	0%	-2%	+3%	+4%
2040 - 2069	-3%	-1%	-1%	-1%	-4%	0%	0%	+2%	+1%	0%	+5%	+3%
2070 - 2099	-3%	-4%	0%	-2%	-6%	+1%	-6%	+1%	-2%	-2%	+3%	+3%

Average Monthly Radiation (B1 Scenario)

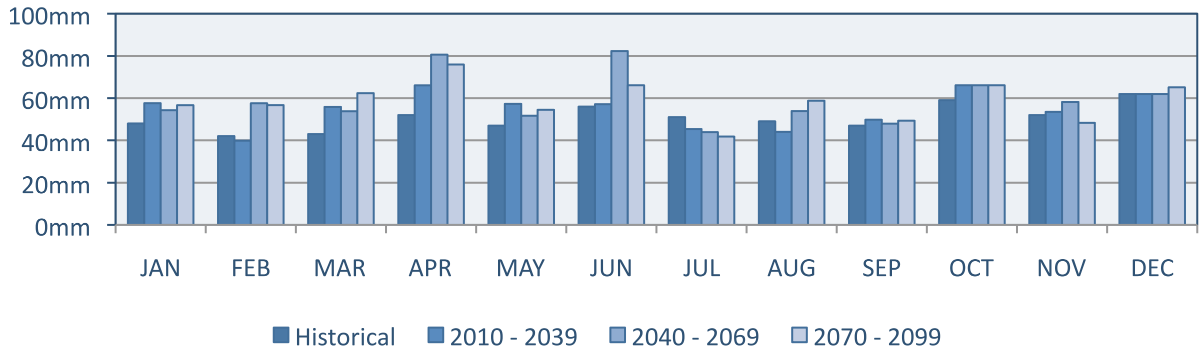
Data not available

HADCM3

Hadley Centre for Climate Prediction and Research, United Kingdom

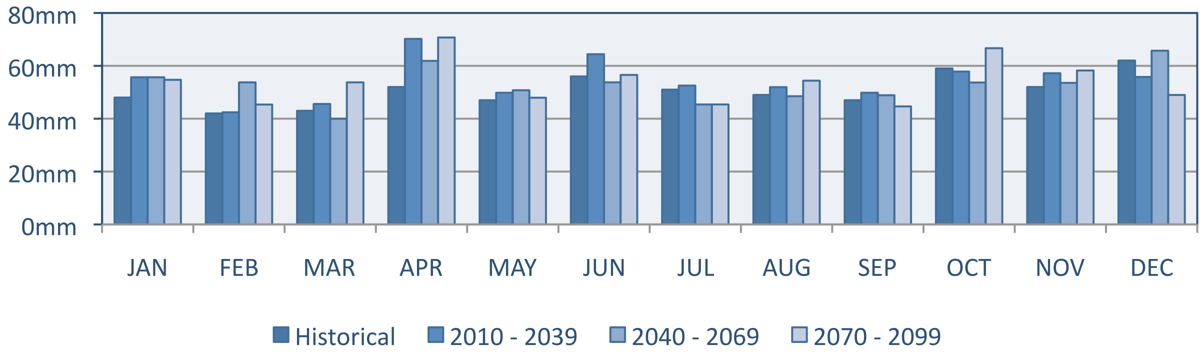
HaDCM3 is a coupled atmosphere-ocean general circulation model (AOGCM) developed by the Hadley Center at the Meteorology Once, UK. The atmosphere component of this climate model has 19 vertical levels and a horizontal 86 resolution of 2.5° latitude x 3.75° longitude. At this fine oceanic resolution, the climate model can effectively represent important details in the oceanic current structure.

Average Monthly Rainfall (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	+20%	-5%	+30%	+27%	+22%	+2%	-11%	-10%	+6%	+12%	+3%	0%
2040 - 2069	+13%	+37%	+25%	+55%	+10%	+47%	-14%	+10%	+2%	+12%	+12%	0%
2070 - 2099	+18%	+35%	+45%	+46%	+16%	+18%	-18%	+20%	+5%	+12%	-7%	+5%

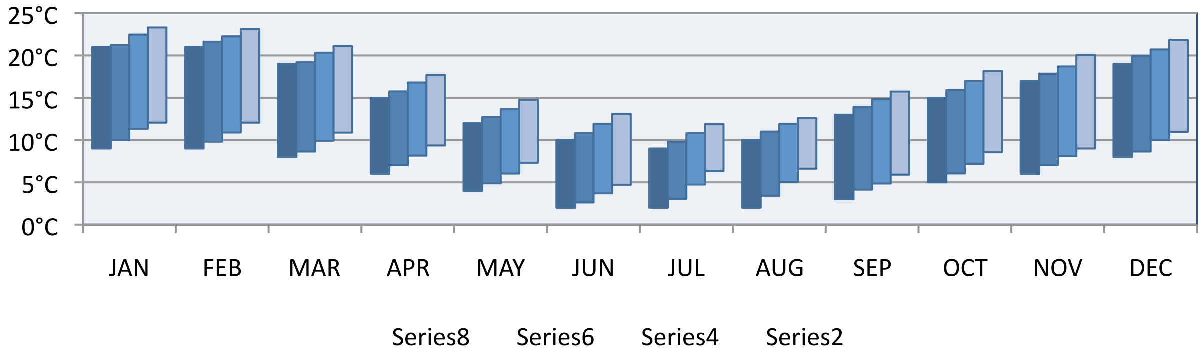
Average Monthly Rainfall (B1 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**48mm**	**42mm**	**43mm**	**52mm**	**47mm**	**56mm**	**51mm**	**49mm**	**47mm**	**59mm**	**52mm**	**62mm**
2010 - 2039	+16%	+1%	+6%	+35%	+6%	+15%	+3%	+6%	+6%	-2%	+10%	-10%
2040 - 2069	+16%	+28%	-7%	+19%	+8%	-4%	-11%	-1%	+4%	-9%	+3%	+6%

2070 - 2099	+14%	+8%	+25%	+36%	+2%	+1%	-11%	+11%	-5%	+13%	+12%	-21%

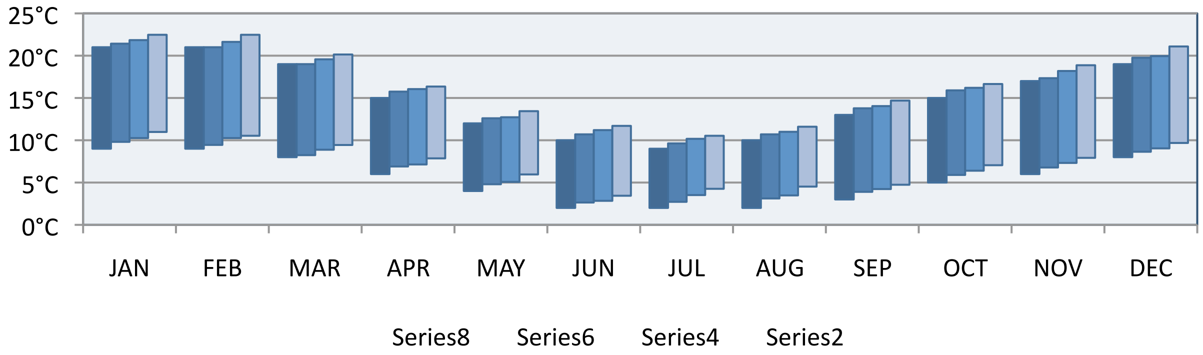
Average Monthly Temperature (A2 Scenario)



TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+11%	+9%	+8%	+17%	+22%	+31%	+53%	+71%	+38%	+21%	+17%	+8%
2040 - 2069	+26%	+21%	+24%	+36%	+51%	+85%	+137%	+152%	+62%	+44%	+35%	+25%
2070 - 2099	+34%	+34%	+36%	+56%	+83%	+136%	+218%	+231%	+97%	+71%	+50%	+37%

TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+1%	+3%	+1%	+5%	+6%	+8%	+9%	+10%	+7%	+6%	+5%	+5%
2040 - 2069	+7%	+6%	+7%	+12%	+14%	+19%	+20%	+19%	+14%	+13%	+10%	+9%
2070 - 2099	+11%	+10%	+11%	+18%	+23%	+31%	+32%	+26%	+21%	+21%	+18%	+15%

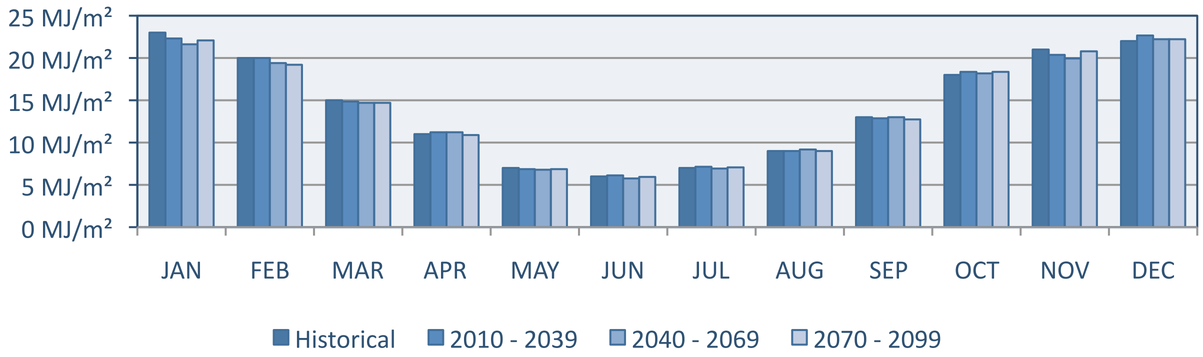
Average Monthly Temperature (B1 Scenario)



TMIN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**9°C**	**9°C**	**8°C**	**6°C**	**4°C**	**2°C**	**2°C**	**2°C**	**3°C**	**5°C**	**6°C**	**8°C**
2010 - 2039	+9%	+5%	+3%	+15%	+20%	+32%	+36%	+56%	+30%	+18%	+13%	+8%
2040 - 2069	+14%	+14%	+11%	+19%	+27%	+42%	+76%	+74%	+41%	+28%	+22%	+13%
2070 - 2099	+22%	+17%	+18%	+31%	+49%	+72%	+113%	+126%	+58%	+41%	+32%	+21%

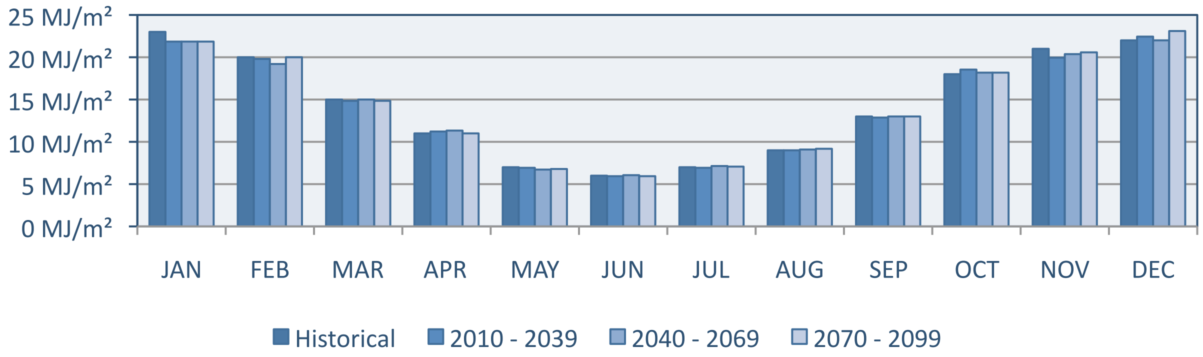
TMAX	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**21°C**	**21°C**	**19°C**	**15°C**	**12°C**	**10°C**	**9°C**	**10°C**	**13°C**	**15°C**	**17°C**	**19°C**
2010 - 2039	+2%	0%	0%	+5%	+5%	+7%	+7%	+7%	+6%	+6%	+2%	+4%
2040 - 2069	+4%	+3%	+3%	+7%	+6%	+12%	+13%	+10%	+8%	+8%	+7%	+5%
2070 - 2099	+7%	+7%	+6%	+9%	+12%	+17%	+17%	+16%	+13%	+11%	+11%	+11%

Average Monthly Radiation (A2 Scenario)



A2	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	-3%	0%	-1%	+2%	-2%	+2%	+2%	0%	-1%	+2%	-3%	+3%
2040 - 2069	-6%	-3%	-2%	+2%	-3%	-4%	-1%	+2%	0%	+1%	-5%	+1%
2070 - 2099	-4%	-4%	-2%	-1%	-2%	-1%	+1%	0%	-2%	+2%	-1%	+1%

Average Monthly Radiation (B1 Scenario)



B1	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Historical	**23**	**20**	**15**	**11**	**7**	**6**	**7**	**9**	**13**	**18**	**21**	**22**
2010 - 2039	-5%	-1%	-1%	+2%	-1%	-1%	-1%	0%	-1%	+3%	-5%	+2%
2040 - 2069	-5%	-4%	0%	+3%	-4%	+1%	+2%	+1%	0%	+1%	-3%	0%
2070 - 2099	-5%	0%	-1%	0%	-3%	-1%	+1%	+2%	0%	+1%	-2%	+5%