Estimating the Impacts of Climate Change on Victoria's Runoff using a Hydrological Sensitivity Model

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Executive Summary

This report provides estimated ranges of changes in mean annual runoff for all major Victorian catchments in 2030 and 2070 as a result of climate change. These changes are very approximate and are best used indicate the direction and magnitude of possible changes to water supply. These estimates should be considered with other major drivers of change which may also impact on supply. Due to the nature of the model used to derive these figures, they are intended for general guidance only. More accurate estimates involving the timing and variability of runoff and streamflow changes accounting for climate, land use and other factors will require a more applied approach.

Estimating the impact of climate change on runoff at the catchment scale has long been a difficult process. It involves taking the output from climate change models, scaling those in some way to estimate local changes, and applying those data to hydrological models. The method illustrated here is intended to provide a simple and quick estimate – a capacity that has previously been unavailable. It provides projections of change for runoff that complement the regional climate change projections for rainfall, temperature and potential evaporation normally provided by CSIRO.

The first part of the report describes the construction of a model representing hydrological sensitivity to climate change. It is a very simple model: percent change in mean annual rainfall and potential evaporation are used to estimate the percent change in mean annual streamflow. The model works best for more small to modest changes: because of non-linear responses of runoff to large changes in climate, results indicating a greater than 50% change from current runoff are not quantified further.

Projected changes in runoff for Victoria

In 2030, the most favourable outcome is a change in mean annual runoff of 0% to -20% occurring in catchments in the east and south of the state (East Gippsland shows a small chance of an increase) and, at worst, the possible change ranges from -5% to -45% in the west of the state. In 2070, increased runoff of 20% in East Gippsland is possible, but the minimum change across most of the state ranges between -5% and -10%. At worst, the model indicates changes that exceed a 50% reduction in all catchments.

<table>
<tr><th>Area</th><th colspan="2">2030 Range of Change</th><th colspan="2">2070 Range of Change</th></tr>
<tr><td></td><td>Wettest</td><td>Driest</td><td>Wettest</td><td>Driest</td></tr>
<tr><td>North-East</td><td>0%</td><td>-20% to -30%</td><td>-5%</td><td rowspan="4">Decreases greater than 50%</td></tr>
<tr><td>North-West</td><td>-5%</td><td>-35% to -45%</td><td>-5% to -10%</td></tr>
<tr><td>South- East</td><td>+5% to -5%</td><td>-20% to -30%</td><td>+20% to -5%</td></tr>
<tr><td>South-West</td><td>-5%</td><td>-30% to -40%</td><td>-5% to -10%</td></tr>
</table>

These changes are independent of any variations in runoff due to changes in natural climate variability or to processes such as land-use change.

Introduction

The hydrological sensitivity of a catchment to climate change can be defined as the change in average water yield (surface runoff and baseflow) to a given change in climate. If hydrological sensitivity can be estimated using simple changes in climate and easily obtained catchment characteristics, it should be possible to approximate potential changes in water yield for any catchment without calibrating and running a hydrological model.

Although the hydrological sensitivity across a range of catchments under current climate has been estimated (e.g. Milly and Dunne, 2002; Dooge et al., 1999), most studies assessing sensitivity to climate change are more strictly assessing hydrological model sensitivity (e.g. Singh and Bengtsson, 2004). That is, a range of climate changes have been applied to a model calibrated for a specific catchment. The resulting sensitivity is specific to that model and that catchment. Applying a single model to a range of catchments will produce an estimate of hydrological model sensitivity to climate change: the response of a particular hydrological model to a known quantum of climate change. Therefore, while model sensitivity to a given catchment can be assessed, it is difficult to take this information and apply it to catchments with different physical characteristics.

To develop a method of assessing the hydrological sensitivity of catchments to climate change (this is largely independent of hydrological model structure), we explored the following two questions:

1. Which catchment characteristics are the main components of hydrological sensitivity?
2. What influence does model structure have on the sensitivity of the hydrological response to a perturbed climate?

The ultimate aim is to develop a simple method of estimating the hydrological sensitivity to a catchment that is independent of individual rainfall-runoff model structure. This report describes results that go part of the way in doing this.

One way to explore the sensitivity of hydrological models to climate change is to apply a set of climate change scenarios to a selection of models over a range of catchments that represent a variety of land uses and climates. These scenarios can either be artificial or represent plausible climate changes. In this situation, the emphasis is not on the precision of a single scenario or the accuracy of the resulting model output, but is instead on exploring a wide range of climatic and hydrological uncertainty.

Jones et al. (submitted) used this approach for 22 catchments across Australia, undertaking sensitivity analyses using three relatively simple hydrological models: two lumped parameter conceptual daily rainfall-runoff models [SIMHYD (Chiew et al., 2002), AWBM (Boughton and Chiew, 2003; Boughton, 2004) and one top-down 2 parameter model (Zhang et al., 2001)]. They described how this information may be used to develop a rule-of-thumb model that can be applied to make rapid estimates of potential changes in runoff under climate change.

Here, we have used the results from that work to create a model for assessing hydrological sensitivity that uses changes in mean annual rainfall (P) and wet environment evapotranspiration (Etw). This simple model is applied to all the major catchments in Victoria to estimate possible ranges of change in mean annual water supply in 2030 and 2070 consistent with the projected changes in climate reported for Victoria by Whetton et al. (2002) and Suppiah et al. (2004).

The next few pages describe the technical aspects of the model, firstly summarising the approach used by Jones et al. (submitted), then describing how the simple model estimating catchment runoff in Victoria was constructed, before presenting the results along with caveats describing their appropriate use.

Approach

Most rainfall-runoff models utilise inputs of mean annual rainfall (P) and potential evapotranspiration (Ep) to estimate changes in runoff. Hydrological model sensitivity to climate change is considered here as the change in mean annual runoff (δQ) resulting from changes in mean annual precipitation (P) and potential evapotranspiration (Ep) produced by a specific hydrological model. The resultant changes in Q can be expressed as:

$\delta Q = f(\delta P, \delta Ep)$ Equation 1

where δQ is change in mean annual runoff, δP is change in mean annual precipitation, δEp is change in mean annual potential evapotranspiration. Recent work shows that the response in Q is fairly consistent across a number of rainfall-runoff models where the P/Ep ratio ranges between about 0.5 and 2 (Jones and Page, 2001; Chiew et al., 2005).

For example, Jones and Page (2001) coupled a climate change scenario generator to a catchment-scale hydrological model for the Macquarie River in eastern Australia, applying over 50 scenarios. They found that Equation 1 could be expressed as:

$\delta Q = A\ \delta P + B\ \delta Ep$ Equation 2

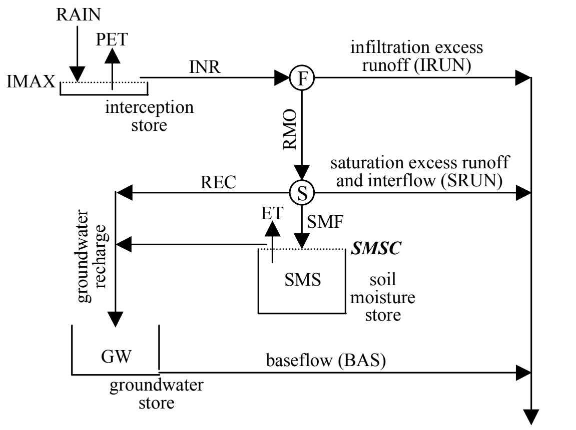
where a and b are constants. This linear relationship performed well over most of the range of potential change for 2030 and 2070 except for exceptionally large decreases in rainfall where the relationship became non-linear. This simple relationship estimated percent change to mean annual flow with a standard error of ±2% mean annual flow for the Macquarie catchment (Jones and Page, 2001).

Factor A is a measure of the sensitivity of the model to change in P and factor B to change in Ep, both variables measured as percent change to the annual total. The use of potential evaporation rather than temperature to measure hydrological sensitivity is preferred because it is a more direct measure of moisture demand from the catchment surface.

The next step involved an assessment of how the A and B factors vary across different catchments (Jones et al., submitted). They used two rainfall-runoff models in this analysis: SIMHYD (Chiew et al., 2002) and AWBM (Boughton and Chiew, 2003). A third model, a simple conceptual model constructed by Zhang et al. (2001), was investigated by Jones et al. (submitted) but is not used here because its simplicity did not adequately account for the biophysical variations between catchments. Both SIMHYD and AWBM have been used widely in Australia.

The hydrological models

SIMHYD is a seven-parameter simple lumped conceptual daily rainfall-runoff model. 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 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.



PET	=	areal potential evapotranspiration (input data)
IMAX	=	lesser of { ***INSC***, PET }
INT	=	lesser of { IMAX, RAIN}
INR	=	RAIN - INT
RMO	=	lesser of { COEFF exp (-***SQ*** x SMS/***SMSC***) , INR }
IRUN	=	INR - RMO
SRUN	=	***SUB*** x SMS/***SMSC*** x RMO
REC	=	***CRAK*** x SMS/***SMSC*** x (RMO - SRUN)
SMF	=	RMO - SRUN - REC
POT	=	PET - INT
ET	=	lesser of { 10 x SMS/***SMSC*** , POT }
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 1: Model structure of SIMHYD

Evapotranspiration from the soil moisture store is estimated as a linear function of the soil wetness, but cannot exceed the atmospherically controlled rate of areal potential evapotranspiration. The soil moisture store has a finite capacity and overflows into the groundwater store. Baseflow from the groundwater store is simulated as a linear recession from the store. The successful calibration (and verification) of SIMHYD on the 22 catchments selected for this study and many other Australian catchments are described in Peel et al. (2000) and Chiew et al. (2002).

AWBM has a similar structure to SIMHYD. It divides the catchment into three partial areas (A1, A2, A3), each with its own storage capacities (C1, C2, C3). Each area is treated separately. Daily rainfall fills the stores, with the spills becoming rainfall excess. A portion of the rainfall excess (baseflow index times rainfall excess) flows to the groundwater store, and the remainder becomes surface runoff. Baseflow from the groundwater store is simulated as a linear recession from the store. Evapotranspiration from all three stores proceeds at the potential rate. The total runoff is the sum of surface runoff and baseflow.

A simplified and robust version of AWBM (UGAWBM3 – see Boughton and Chiew, 2003) was used by Jones et al. (submitted). It has three parameters: average surface store capacity (C_{ave}); baseflow index (BFI) and baseflow recession constant (K_b). The three partial areas are set to default values and the storage capacities are determined from the average surface store capacity (see Figure 2).

In UGAWBM3, the parameter C_{ave} is determined from a set of daily rainfall and runoff data, such that the total modelled runoff is the same as the total recorded runoff. The remaining two parameters, BFI and K_b, are then optimised to provide the best match between the modelled and recorded daily runoffs. The catchments produce Coefficient of Efficiency measurements of between 0.65 and 0.95 with an average of 0.86.

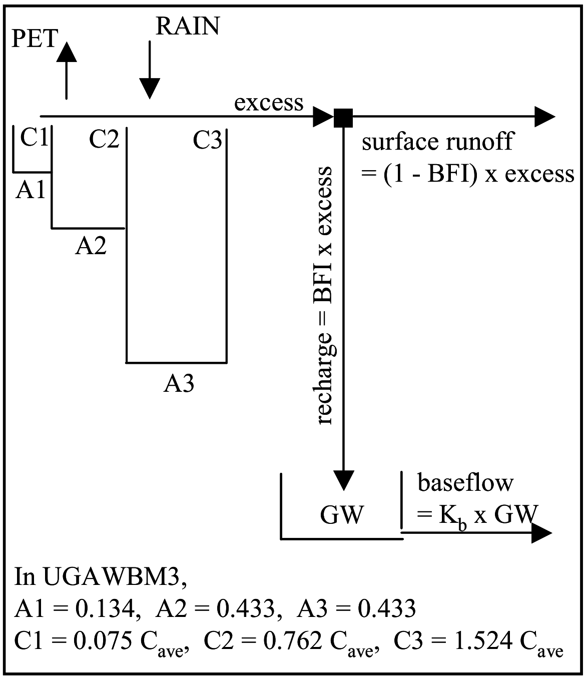


Figure 2: Structure of the AWBM model.

Model sensitivity analysis

The sensitivity analysis was carried out for 22 catchments that produce some of the best model calibration results (Nash-Sutcliffe efficiency; Nash and Sutcliffe, 1970) of 331 largely natural or "unimpaired" catchments across Australia (Peel et al., 2000). They were selected for an efficiency rating for monthly runoff prediction of greater than 0.8, a calibration against at least 15 years of streamflow data and to provide a good representation of different climates across Australia. Cross correlation between parameters was not addressed, as the emphasis was on the best reproduction of streamflow possible.

The sensitivity analysis involved the application of regular increments of change in annual P and Ep to inputs of daily data. The results are expressed as changes in mean annual runoff. Rainfall increments of -15%, -10%, 0 and +10% were used and Ep increments of 0, +5% and +10% for a total of 12 samples for each model run in each catchment. The constant factors, A and B, were determined by method of least squares regression, by minimising the sum of squares of the difference between δQ determined from the AWBM and SIMHYD modelling results and δQ estimated by equation (1). In most cases, the resulting R^2 statistic ranged between 0.97–0.999 and standard error was <2% of mean annual flow.

Figure 3 shows the relationship between the derived A and B factors for the SIMHYD and AWBM models across the 22 catchments.

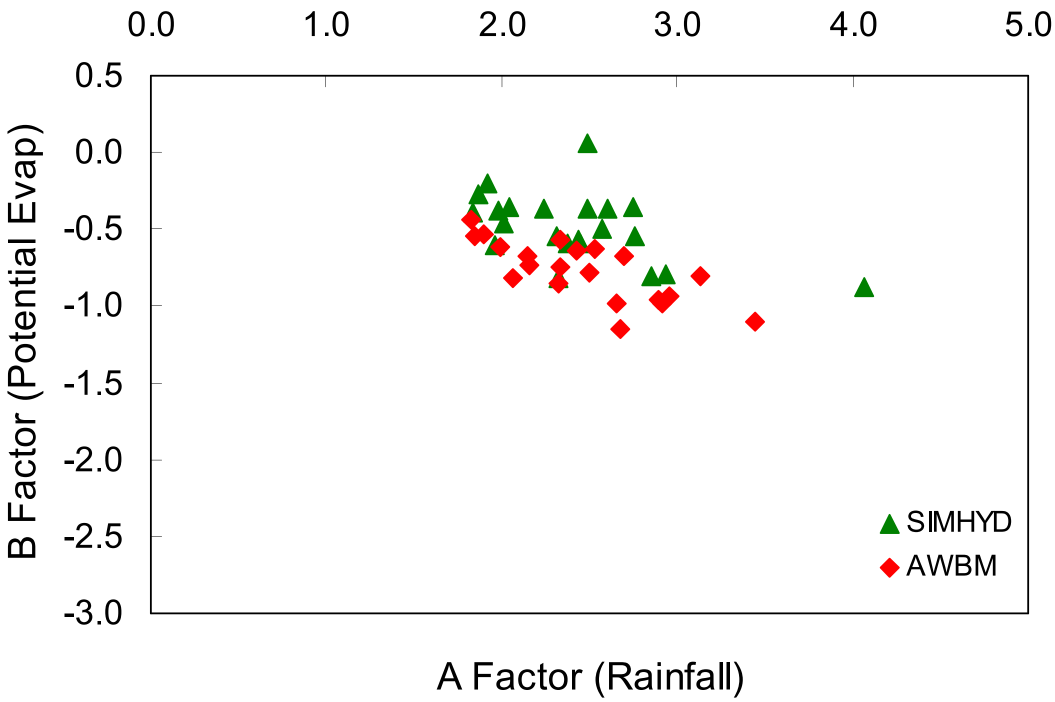


Figure 3. Relationship between A and B factors for the SIMHYD and AWBM models across the 22 catchments.

Both models show that runoff is more sensitive to changes in rainfall than to changes in Ep. The sensitivity of runoff to rainfall is similar in the SIMHYD and AWBM models (Average A factor of 2.5 and 2.4 respectively). The runoff sensitivity to Ep is greater in AWBM

(Average B factor = -0.8) than SIMHYD (Average B factor = -0.5). The B factors have negative values showing that increases in potential evaporation reduce runoff. Therefore, the overall sensitivity of the SIMHYD and AWBM models to climate change across a range of catchments (measured as the standard deviation of values for the 22 catchments) is similar, with AWBM being slightly more sensitive to rainfall decreases and SIMHYD to rainfall increases (Jones et al., submitted). The values of the A and B factors from the two models were also highly correlated across the 22 catchments, being 0.83 for the A factor and 0.66 for the B factor. The A and B factors were also correlated with a wide range of both hydroclimatic and physical catchment characteristics (Table 1).

Table 1. Correlation between major catchment characteristics and A and B factors for each of the SIMHYD and AWBM models.

	Latitude	Longitude	Area (km^2)	Annual rainfall (mm)	Annual runoff (mm)	Runoff coefficient (%)	Annual Ep (mm)	Annual Ep/P (ratio)	Baseflow Index BFI
SIMHYD (A Factor)	0.05	-0.10	0.50	-0.47	-0.72	-0.83	-0.10	0.20	-0.10
SIMHYD (B Factor)	-0.31	-0.15	-0.17	-0.10	0.13	0.22	0.24	0.50	-0.34
AWBM (A Factor)	-0.05	-0.36	0.35	-0.53	-0.75	-0.87	-0.05	0.43	0.03
AWBM (B Factor)	0.08	0.09	-0.45	0.15	0.33	0.45	-0.07	-0.11	-0.18

Table 1 shows that correlations between A factor and rainfall were moderately negative (-0.47 to -0.53), higher for runoff (-0.72 to -0.75) and highly negative for runoff coefficient (runoff as a percentage of rainfall: -0.83 to -0.87). Therefore, catchment sensitivity to rainfall change (measured as percentage change from the baseline) increases as catchments become drier.

Correlations with the A factor were also negative for leaf area index, the proportion of woody vegetation and plant water-holding capacity (not shown). These negative correlations imply that hydrological sensitivity decreases with higher amounts of land cover and soil moisture. However, both factors increase with catchment rainfall and so also show proportional increase with the runoff co-efficient. Further tests, which involved manipulating these factors within a hydrological model, indicated that increasing soil depth and vegetation cover will make a catchment more sensitive to a given quantum of climate change.

The B factor was less sensitive to catchment characteristics, being most highly correlated with annual mean rainfall, percent runoff and vegetation characteristics. Ep sensitivity is also partially model dependent because of the different ways in which it is treated in different models. SIMHYD evaporates at a reduced level at low soil moisture whereas AWBM evaporates at the areal potential rate between field capacity and wilting point, so is slightly more sensitive to changes in potential evapotranspiration.

In summary, these tests show that for these two hydrological models, the simulated climate change response of runoff to δP and δEp is highly correlated between catchments, that δQ is two to three times more sensitive to δP than δEp, that these sensitivities increase with decreasing runoff co-efficients (i.e. with catchment aridity). Correlations between leaf area index, soil depth and catchment sensitivity are not independent of rainfall, so negative correlations between these factors across different catchments can largely be explained through rainfall variation. However, rainfall-runoff model simulations show that if two catchments in the same climate have a shallow and deep soil respectively, the catchment with the deeper soil will be more sensitive to climate change. This is partly due to the greater role of Ep in catchments with deeper soils, but the role of different catchment characteristics in hydrological sensitivity needs to be examined further.

Sensitivities of both the A and B factors as a function of the runoff coefficient (runoff as a percentage of rainfall) are shown in Figure 4.

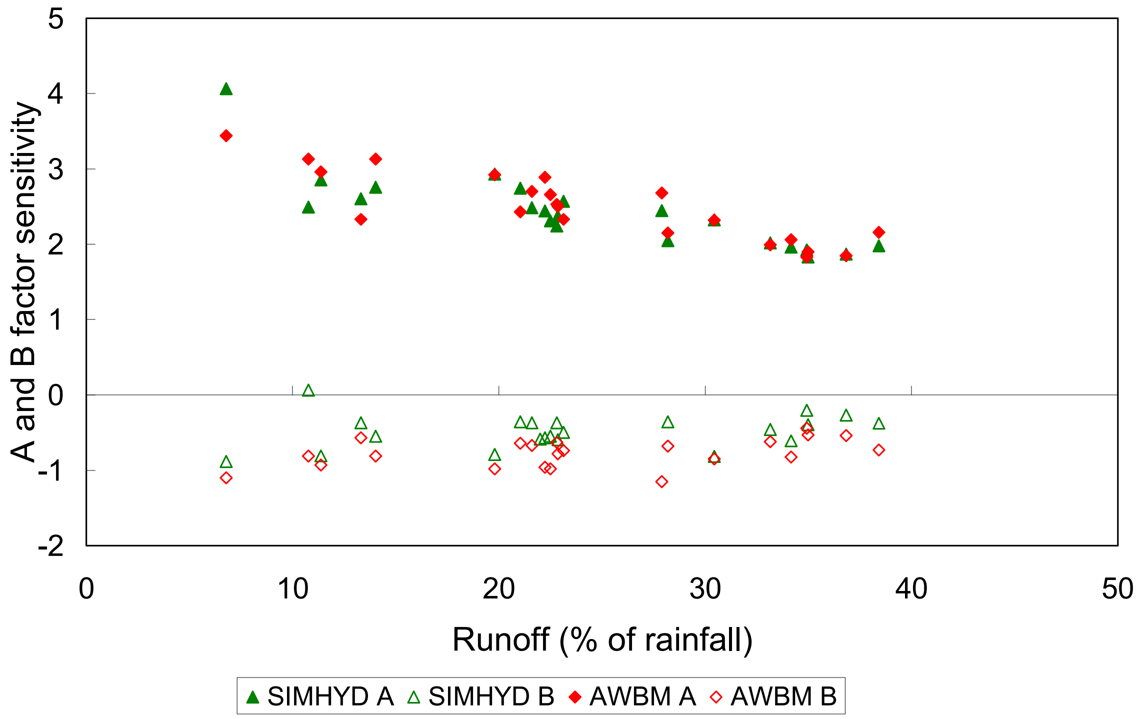


Figure 4. Sensitivity of A and B factors for the SIMHYD and AWBM models plotted against runoff as a percentage of mean annual rainfall over 22 catchments.

A simple model for hydrological sensitivity

This section describes how the information on hydrological sensitivity has been developed into a simple model estimating how mean annual flow may change given data on changes in mean annual P and Ep.

In the current study, for Ep we have used wet environment (or areal) evapotranspiration (Etw; see Morton, 1983; BoM, 2001). Etw is a more realistic measure of potential evaporation for hydrological modelling than either A Class pan evaporation or equivalent measures of point potential evapotranspiration (Etp). The difference between potential evapotranspiration at a point and over a larger area is that Ep from a point is too small to modify the overpassing airmass, whereas areal Ep measures the total potential evapotranspiration coming from a surface in equilibrium with the overpassing airmass, and where water is unlimited. It follows that areal potential evaporation is less than evaporation at a point. The application of a pan factor to A Class pan evaporation has often been used to estimate Etw, but differences in changes between Etp and Etw under climate change means that it is best not to use this approach to estimate hydrological impacts.

The highest joint correlations between the A and B factors and the range of catchment variables explored in the previous section was for the runoff coefficient measured as a percentage of rainfall. Therefore, the following simple model was constructed:

$$\delta Q = (C \times Qc \times \delta P) + (D \times Qc \times \delta Etw) \qquad \text{Equation 3}$$

where Qc is the runoff coefficient measured as runoff a percentage of rainfall and C and D are constants.

The values for C and D were constructed by the least squares regression method by regressing the A and B factors from Equation 2 against Qc using all of the SIMHYD and AWBM results, so the resulting outcome has a hydrological sensitivity midway between the two models. The results are shown in Table 2. Therefore C × Qc = A, and D × Qc = B in Equation 2.

Table 2 shows that the variation in the C factor will have the greatest bearing on δQ. The strategy in choosing the runoff co-efficient was to maximise the predictability of the A abd B factors as in Equations 2. Because δP is the driving variable (it is up to 3.5 times more sensitive than δEtw) the low R^2 variable for the D factor is of low concern given the much high R^2 for the C factor.

Table 2. Regression factors for C and D factors in Equation 2. The factor y_0 is the origin for the relationship, the A factor is multiplied with Qc to obtain C and D respectively.

Factor	**y_0**	**A**	**R^2**	**Standard Error**
C	3.5172	-0.0440	0.71	0.25
D	-0.8079	0.0074	0.07	0.24

The simple model in Equation 3 was applied in the following manner:

1. Average annual runoff for the major catchments was calculated from figures in the National Land and Water Resources Atlas database and converted to a runoff co-efficient by catchment area.

2. Patterns of change per degree of global warming for δP and δEtw from a range of global climate models were scaled by low, median and high estimates of mean global warming from IPCC (2001) for 2030 (0.54°C, 0.85°C, 1.24°C) and 2070 (1.17°C, 2.??, 3.77°C).
3. Equation 3 (using the runoff coefficient calculated in Step 1) was applied to each catchment to calculate the A and B factors.
4. Equation 2 was applied to calculate change in average annual change runoff for each catchment for 2030 and 2070.

The global climate models from which δP and δEtw were produced for Step 2 were the CSIRO Cubic Conformal, Mark 2 and Mark 3 models; the Canadian CGCM2, CGCM2 A2 SRES and CGCM2 B2 SRES models; the German ECHAM4/OPYC3 model; and the UK HadCM3, HadCM3 A2 SRES and HadCM3 B2 SRES models. The low, high and mid-range estimates of δP and δEtw in 2030 and 2070 were used to assess the range of possible change in δQ for 29 Victorian catchments,

Results

The output from ten climate models applied to three scenarios of global warming produces thirty projections of change in mean annual runoff each for 2030 and 2070. The results are summarised as the ranges of change throughout state in Table 3, and for each catchment in Table 4, rounded to the closest 5%. Values above 50% are not shown specifically because of the non-linear response of runoff to large changes in climate, which makes the results of this linear model unreliable. The results are also shown in Figure xx.

Table 3. Ranges of change in mean annual runoff for 2030 and 2070 summarised throughout Victoria.

Area	**2030 Range of Change**		**2070 Range of Change**	
	Wettest	Driest	Wettest	Driest
North-East	0%	-20% to -30%	-5%	Decreases greater than50%
North-West	-5%	-35% to -45%	-5% to -10%	
South- East	+5% to -5%	-20% to -30%	+20% to -5%	
South-West	-5%	-30% to -40%	-5% to -10%	

Overall, the potential decreases in runoff tend to be smaller in the north-east and south-east and somewhat higher in the north-west and south-west. There is even a potential for an increase in runoff in East Gippsland.

In 2030, the most favourable outcomes are generally 0% in the north-east and south-east (East Gippsland shows a small chance of an increase) and -5% in the north-west and south-west. The driest outcomes range from -20% to -30% in the north-east and south-east, to -30% and -40% in the southwest and up to -45% in the north-west.

In 2070, increased runoff in East Gippsland is possible, but the minimum change across most of the State is between -5% and -10%. The largest potential changes in runoff indicated by the model exceed 50% in all Surface Water Management Areas (SWMAs).

Figure 5 shows the changes in runoff in 2030 for each catchment, illustrating the total range and the range obtained using the median global warming from IPCC (2001). The central coloured bar within the upright lines shows the range of changes in runoff obtained using the median global warming (0.85°C) for each catchment. The short tail between the wettest outcome and the wettest outcome under median warming, and the long tail between the two at the dry end shows that the outcomes are skewed towards lesser changes. Very dry outcomes are possible, but less likely. A similar pattern would be expected to occur in 2070, where a change occurring in the wetter two-thirds of the range is more likely than a drier outcome.

Caveats

To interpret these results appropriately, the following factors need to be taken in account:

- The baseline data on runoff is taken from the 1997–2001 National Land and Water Resources Atlas, which is based on data supplied by the Victorian Government and water authorities. Changes are expressed as percentage change from those figures (see http://audit.ea.gov.au/ANRA/water/docs/state_technical/VIC_tecpage.html for a description of the method for deriving mean annual runoff). A more rigorous approach would see a standard length of record used, as was the case for baseline climate (e.g. 1961–1990).
- Both runoff and runoff changes are assessed at the catchment scale. If the changes were area-weighted or contained the spatial detail to represent the higher runoff areas in each catchment more explicitly, the results would be more conservative. For example, most of the runoff within Victoria's catchments is in upland areas, so that climate changes in those places will have the greatest effect on runoff rather than changes averaged across the whole catchment. However, the climate models do not offer that spatial detail in terms of projected climate change because of their large grid sizes (with the exception of the CSIRO Cubic Conformal model), nor do we have access to runoff data at this scale. However, the exploration of a higher resolution approach is planned.
- If changes in decadal mean rainfall occur due to factors other than the greenhouse effect (e.g. long-term variations in natural climate) they will be additional to changes estimated here. This may be a factor if the current run of dry years dating from 1994 continues and climate changes due to the enhanced greenhouse effect also intensify. Alternatively, if wetter, flood-dominated periods similar to the period 1948–1976 occur in the future, the impact of long-term rainfall reductions due to greenhouse will be less severe.
- The figures provided in this report are meant to provide a broad indication of the likely range of mean changes in runoff in Victorian catchments due to the enhanced greenhouse effect. Both the CSIRO researchers and experts within the Victorian Department of Sustainability and Environment, strongly advise that any detailed strategic planning regarding the future allocation and management of water resources should be based on more rigorous scientific assessments and also include an evaluation of other potential impacts on water resources as well as climate change.
- More research is also being planned on how the impacts of the enhanced greenhouse effect and ongoing natural climate variability may combine. This will take place under CSIRO's Healthy Country Flagship Program and the South-eastern Australian Climate Project. Further research will also investigate the impact of using a more spatially explicit approach for estimating hydrological sensitivity to climate change as anticipated by some of the above limitations.

Table 4. Ranges of change in runoff (percentage change of annual average runoff) for 2030 and 2070 across Victoria's major surface water management areas (see Figure 6). The wettest and driest changes delimit measure the total range of change (rounded to the nearest 5%) from all ten climate models in 2030 and 2070. Runoff, developed yield and development category are from the NLWRA database.

Murray-Darling Drainage Division	**Area (km^2)**	**Runoff (ML)**	**Developed Yield (ML)**	**Development Category***	**2030 wettest**	**2030 driest**	**2070 wettest**	**2070 driest**
Upper Murray River[1]	10150	2803000	837950	High Development	0.0	-20.0	-5.0	>-50
Kiewa River	1913	679000	9000	High Development	0.0	-20.0	-5.0	>-50
Ovens River	7985	1692000	26000	High Development	0.0	-25.0	-5.0	>-50
Broken River	7100	326000	32000	High Development	0.0	-35.0	-5.0	>-50
Goulburn River	16858	3366000	1943000	High Development	0.0	-35.0	-5.0	>-50
Campaspe River	4048	305000	121000	High Development	-5.0	-35.0	-5.0	>-50
Loddon River	15658	415000	109000	High Development	-5.0	-35.0	-5.0	>-50
Avoca River	14211	136200	3380	High Development	-5.0	-40.0	-5.0	>-50
Mallee	21595	0	0	High Development	-5.0	-45.0	-5.0	>-50
Wimmera-Avon Rivers	30409	316400	94250	Over Development	-5.0	-40.0	-10.0	>-50
South-east Drainage Division								
East Gippsland	4521	655000	1230	Low Development	5.0	-30.0	20.0	>-50
Snowy River	6856	863000	5400	Medium Development	0.0	-30.0	0.0	>-50
Tambo River	4212	329000	6880	Medium Development	0.0	-30.0	0.0	>-50
Mitchell River	4873	1100000	18900	Medium Development	0.0	-25.0	-5.0	>-50
Thomson-Macalister Rivers[2]	6426	1080600	427370	High Development	0.0	-25.0	-5.0	>-50
Latrobe River	4676	887000	261560	Medium Development	0.0	-20.0	-5.0	>-50
South Gippsland	6789	851000	21870	Low Development	-5.0	-25.0	-5.0	>-50
Bunyip River	4078	354000	46280	Low Development	-5.0	-30.0	-5.0	>-50
Yarra River	4110	1200000	466300	High Development	0.0	-20.0	-5.0	>-50
Maribyrnong River	1453	125400	9980	Low Development	-5.0	-30.0	-5.0	>-50
Werribee River	1978	147000	35900	High Development	-5.0	-30.0	-5.0	>-50
Moorabool River	2225	91400	45270	Medium Development	-5.0	-35.0	-10.0	>-50
Barwon River	3809	250800	45700	Medium Development	-5.0	-30.0	-10.0	>-50
Lake Corangamite	4081	120500	750	High Development	-5.0	-40.0	-10.0	>-50
Otway Coast	3876	750000	26100	Low Development	-5.0	-30.0	-10.0	>-50
Hopkins River	10096	405600	10440	Medium Development	-5.0	-35.0	-10.0	>-50
Portland Coast	3963	231000	1100	Low Development	-5.0	-40.0	-10.0	>-50
Glenelg River	11998	704400	72770	High Development	-5.0	-35.0	-10.0	>-50
Millicent Coast	7426	4000	210	High Development	-5.0	-35.0	-10.0	>-50

[1] The Upper Murray River contains both the Victorian portion of the Upper Murray River catchment and the Mitta Mitta River catchment.
[2] The Thomson-Macalister includes the Thomson, Macalister and Avon catchments.

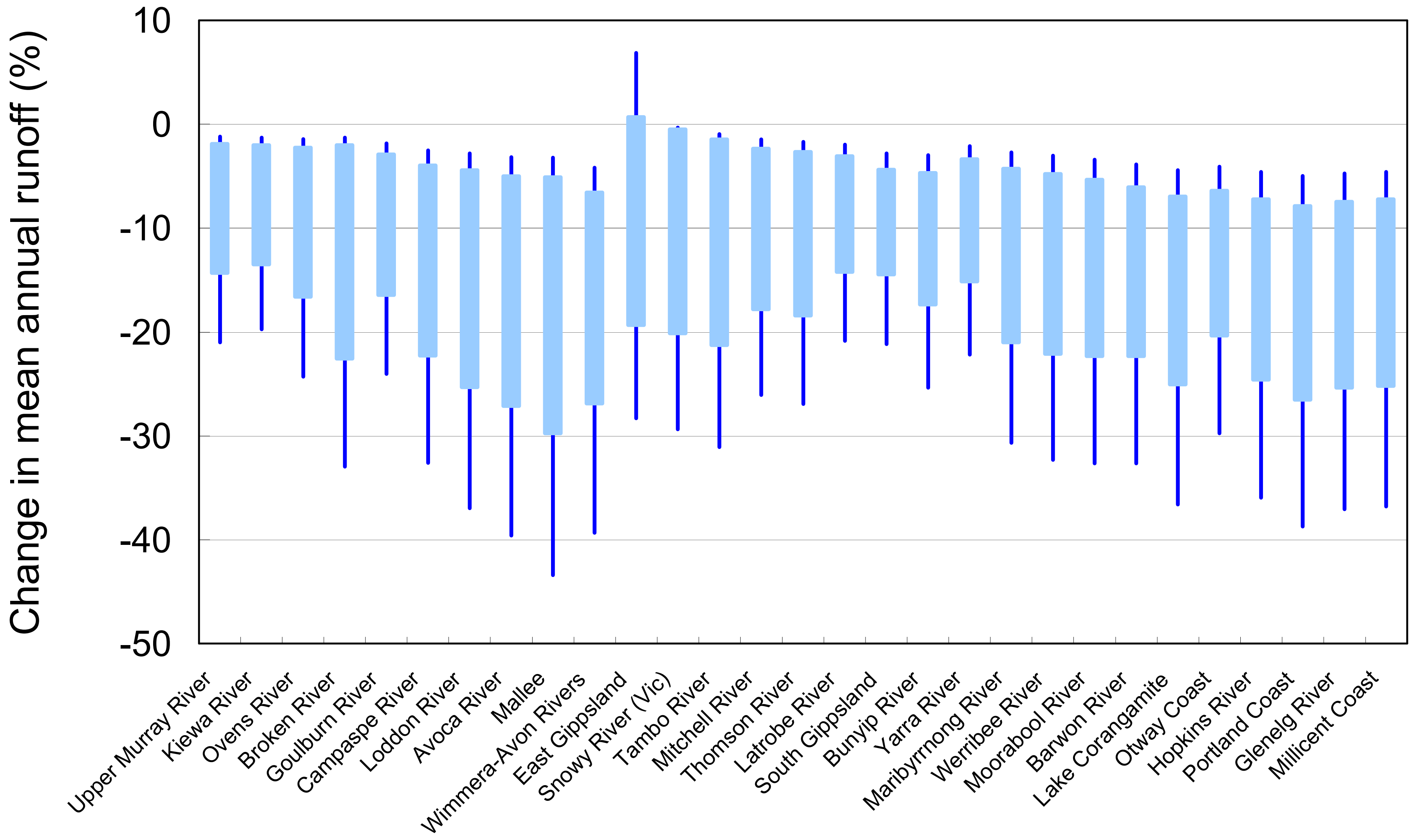


Figure 5. Range of possible change in runoff for 2030 across Victoria's major surface water management areas. The vertical lines measure the total range of change from ten climate models with a range of global warming of 0.54–1.24°C. The central boxes project the range of change at a 0.85°C (median) global warming. These show that the results are biased towards smaller decreases. Note that the Mallee has no effective runoff.

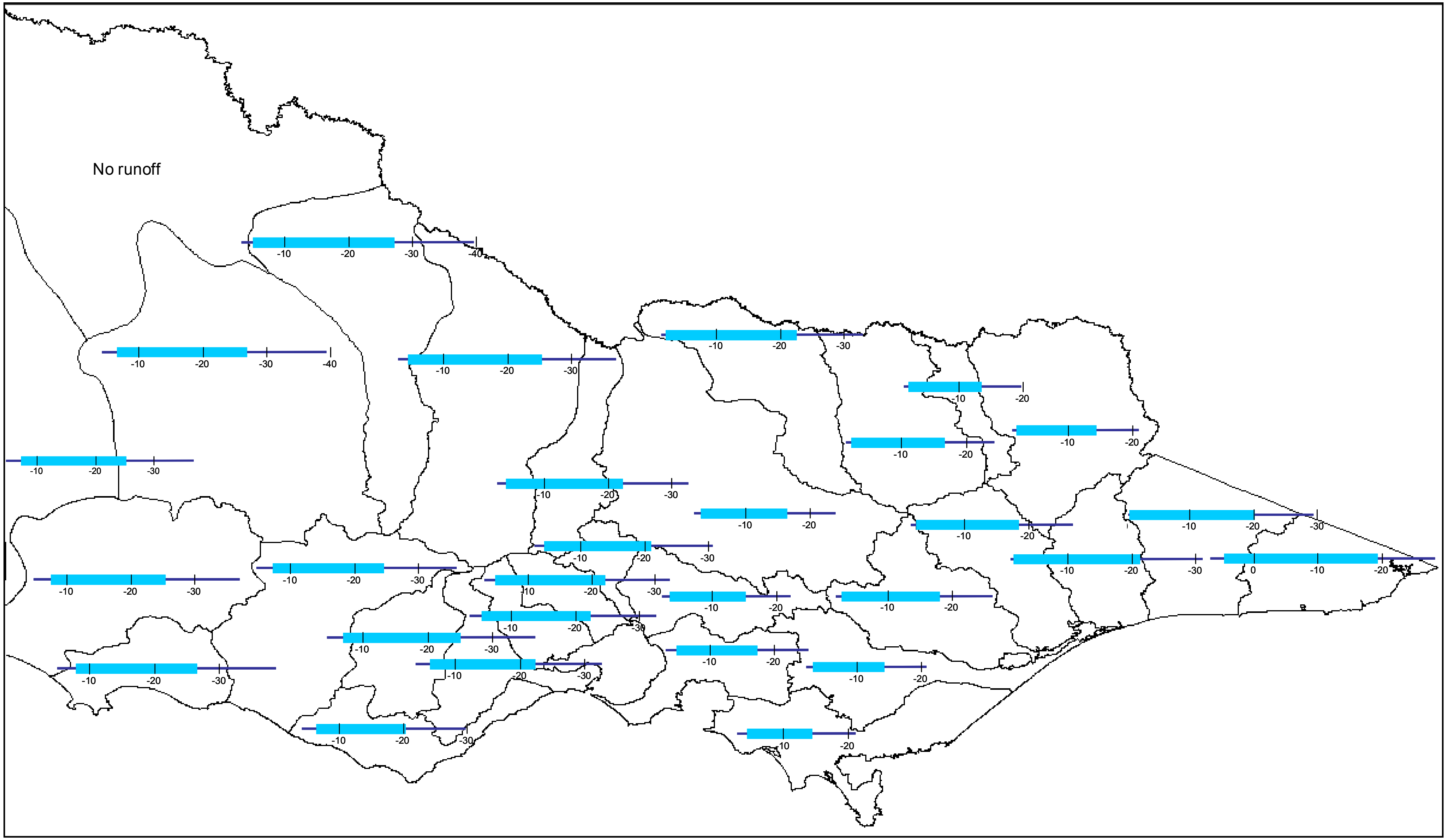


Figure 4. Victoria's 29 major surface water management areas with changes in mean annual runoff from Figure 3. Note that decreases run from right to left.

Individual Areas

Interpretation of changes

The following pages contain a catchment-by-catchment description of major biophysical characteristics, water resources and water use, together with a graphical representation of the results of the simple model for 2030. The catchment descriptions are sourced from the online National Land and Water Resources 1997–2001 Atlas.

An example is shown in Figure 5. The shaded bar shows the range of change as produced by the hydrological sensitivity model. Within that bar are thirty points representing the product of the output from ten climate models multiplied by three values of global warming. Those values are 0.54°C, 0.85°C and 1.24°C, which are the low, median and high outcomes from the IPCC (2001) projections of global warming based on the SRES emission scenarios (see CSIRO, 2001).

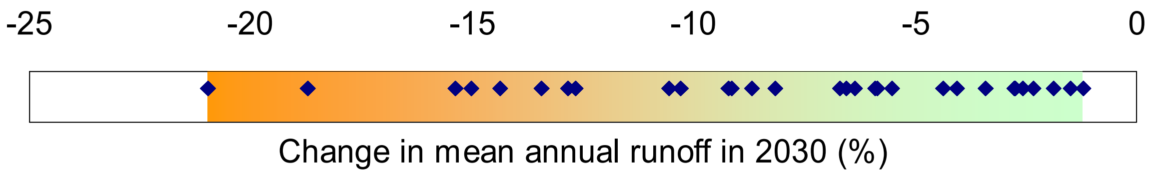


Figure 5. Range of possible change in mean annual runoff for 2030.

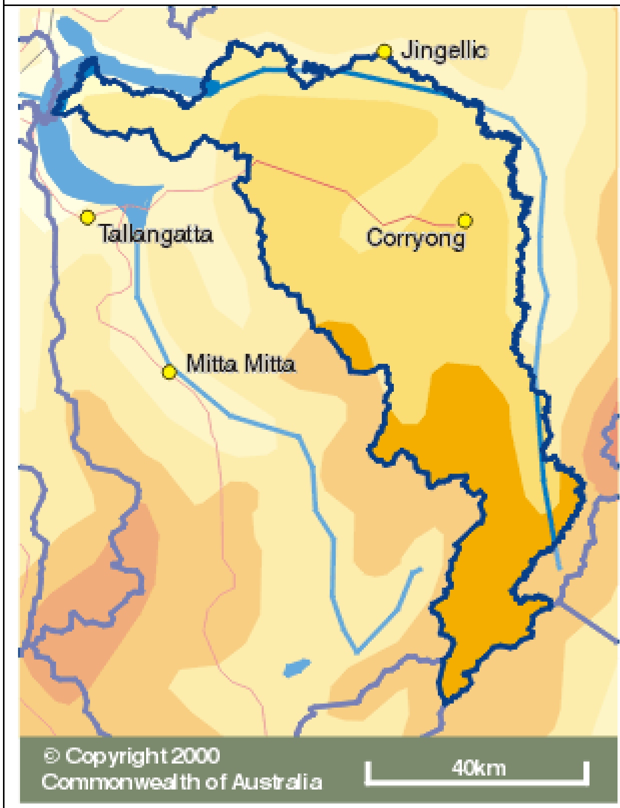
The scatter of these outcomes will indicate whether modest or severe reductions in runoff are projected. In most cases, the models tend to cluster towards the wetter two-thirds or half of the possible range. This can be taken as a guide to where the most likely outcome for the impact of greenhouse-induced climate change on mean annual runoff for each catchment lies. Note that the caveats in the previous section caution that natural climate variability can also affect such outcomes.

How likely is it that the eventual change in mean runoff will occur within the stated range for each catchment? The answer to this question is unknown – currently, there is no objective method of determining the likelihood of runoff reductions falling outside the ranges specified here. It is possible that climate change will affect rainfall and potential evaporation in such a way that has not been captured by any of the models. However, model results point strongly to runoff decreases across the entire state. Although increases in runoff are possible, apart from the East Gippsland SWMA, we have no cases where model output producec estimates of increased runoff at the catchment scale anywhere in Victoria. The most likely places where runoff may increase are along the east and the south coast.

We also have little idea of how decadal scale and longer aspects of natural climate variability may develop, but they could produce changes in rainfall of as much as ±20% from the long-term mean. In addition to the impacts of climate change on mean annual rainfall and evaporation, other associated factors such as the potential for more intense rainfall and changes in fire risk and land use in response to climate change will also be expected to result in some changes in catchment water balances. However, according to current science, these factors are not expected to have as large an impact on catchment water balances as changes in the basic climate parameters (i.e. rainfall and evaporation).

Upper Murray River

Note: both the Upper Murray River and Mitta Mitta River contribute to the Upper Murray Entry in Table 4 and Figures 4 and 5.



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0	-20%
2070	-5%	-50%

*Rounded to the nearest 5%

The Upper Murray River (VIC) Surface Water Management Area (SWMA) refers to the catchment draining to the Murray River above Hume Dam in Victoria. It has a total area of 3,900 km^2.

Rainfall varies from around 700 mm in the lower catchment to over 1,000mm on the higher ridges. The mean annual runoff of the basin is 1,364,000 ML.

Major land uses include forestry, grazing and dairying. Average annual surface water use is 3,450 ML with urban/industrial representing 12% of total use, irrigation 81%, and rural 7%.

Climate change is expected to produce an earlier peak in runoff from snow melt. Major long-term issues affecting water supply are post-fire impacts on hydrology, water use by re-afforestation in the upper catchment and rainfall changes under climate change.

Area:

3,900 km^2

Total storage volume:

no data

Total surface water use:

3,450 ML/yr

Development category:

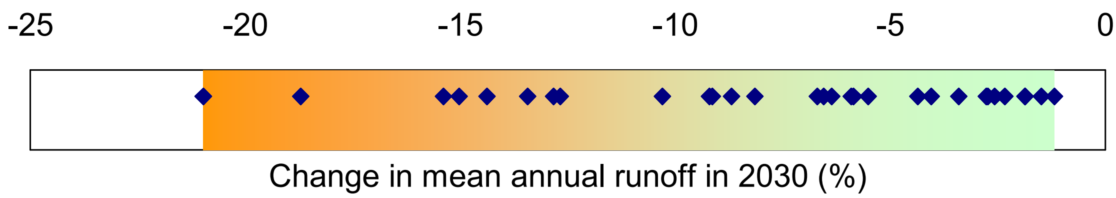
HIGH DEVELOPMENT

Developed yield:

837,950 ML

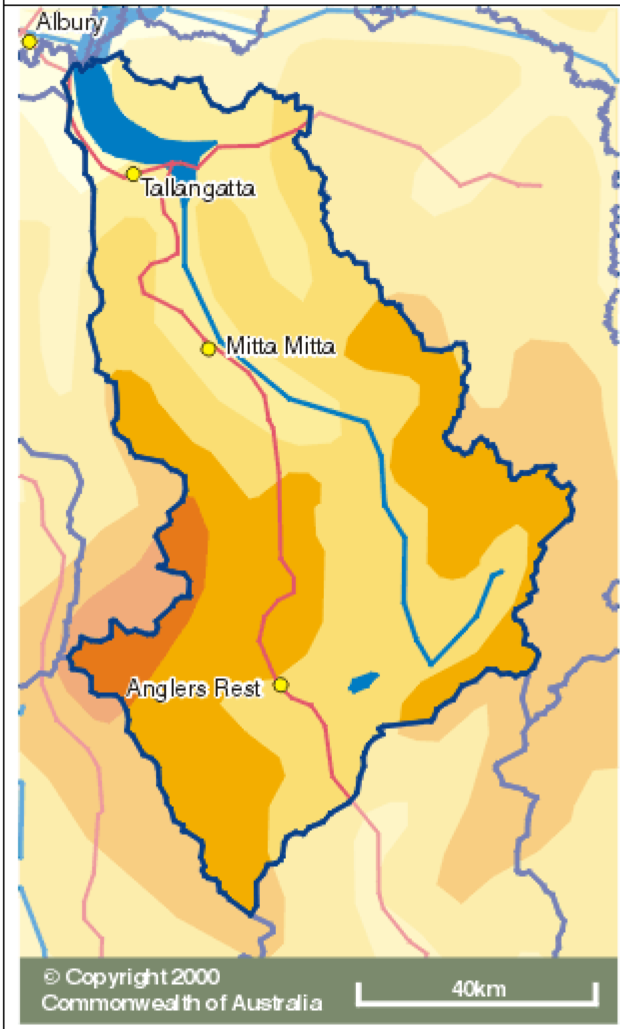
Mean annual runoff:

1,364,000 ML/yr



Mitta Mitta River

Note: both the Upper Murray River and Mitta Mitta River contribute to the Upper Murray Entry in Table 4 and Figures 4 and 5.



The Mitta Mitta Surface Water Management Area (SWMA) feeds into Lake Hume in north-eastern Victoria. It has a total area of 6,250 km^2. The main storage in the catchment Lake Dartmouth, Victoria's largest. Lake Hume regulates water from the Mitta Mitta River and the Upper Murray River Basin, which is supplemented by water from the Snowy River.

Rainfall varies from around 700 mm in the lower catchment to over 2100mm at Mt Bogong. The mean annual runoff of the basin is 1,439,000 ML.

Major land uses include forestry, water conservation, grazing, dairying and tourism.

Average annual surface water use is 20,835 ML with urban/industrial representing 3% of total use, irrigation 95%, and rural 2%. A further 577,000 ML of water is supplied to NSW.

Climate change is expected to produce an earlier peak in runoff from snow melt. Major long-term issues affecting water supply are post-fire impacts on hydrology, water use by re-afforestation in the upper catchment and rainfall changes under climate change.

Area:

6,250 km^2

Total storage volume:

4,000,087 ML

Total surface water use:

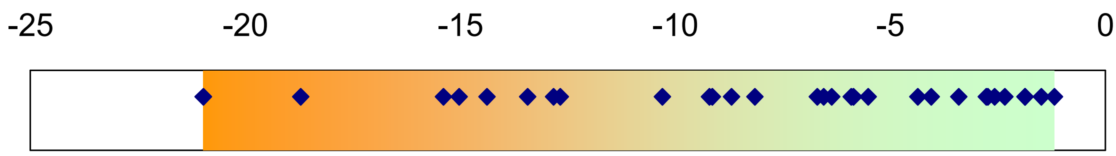
20,835 ML/yr

Development category:

HIGH DEVELOPMENT

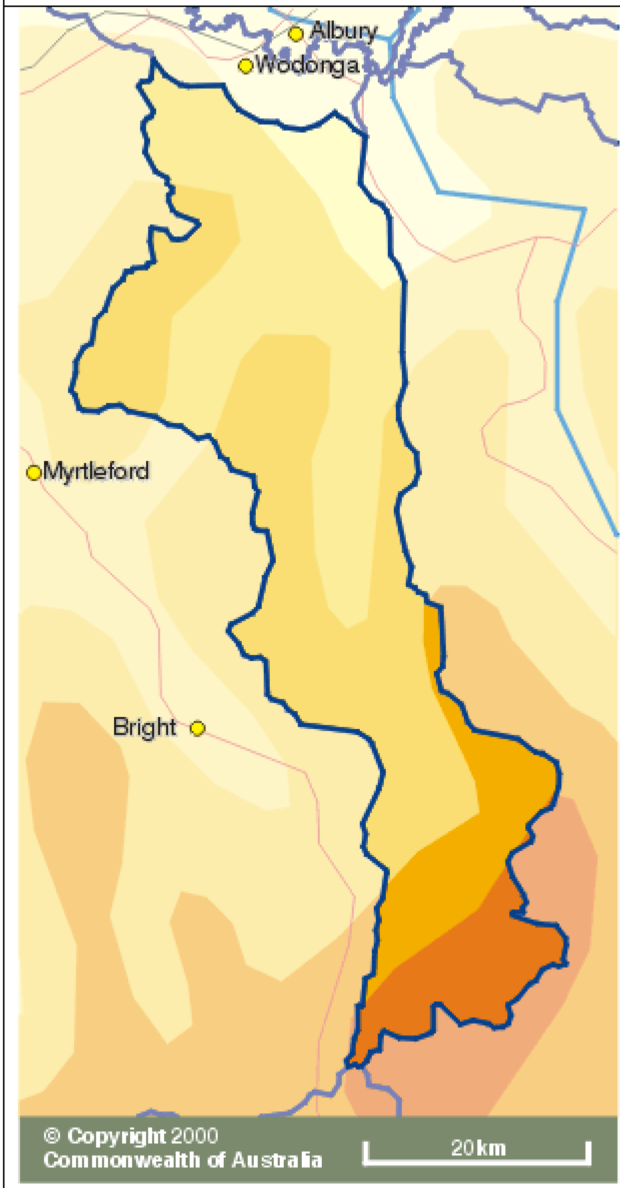
Mean annual runoff:

1,439,000 ML/yr



Change in mean annual runoff in 2030 (%)

Kiewa River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0	-20%
2070	-5%	>-50%

The Kiewa Surface Water Management Area (SWMA) is between the Mitta Mitta and Ovens SWMAs. It has a total area of 1913 km^2. The catchment is about two-thirds farmland and one-third forest on the upper slopes.

Rainfall varies from around 700 mm in the lower catchment to over 2400mm on the bogong High Plains. The mean annual runoff of the basin is 679,000 ML.

The lower basin land-use includes dairying, mixed cropping and grazing. In the upper catchment tobacco, cool climate wine and tourism dominate.

Average annual surface water use is 14,910 ML with urban/industrial representing 43% of total use, irrigation 47%, and rural 10%. A number of small water storages supply hydropower. 60% of supply comes from within the catchment, with the remainder coming from the Murray River.

Climate change is expected to produce an earlier peak in runoff from snow melt. Major long-term issues affecting water supply are post-fire impacts on hydrology, changing irrigation demand and rainfall changes under climate change.

Area:

1,913 km^2

Total storage volume:

28,400 ML

Total surface water use:

14,910 ML/yr

Development category:

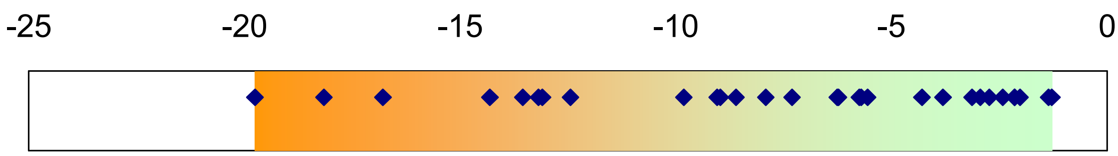
HIGH DEVELOPMENT

Developed yield:

9,000 ML

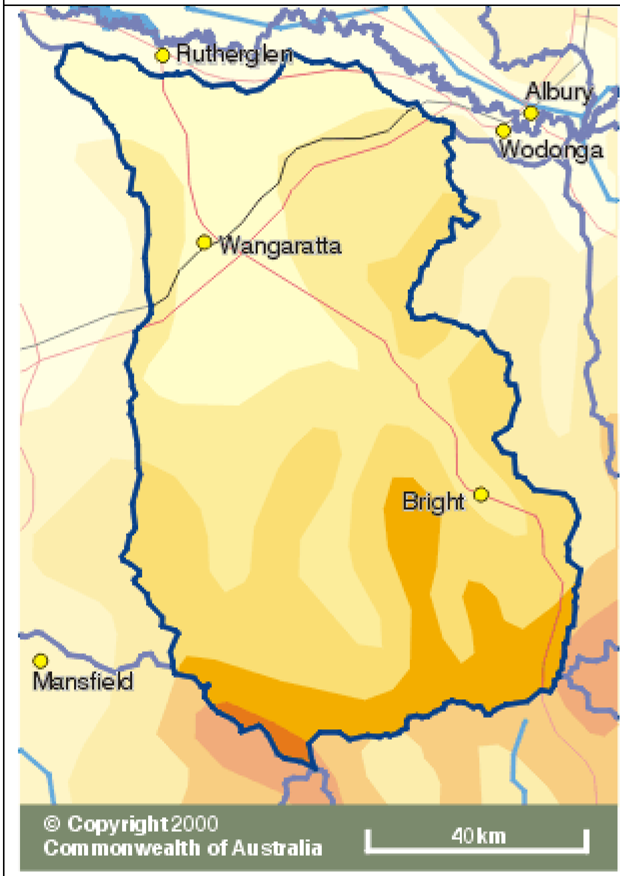
Mean annual run-off:

679,000 ML/yr



Change in mean annual runoff in 2030 (%)

Ovens River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0%	-25%
2070	-5%	>-50%

The Ovens Surface Water Management Area (SWMA) is between Kiewa and Goulburn-Broken SWMAs. It has a total area of 7,985 km^2. The King River is a significant tributary. The main storages are Lake Buffalo on the Buffalo River and Lake William Hovel on the King River.

Rainfall varies from around 630 mm at Wangaratta to 1890 mm at Mt Buffalo. Mean annual runoff is 1,692,000 ML.

Major land uses include forestry, tobacco growing, viticulture, sheep grazing and beef cattle. Average annual surface water use is 39,340 ML with urban/industrial representing 23% of total use, irrigation 67%, and rural 10%. Consumption from within the catchment supplies about 66% of the total; the remaining 34% comes from the Murray River.

Climate change is expected to produce an earlier peak in runoff from snow melt. Major long-term issues affecting water supply are post-fire impacts on hydrology, changing irrigation demand and rainfall changes under climate change. Large floods from orographic uplift of storm systems are also an issue.

Area:

7,985 km^2

Total storage volume:

38,400 ML

Total surface water use:

39,340 ML/yr

Development category:

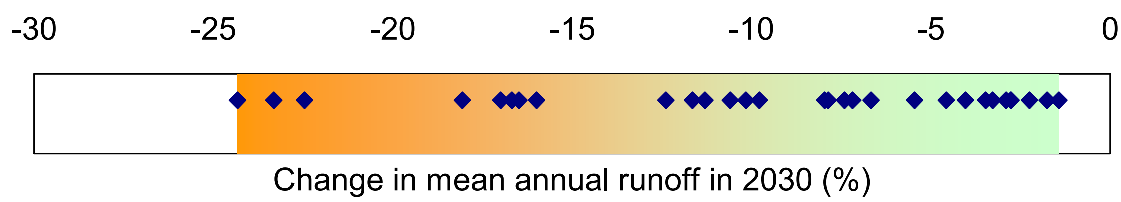
HIGH DEVELOPMENT

Developed yield:

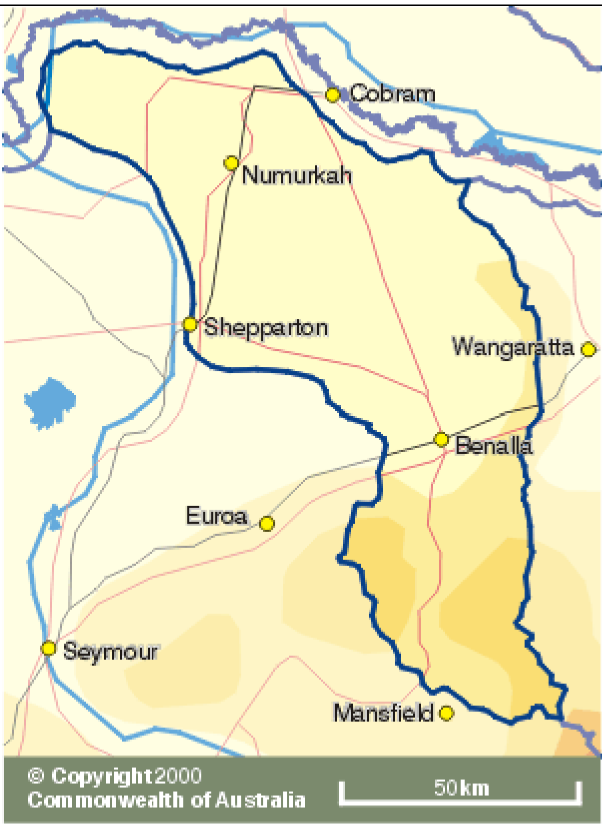
26,000

Mean annual runoff:

1,692,000 ML/yr



Broken River



Projected Percentage Change in Annual Average Runoff

	Wettest	Driest
2030	0%	-35%
2070	-5%	>-50%

The Broken River Basin is between the Ovens and Goulburn Basins. It has a total area of 7,100 km^2. The major storage is Lake Nillahcootie on the Broken. Lake Mokoan is an off-river storage planned for closure.

Rainfall varies from around 470 mm at Cobram to 1,270 mm at Mt Strathbogie. The mean annual runoff of the basin is 326,000 ML.

Major land-uses include grazing, mixed cereal and livestock farming in dryland areas. Extensive irrigation sustains fruit growing, dairying and livestock production. Forest areas remain in the south, the Warby Ranges and the Barmah State Forest. Average annual surface water use is 897,125 ML, with irrigation using 95%, rural water 4% and urban/industrial water 1%. About 60% of this water comes from the Murray, 35% from the Goulburn and 4% from within the catchment.

Major long-term issues affecting water supply are post-fire impacts on hydrology, changing irrigation demand and rainfall changes under climate change. Large floods from orographic uplift of storm systems are also an issue.

Area:

7,100 km^2

Total storage volume:

524,690 ML

Total surface water use:

897,125 ML/yr

Development category:

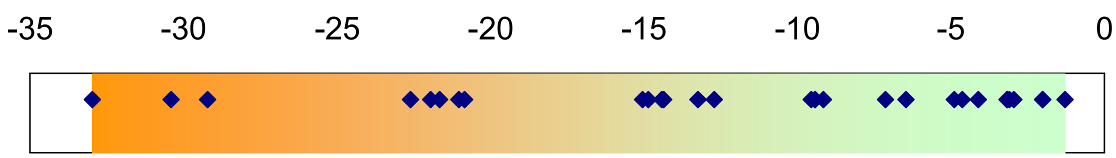
HIGH DEVELOPMENT

Developed yield:

32,000 ML

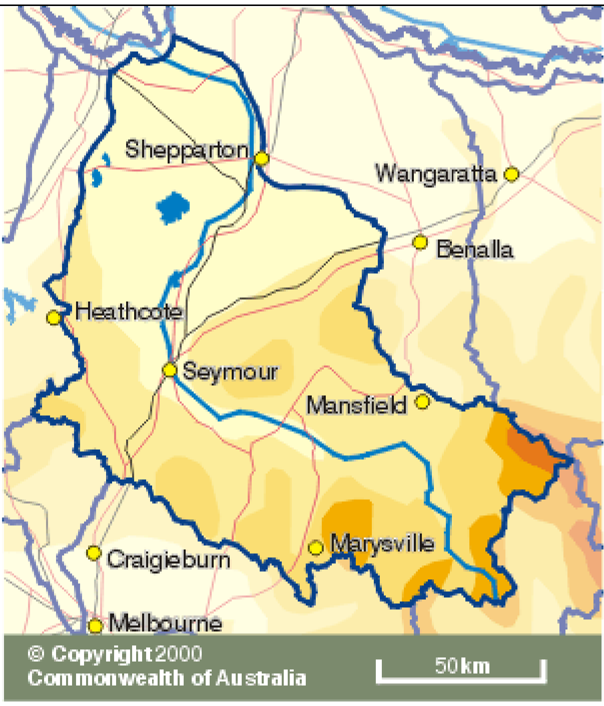
Mean annual runoff:

326,000 ML/yr



Change in mean annual runoff in 2030 (%)

Goulburn River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0	-35%
2070	-5%	>-50%

The Goulburn River Basin is between the Broken and Campaspe Basins. It has a total area of 16,858 km^2. The main stream is the Goulburn River; main tributaries include the Howqua, Acheron, and Yea Rivers. The major storages are Lake Eildon, Goulburn Weir and the Waranga Basin.

Rainfall varies from around 450 mm at Cobram to 1,600 mm near Mt Bulla. The mean annual runoff of the basin is 3,366,000 ML.

Major land-uses include dairying in the south-east and extensive irrigation horticulture, dairy and cropping in the north. The catchment is mostly cleared.

Average annual surface water use is 919,770 ML with urban/industrial using 3%, irrigation 94% and rural 3%. 93% of this water use comes from internal sources and 7% from the Murray River. 1,030,600 ML is exported to the Broken, Campaspe, and Loddon River Basins.

Major long-term issues affecting water supply are changing irrigation demand and projected rainfall reductions. Dryland and irrigation salinity are of major concern. Large floods from orographic uplift of storm systems are also an issue.

Area:

16,858 km^2

Total storage volume:

3,843,906 ML

Total surface water use:

919,770 ML/yr

Development category:

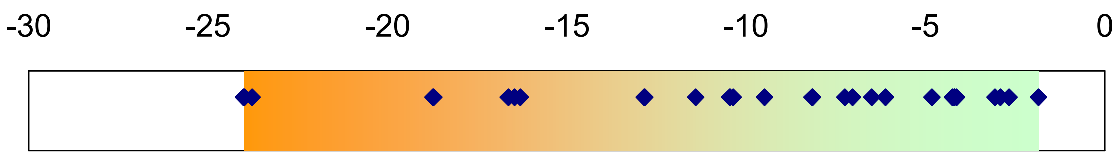
HIGH DEVELOPMENT

Developed yield:

1,943,000

Mean annual runoff:

3,366,000 ML/yr



Change in mean annual runoff in 2030 (%)

Campaspe River

The Campaspe River Basin is between the Goulburn and Loddon Basins. It has a total area of 4,048 km^2. The main stream is the Campaspe River, and the Coliban River the major tributary. The major storages are the Malmsbury, Lauriston and Upper Coliban reservoirs and Lake Eppalock.

Rainfall varies from around 400 mm on the northern plains to 1,080 at Trentham. The mean annual runoff of the basin is 305,000 ML.

Major land uses include agriculture, dairying, viticulture and fruit growing under irrigation, dryland farming produces cereal crops, beef cattle, lambs and wool. The catchment is mostly cleared. Average annual surface water use is 441,980 ML, with irrigation using 95% rural 4% and urban/industrial using 1%. Approximately 76% is imported from the Goulburn Basin, 4% from the Murray River and 20% is supplied locally. An average of 31,400 ML is exported annually to the Loddon Basin.

Major long-term issues affecting water supply are changing irrigation demand and projected reductions in rainfall. Dryland and irrigation salinity are of major concern.

Area:

4,048 km^2

Total storage volume:

410,704 ML

Total surface water use:

441,980 ML/yr

Development category:

HIGH DEVELOPMENT

Developed yield:

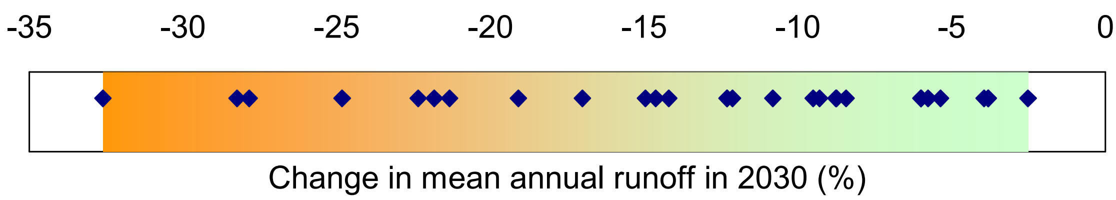
121,000 ML

Mean annual runoff:

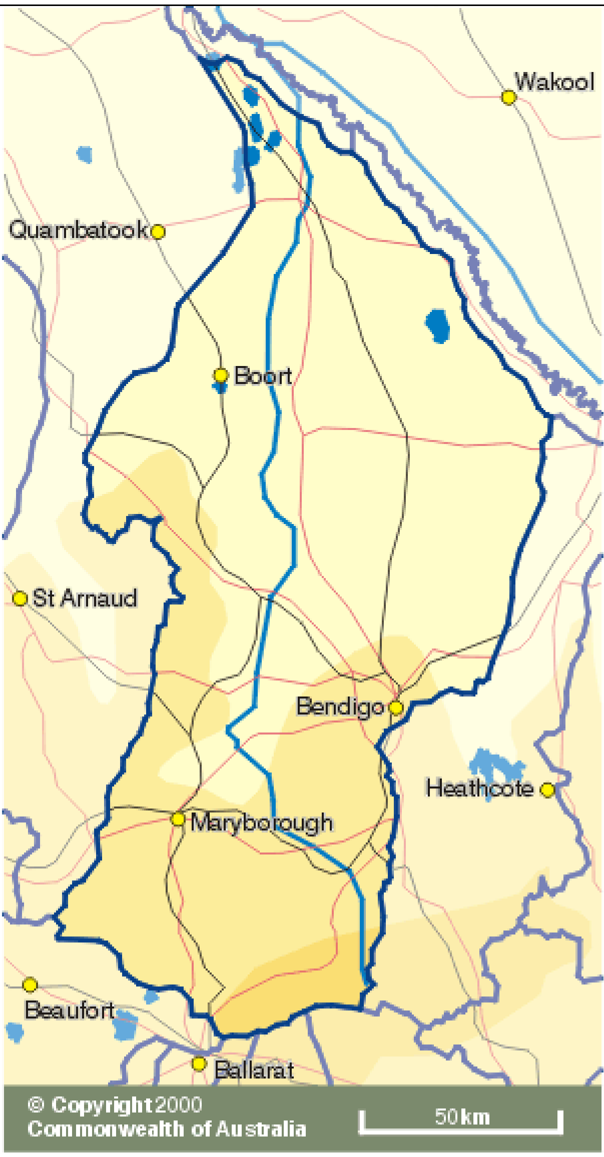
305,000 ML/yr

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-35%
2070	-5%	>-50%



Loddon River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-35%
2070	-5%	>-50%

The Loddon River Basin is between the Campaspe and Avoca Basins. It has a total area of 15,658 km^2. The major storages include Cairn Curran, Tullaroop, Kow Swamp and Laanecoorie reservoirs.

Rainfall varies from 375 mm on the northern plains to 750 in the upper catchment. The mean annual runoff of the basin is 415,000 ML.

The Basin is 80% cleared with mixed grazing of sheep and cattle and some crops in the south and the irrigation of wheat, barley, oats and hay in the north. Forest remnants include the Wombat Forest and areas of box-ironbark forest. Average annual surface water use is 1,175,530ML, with irrigation using 94% and rural and urban/industrial using 4% and 2% respectively. Approximately 60% of this water comes from the Murray River, 29% from the Goulburn River, 2% from the Campaspe River and 9% is local.

Major long-term issues affecting water supply are changing irrigation demand and projected reductions in rainfall. Dryland and irrigation salinity are of major concern.

Area:

15,658 km^2

Total storage volume:

339,724 ML

Total surface water use:

1,175,530 ML/yr

Development category:

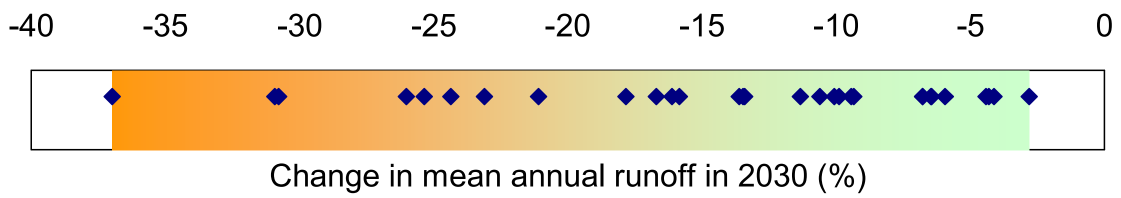
HIGH DEVELOPMENT

Developed yield:

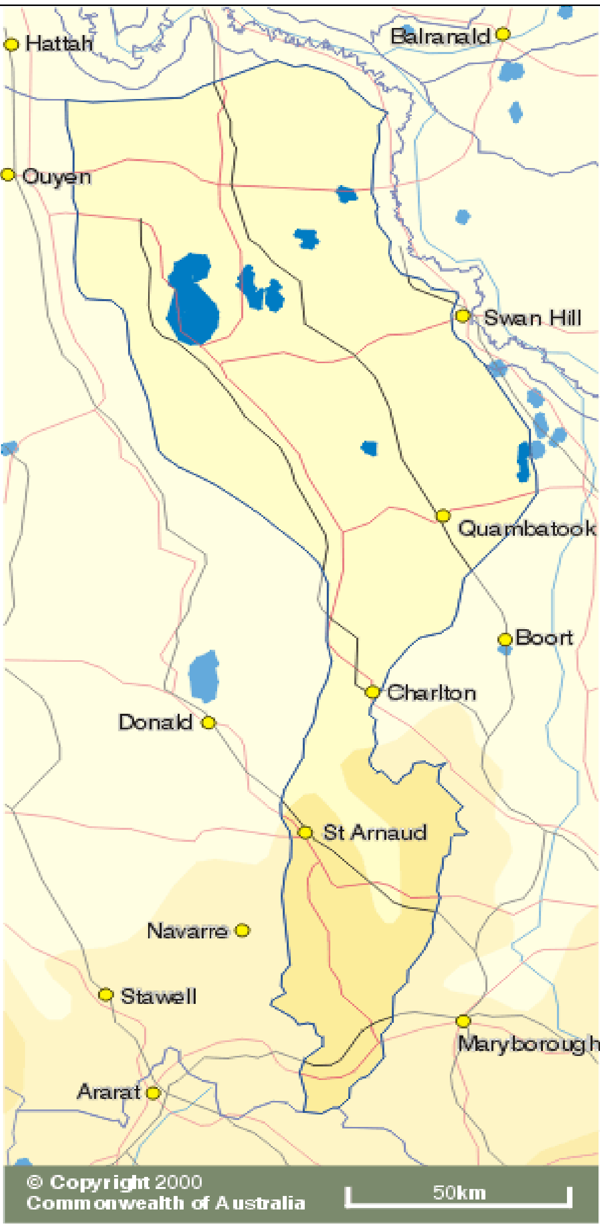
109,000 ML

Mean annual runoff:

415,000 ML/yr



Avoca River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-40%
2070	-5%	>-50%

The Avoca River Basin is between the Mallee and Loddon Basins. It has a total area of 14,211 km^2. The river terminates in Lake Bael Bael overflowing into the Murray during large floods.

Rainfall varies from 310 mm on the northern plains to 610 in the upper catchment. The mean annual runoff of the basin is 136,200 ML.

The mostly cleared Basin is dominated by wheat and sheep farming. Remnant box-ironbark and Mallee forest supply honey and oils. Average annual water use is 39,840 ML of which 40% is for rural use, irrigation 48% and 12%. Approximately 51% comes from the Murray River, 26% from the Glenelg and Wimmera Rivers, 14% from the Goulburn and 9% is local.

Major long-term issues affecting water supply are an existing high variability of flow and reliance on imported water. Rainfall changes leading to reduced supply, dryland and irrigation salinity and loss of wetlands are also of concern.

Area:

14,211 km^2

Total storage volume:

845 ML

Total surface water use:

39,840 ML/yr

Development category:

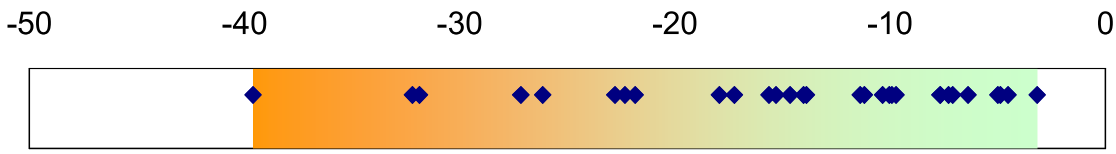
HIGH DEVELOPMENT

Developed yield:

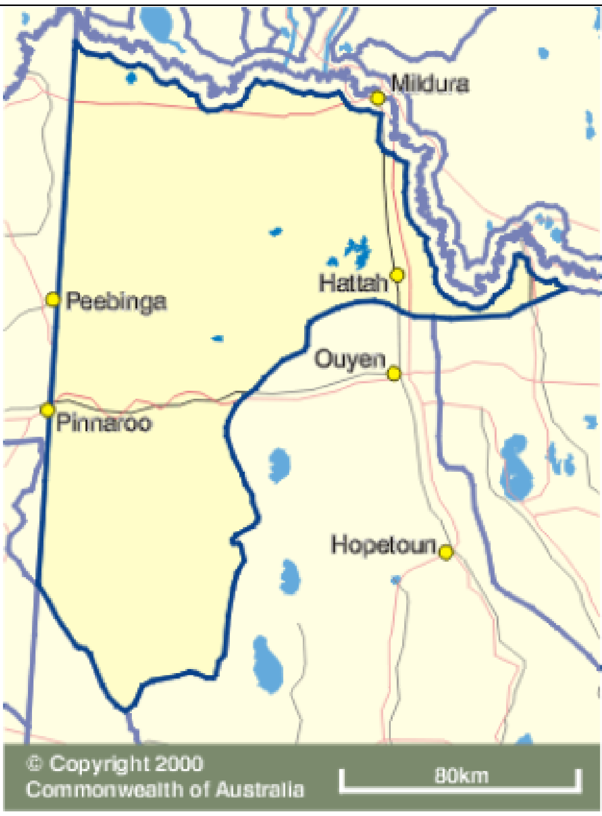
3,380 ML

Mean annual runoff:

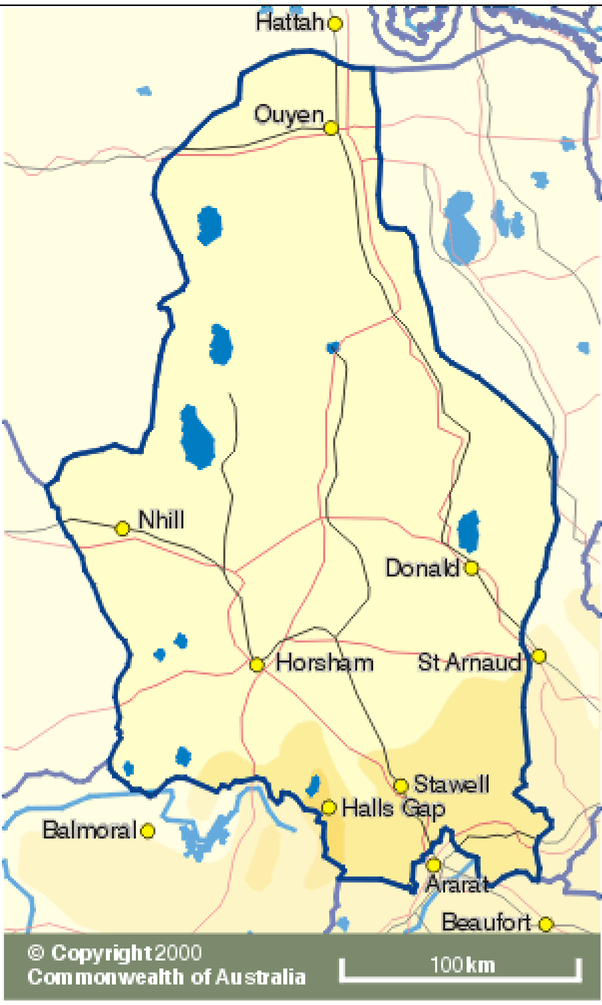
136,200 ML/yr



Change in mean annual runoff in 2030 (%)

Mallee	
	The Mallee Basin is a largely internally drained region with negligible runoff. There are several intermittent streams in a total area of 21,595 km^2. The northern part is Murray River floodplain and the southern part is mainly mallee. There are no significant storages. Rainfall varies from around 330 mm near Ouyen, about 250 mm in the north-west corner and close to 400 mm in the south. The mean annual runoff of the basin is 0 ML. Major land-uses include dryland cereal crops and sheep grazing. Close to the Murray River beef cattle, pigs and sheep are grazed on irrigated pastures, along with citrus fruits, vines and vegetables. Average annual water use in the Mallee is 362,420 ML of which 88% is irrigation, urban industrial 4 % and rural use 9 %. 100% of irrigation water, 90% of urban/industrial water and 35% of rural water comes from the Murray. Imported water from the Wimmera and Glenelg River Basins is 10% and 65% respectively. The major long-term issue is the total reliance on imported water, irrigation and riverine salinity and security of groundwater supply. Reductions in flow would have regionally serious consequences. **Area:** 21,595 km^2 **Total storage volume:** no data **Total surface water use:** 362,420 ML/yr **Development category:** HIGH DEVELOPMENT **Mean annual runoff:** 0 ML/yr
Note: there is no significant runoff in this catchment	

Wimmera–Avon	



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-40%
2070	-10%	>-50%

The Wimmera-Avon SWMA consists of two separate rivers in internally drained catchments covering a total area of 30,409 km^2. The northern part has no significant runoff. The major storages include Wartook Reservoir, Lake Lonsdale, Fyans Lake and Lake Bellfield.

Rainfall varies from around 330 mm at Ouyen to 790 mm in the Grampians. The mean annual runoff of the basin is 316,400 ML.

Most of the basin is cleared. Dryland grain and sheep grazing are major land-uses. Two small irrigated in the south support mixed farming. Average annual surface water use is 130,030 ML. Rural domestic and stock users utilize 67% available surface water; irrigation and urban/industrial water use 21% and 12% respectively. 21% of the Basin's water is exported through the Wimmera-Mallee Stock and Domestic system. Some water is imported from the Glenelg.

Major long-term issues affecting water supply are an existing high variability of flow and over allocation of resources. Salinity is an issue fro both the Wimmera River and dryland areas. Reductions in flow would have regionally serious consequences.

Area:

30,409 km^2

Total storage volume:

404,661 ML

Total surface water use:

130,030 ML/yr

Development category:

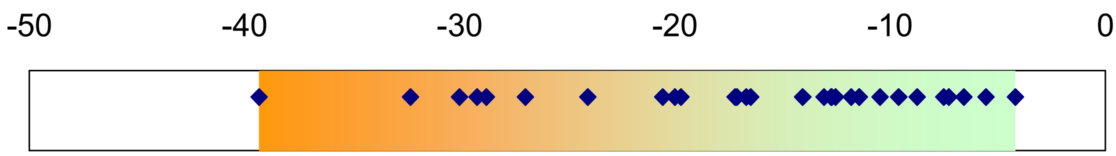
OVER DEVELOPMENT

Developed yield:

94,250 ML

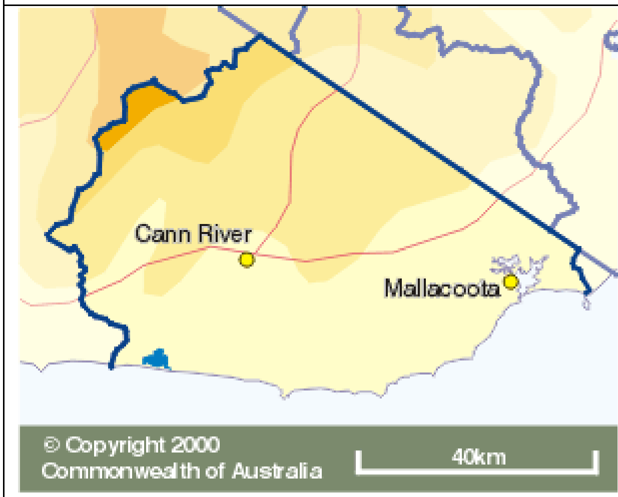
Mean annual runoff:

316,400 ML/yr



Change in mean annual runoff in 2030 (%)

East Gippsland



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	+5%	-30%
2070	+20%	>-50%

The East Gippsland Basin is a mountainous region consisting of the Genoa, Betka, Wingan, Thurra, Cann, and Bemm Rivers.

Rainfall ranges from 800 to 1,000 mm along the coast to 1,400 mm in the mountains. The mean annual runoff of the basin is 655,000 ML.

Agriculture in the basin is dominated by beef cattle production. Hardwood timber production is the major industry, and much of the coastal region has been retained for conservation purposes.

The average annual water consumption in the basin is only 520 ML. Approximately 51% of that used is for irrigation, 43% for urban and industrial use and 6% for rural use.

Long-term issues affecting water supply are a change in timing of flow due to earlier snowmelt. Increases and decreases in rainfall are projected for the region, but most models produce decreases.

Area:

4,521 km^2

Total storage volume:

no data

Total surface water use:

520 ML/yr

Development category:

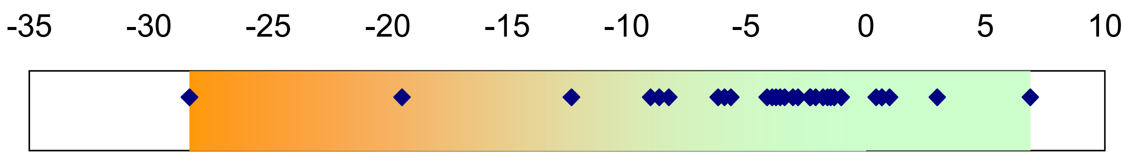
LOW DEVELOPMENT

Developed yield:

1,230 ML

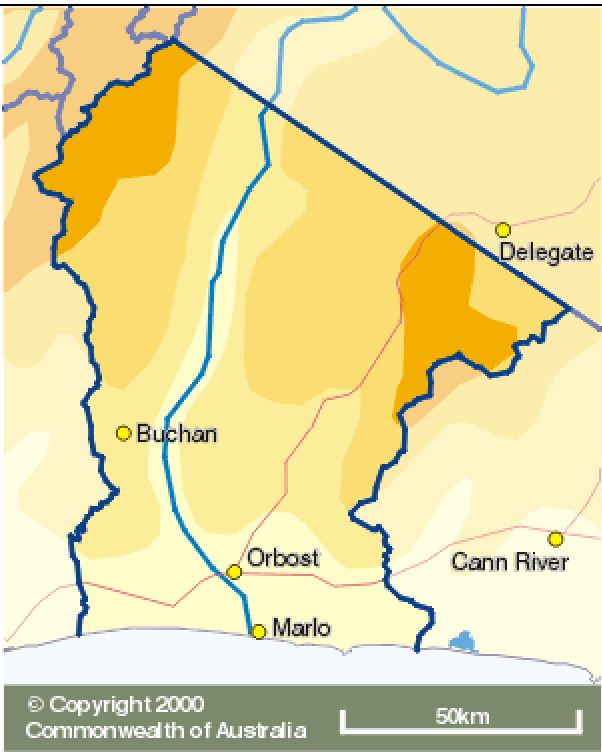
Mean annual runoff:

655,000 ML/yr



Change in mean annual runoff in 2030 (%)

Snowy River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0%	-30%
2070	0%	>-50%

The Snowy River originates in NSW and flows into Victoria. The major tributaries in the Victorian part include the Suggan Buggan, Little, Murrindal, Buchan, Deddick, Rodger and Brodribb rivers. Less than half of the total catchment area (15,500 km^2) lies in Victoria.

Rainfall ranges from 700 to 800 mm along the coast and up to 1,200 mm in the central basin, although a rainshadow of 700 mm also occurs in the upper catchment. The mean annual runoff of the Victorian part of the basin is 863,000 ML and 804,000 in the NSW part.

Land-use includes hardwood timber production from native forest, horticulture and pasture on flood plains, and cattle and sheep grazing on plateaux and slopes.

Average annual water use within the Victorian part of the Basin is 2,385 ML; with urban and industrial use representing 29% of the total use, irrigation 68% and rural 4%.

Long-term issues affecting water supply are a scheme to return environmental flows to the Snowy River, change in timing of flow due to earlier snowmelt and possible rainfall changes in both NSW and Victoria.

Area:

6,856 km^2

Total storage volume:

136 ML

Total surface water use:

2,130 ML/yr

Development category:

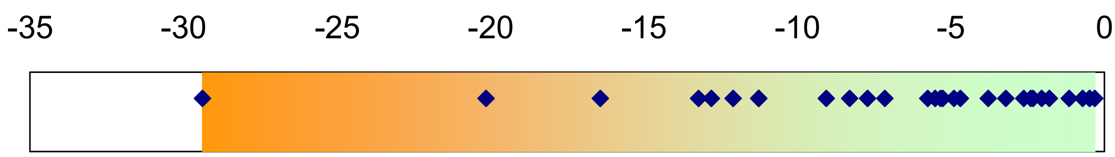
MEDIUM DEVELOPMENT

Developed yield:

5,400 ML

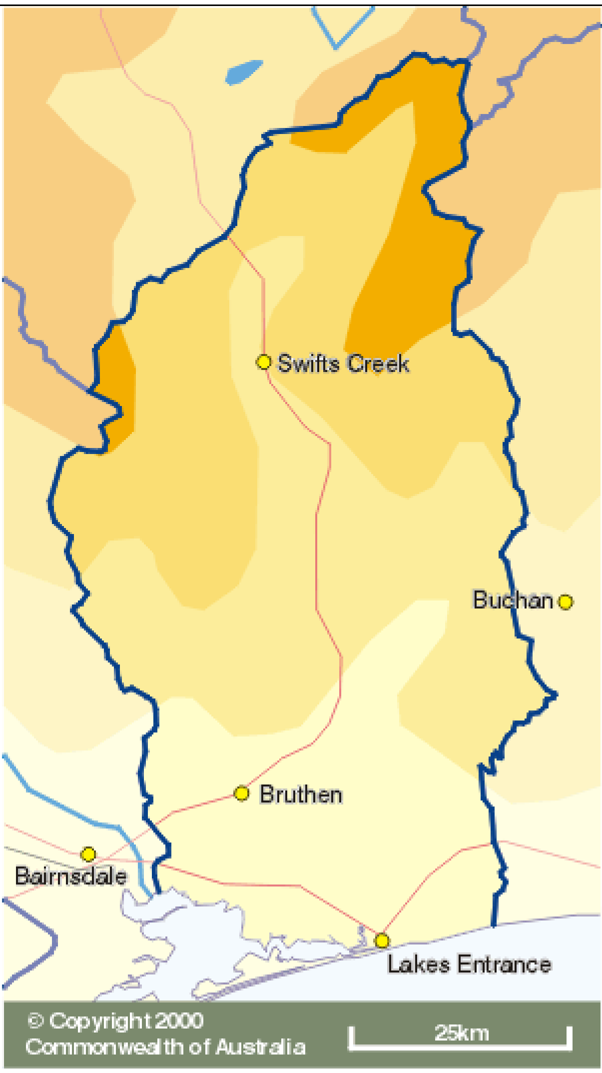
Mean annual runoff:

863,000 ML/yr



Change in mean annual runoff in 2030 (%)

Tambo River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0%	-30%
2070	0%	>-50%

The Tambo River Basin lies between the Snowy and Mitchell River SWMAs. The basin is 4,212 km^2 in area. There are two major river systems, the Tambo and the Nicholson, that flow into the Gippsland Lakes and Boggy Creek which flows into Lake Tyers.

Rainfall decreases from north to south, ranging from around 1,000 mm to about 750 mm. A rain shadow over part of the Tambo River falls below 700 mm. The mean annual runoff is 329,000 ML.

Cattle and sheep farming and grain production are the major forms of agriculture with some mixed farming and horticulture. Tourism and fishing are also important.

The average average annual surface water use is 2,850 ML; 42% irrigation, 48% urban and industrial and the remaining 10 % rural use.

The most significant water resource issue concerns the health of the Gippsland Lakes. Flooding can be severe on occasion.

Area:

4,212 km^2

Total storage volume:

640 ML

Total surface water use:

2,850 ML/yr

Development category:

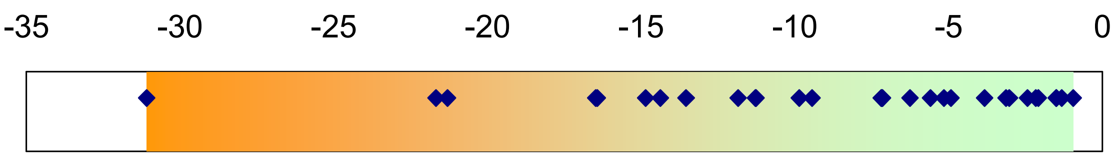
MEDIUM DEVELOPMENT

Developed yield:

6,880 ML

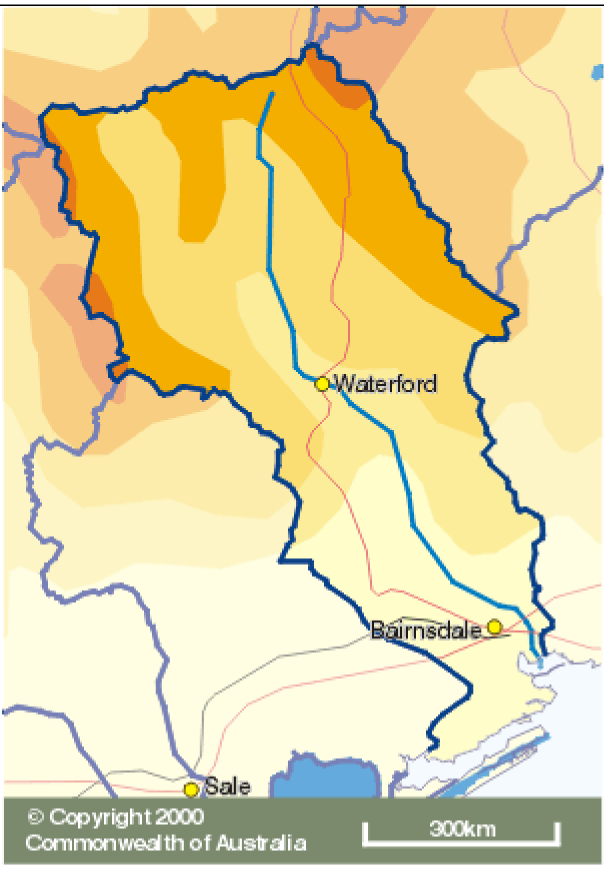
Mean annual runoff:

329,000 ML/yr



Change in mean annual runoff in 2030 (%)

Mitchell River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0%	-25%
2070	-5%	>-50%

The Mitchell River Basin covers an area of 4,873 km^2. The headwaters are known as the Wonnangatta River. Major tributaries are the Wongungarra, Dargo and Wentworth Rivers.

Average annual rainfall ranges from 1,600 mm on the Dargo Plains to less than 700 mm in the Wonnangatta River valley. Along the coast rainfall is about 700 mm. The mean annual runoff of the Mitchell is 1,100,000 ML.

The alluvial plains are intensively farmed, the major activities including dairying, grazing and grain production.

Average annual water use within the basin is 11,640 ML; with urban and industrial use representing 22% of the total use, irrigation 75% and rural 3%.

The most significant water resource issue concerns the health of the Gippsland Lakes. Flooding can be severe on occasion.

Area:

4,873 km^2

Total storage volume:

no data

Total surface water use:

11,640 ML/yr

Development category:

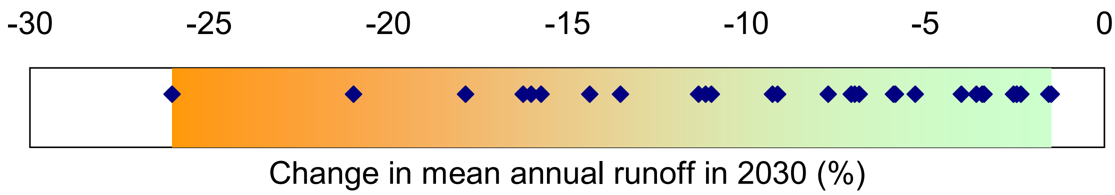
MEDIUM DEVELOPMENT

Developed yield:

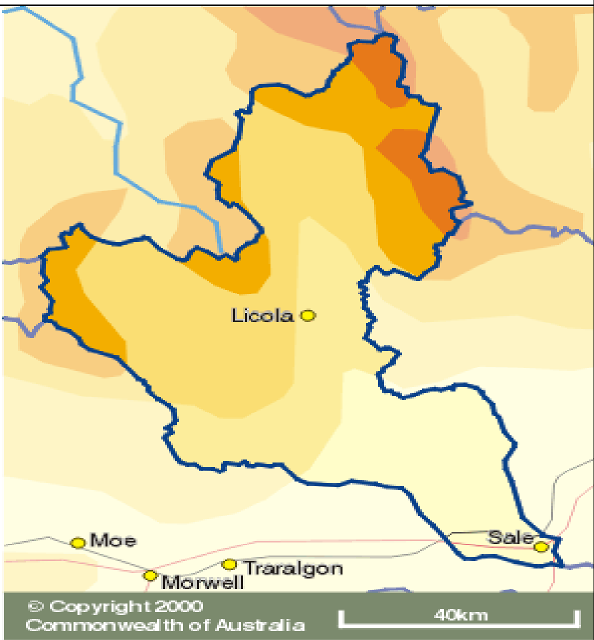
18,900 ML

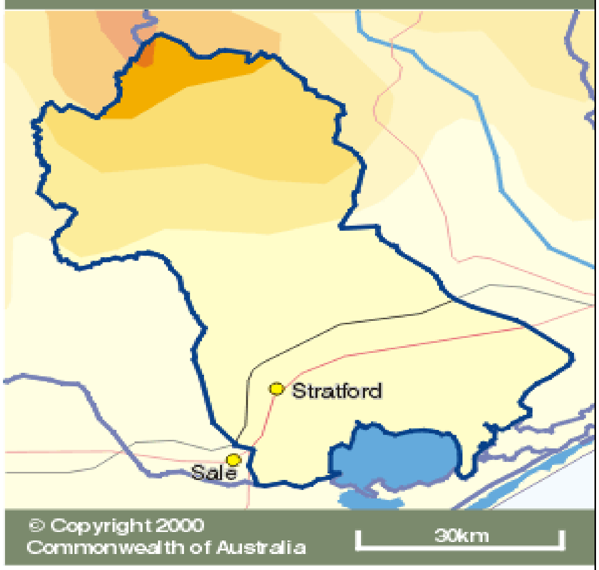
Mean annual runoff:

1,339,000 ML/yr (note in Table 4 = 1,100,000)



Thomson-Macalister Rivers





Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0%	-25%
2070	-5%	>-50%

The Thomson River joins the Latrobe River to the south of Sale and covers 4,597 km^2. The Macalister River joins the Thomson near Sale. The two major storages are Lake Glenmaggie and the Thomson Reservoir. The Avon River flows into Lake Wellington and covers 1,829 km^2.

Average annual rainfall ranges between 1,200 mm in ranges to about 600 mm on the plains. Mean annual runoff from the Thomson-Macalister is 841,600 ML and from the Avon is 239,000 ML.

Dairying is the main farming activity, mixed farming of beef cattle and sheep for wool and meat is also common, as is vegetable growing.

Water use within the Thomson-Macalister is 178,920 ML; urban and industrial use is 1%, irrigation 97% and rural 2%. 230,060 ML is transferred to the Latrobe, Melbourne Water Supply System and the Avon River SWMA. Water use in the Avon is 47,030 ML (84% from the Thomson); 99% for irrigation, 0.5% for urban and industrial use, and 0.5% for rural use.

Environmental flows and river health are significant regional issues. The Thomson Reservoir is a large water source for the Greater Melbourne Region.

Area:

6,426 km^2

Total storage volume:

1,314,239 ML

Total surface water use:

178,920 ML/yr

Development category:

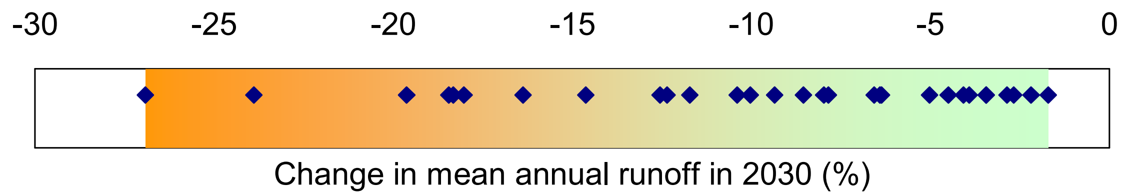
HIGH DEVELOPMENT

Developed yield:

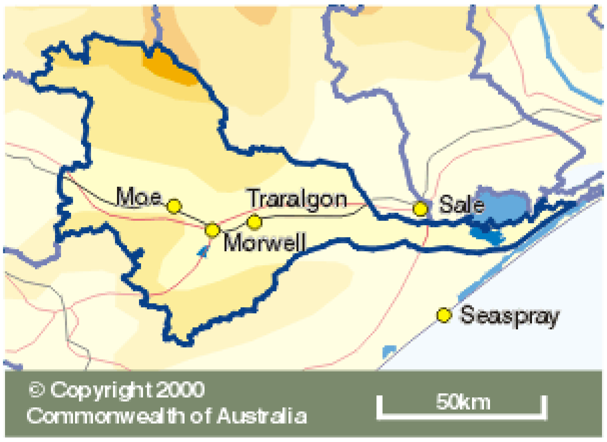
427,370 ML

Mean annual runoff:

1,080,600 ML/yr



Latrobe River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0%	-20%
2070	-5%	>-50%

The Latrobe River Basin flows west to east to Lakes Wellington and Victoria. The principal tributaries are the Toorongo, Tanjil, Tyers, Moe and Morwell Rivers. Major storages are Blue Rock Lake, Yallourn Storage, Hazelwood Pondage and Moondarra Reservoir. The total area of the basin is approximately 4,676 km^2.

Annual rainfall decreases from over 1,500 mm to 625 mm. Mean annual runoff is 887,000 ML.

Agriculture and timber production are main land-uses, but the dominant industry is coal mining and energy generation. 65% of water taken from the Latrobe River is used for thermal power.

Surface water use is 194,100 ML; 24% irrigation use, 75% urban and industrial use and 1% rural use. Power generation uses 73% of total urban/industrial surface water and paper production most of the rest. 15% of surface water comes from the Thomson and Bunyip Basins. supplying 70% of the irrigation.

Lake Wellington is threatened by declining water quality. River health is also a regional issue.

Area:

4,676 km^2

Total storage volume:

1,314,239 ML

Total surface water use:

225,950 ML/yr

Development category:

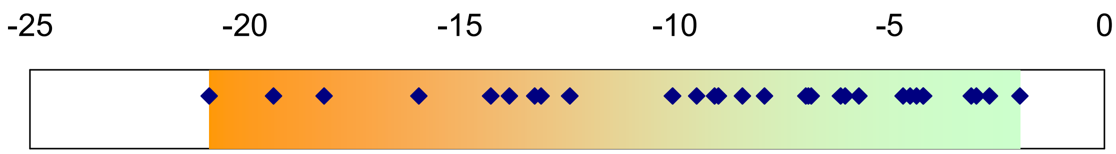
MEDIUM DEVELOPMENT

Developed yield:

261,560 ML

Mean annual runoff:

887,000 ML/yr



Change in mean annual runoff in 2030 (%)

South Gippsland

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-25%
2070	-5%	>-50%

The South Gippsland Basin covers 6,789 km^2 and includes Wilson's Promontory and Phillip Island. The main stream networks are the Bass, Powlett, Tarwin, Franklin, Agnes and Tarra Rivers. The two domestic water storages are the Candowie and Lance Creek Reservoirs.

Average rainfall varies from 755 mm at Yarram to 1,083 mm at the Wilson's Promontory. The Strzelecki Ranges receive up to 1,500 mm. The mean annual flow of the basin is 851,000 ML.

Major land-uses in the basin include dairying, crops, pigs, cattle and sheep for wool. Major tourism destinations include Wilson's Promontory and Phillip Island.

Average annual water use is 11,860 ML; 52 % for urban and industrial use, 35 % for irrigation and the remaining 13% for rural use.

Long-term issues for water resources mainly concern patterns of regional development and changes in water demand.

Area:

6,789 km^2

Total storage volume:

10,136 ML

Total surface water use:

11,860 ML/yr

Development category:

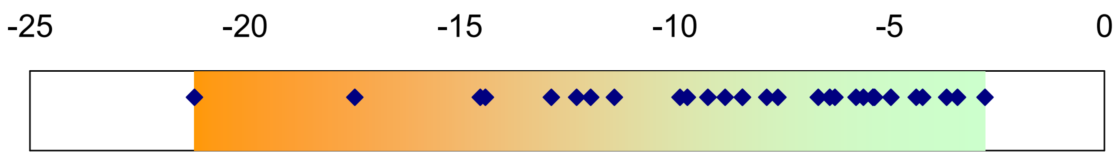
LOW DEVELOPMENT

Developed yield:

21,870 ML

Mean annual runoff:

851,000 ML/yr



Change in mean annual runoff in 2030 (%)

Bunyip River

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-30%
2070	-5%	>-50%

The Bunyip River Basin includes the south-eastern suburbs of Melbourne and the Mornington Peninsula, covering 4,078 km^2. The major river systems are the Patterson River, Cardinia and Toomuc Creeks, Bunyip and Tarago Rivers, Yallock Creek and Lang Lang River. Major storages are the Tarago, Devil Bend and Cardinia Reservoirs.

Average annual rainfall ranges from 750 mm up to 1,200 mm at high elevations. Mean annual flow of the basin is 354,000 ML.

Major agricultural activities are dairying, cropping, intensive livestock and horticulture. The Koo-wee-rup Swamp supports market gardens. The outer fringe of Melbourne contains small hobby farms.

Average annual surface water use of the basin is 150,640 ML. Urban and industrial use represents 96% , irrigation 3% and rural water use 1%. 140,000 ML is imported from the Thomson and Yarra catchments.

Long-term issues for water resources mainly concern patterns of regional development, and changes in supply and demand. Instream water quality is often poor in rural and urban areas.

Area:

4,078 km^2

Total storage volume:

341,243 ML

Total surface water use:

150,640 ML/yr

Development category:

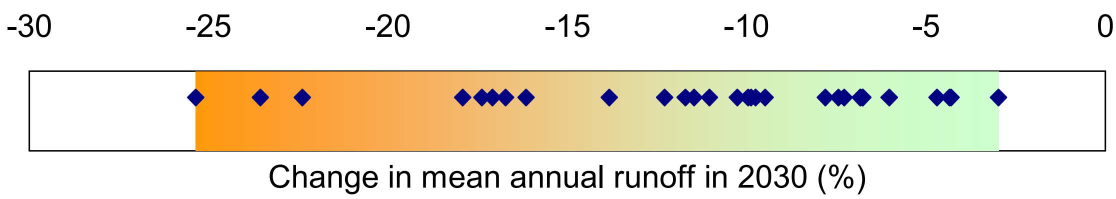
LOW DEVELOPMENT

Developed yield:

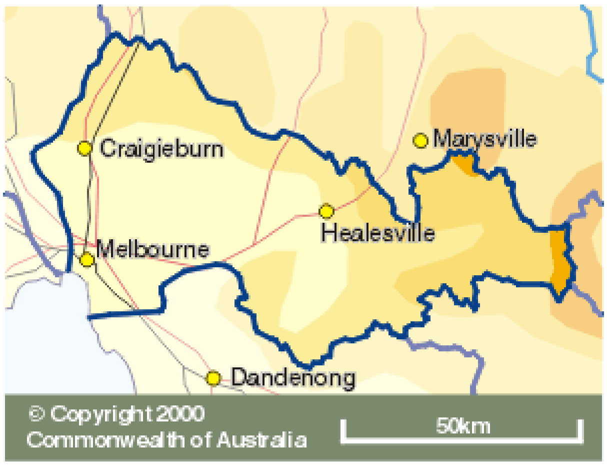
46,280 ML

Mean annual runoff:

354,000 ML/yr



Yarra River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	0%	-20%
2070	-5%	>-50%

The Yarra Basin extends east from Melbourne, covering a total area of 4,110 km^2. The major tributaries of the Yarra are the O'Shannassy, Little Yarra, Watts, and Plenty Rivers, and Armstrong, Diamond, Darebin and Merri Creeks. The major storages include the Upper Yarra, Maroondah, Silvan, O'Shannassy, Yan Yean and Sugarloaf Reservoirs.

Rainfall ranges from 600 mm per year in the west up to 1,600 mm in the north-east. The mean annual flow of the basin is 326,230 ML.

Much of the basin is urbanised, but otherwise agricultural production is diverse including berry farms, viticulture, orchards, beef cattle and market gardening.

Average annual use in the Yarra River Basin is 326,230 ML; 90% for urban/industrial supply and 10% for irrigation. About 21% is imported from the Thomson and Goulburn River Basins. 163,400 ML is exported to the Bunyip, Werribee and Maribyrnong basins.

Long-term issues for water resources mainly concern patterns of regional development, and changes in supply and demand. Instream water quality is often poor in urban areas.

Area:

4,110 km^2

Total storage volume:

437,651 ML

Total surface water use:

326,230 ML/yr

Development category:

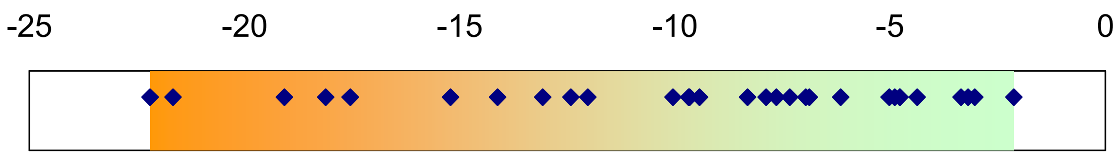
HIGH DEVELOPMENT

Developed yield:

466,300 ML

Mean annual runoff:

1,200,000 ML/yr



Change in mean annual runoff in 2030 (%)

Maribyrnong River

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-30%
2070	-5%	>-50%

The Maribyrnong River Basin covers 1,453 km^2. The major tributaries are Deep, Emu and Jackson Creeks. Rosslynne Reservoir is the only major storage.

The average annual rainfall exceeds 1,000 mm, declining to around 500 mm in the south. The mean annual flow of the basin is 125,400 ML.

Almost 80% of the basin supports sheep, dairy and beef cattle, and some cereals. Small pockets of intensive market gardening occur in the south. Areas of forest remain in the Macedon and Cobaw Ranges. The lower 15 km of the Basin is urban.

The average annual consumption is 22,080 ML with 15,030 ML coming from the Melbourne Water Supply System, and the remaining 7,050 ML sourced internally. Urban/industrial use accounts for 94% of water use; the remaining 6% is irrigation and rural use.

Long-term issues for water resources mainly concern patterns of regional development, and changes in supply and demand. In-stream water quality is often poor in urban areas.

Area:

1,453 km^2

Total storage volume:

25,080 ML

Total surface water use:

22,080 ML/yr

Development category:

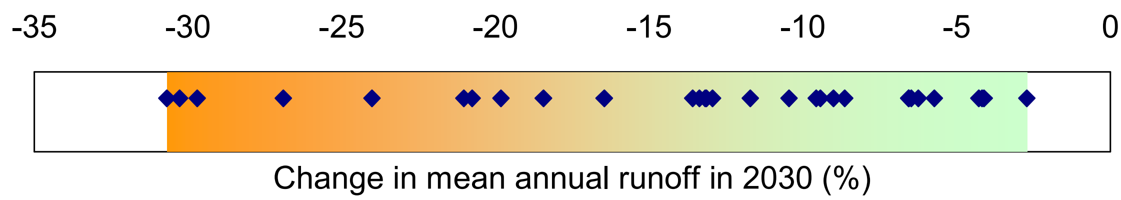
LOW DEVELOPMENT

Developed yield:

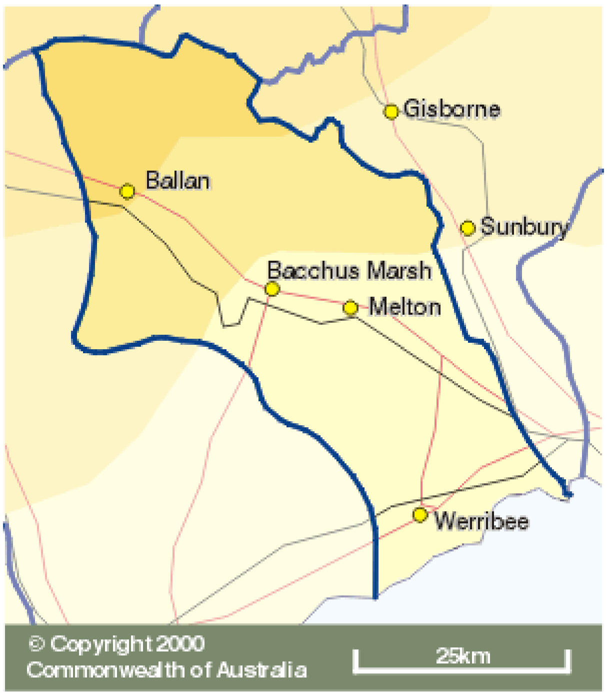
9,980 ML

Mean annual runoff:

125,400 ML/yr



Werribee River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-30%
2070	-5%	>-50%

The Werribee River Basin is west of Melbourne, and covers an area of 1,978 km^2. The major tributaries are the Lerderderg River and Parwan, Goodman, Pyrites, Djerriwarrh, Arnold and Toolern Creeks. Major storages are the Pykes Creek, Melton and Merrimu Reservoirs.

Average annual rainfall in the north is ~1,000 mm, about 400 mm in the Werribee Plains rain shadow and >500 mm near the Bay. Mean annual flow of the basin is 147,000 ML.

The major land use is dryland agriculture on the plains and hills and irrigation on the Werribee Delta. The Wombat State Forest in the north provides hardwood timber. The eastern half is mostly urban.

Average water use in the Basin is 32,200 ML; 75 % for irrigation, 25% for urban and industrial use and <1% for rural use. The Melbourne Water Supply District consumes another 50,100 ML.

Long-term issues for water resources mainly concern patterns of regional development, and changes in supply and demand. In-stream water quality is often poor on the cleared plains and in urban areas.

Area:

1,978 km^2

Total storage volume:

77,633 ML

Total surface water use:

82,300 ML/yr

Development category:

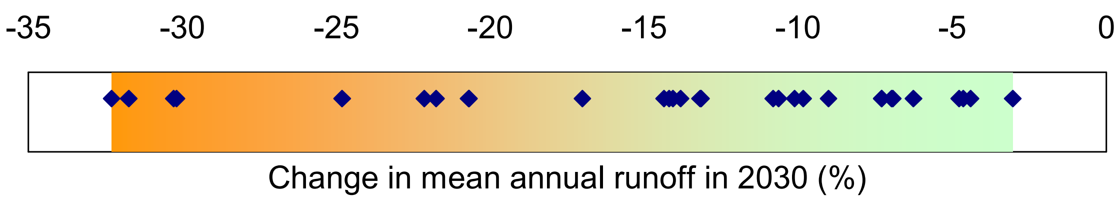
HIGH DEVELOPMENT

Developed yield:

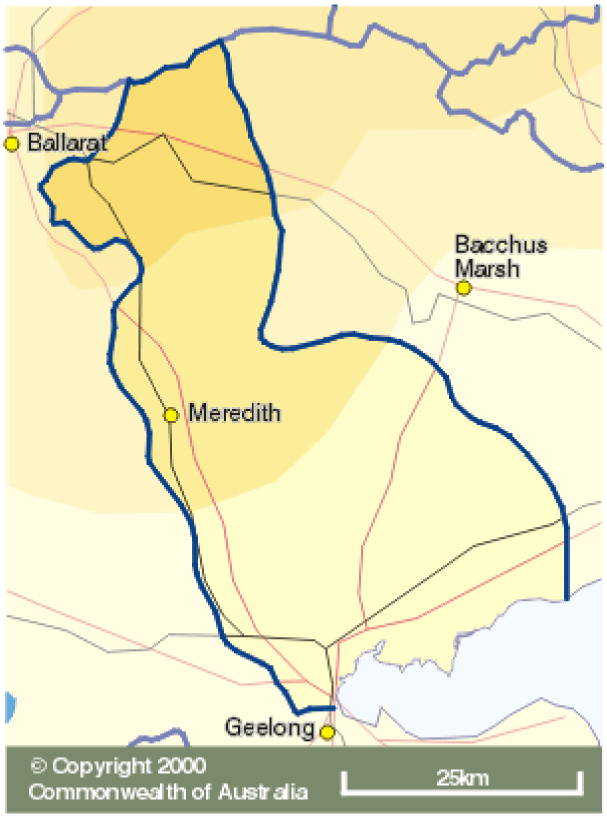
35,900 ML

Mean annual runoff:

147,000 ML/yr



Moorabool River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-35%
2070	-10%	>-50%

The Moorabool River Basin covers an area of 2,225 km^2. The Moorabool River joins the Barwon River at Geelong. Little River originates in the Brisbane Ranges and discharges into Port Phillip Bay. The major storages are the Lal Lal, Moorabool and Bostock Reservoirs.

Annual rainfall in the basin varies from 950 mm to 500 mm from north to south. The mean annual flow of the basin is 91,400 ML.

The major agricultural land uses are beef and sheep grazing, and cropping. Remnant natural forests occur in the north-east. Geelong has a strong manufacturing and industrial base.

Average annual water use 22,530 ML; 87% for urban and industrial use; 3% for irrigation, and 10% rural use. About 70% of this water comes from the Barwon and about 10,000 ML per year goes to Ballarat.

Long-term issues for water resources mainly concern patterns of regional development, and changes in supply and demand. Water shortages are common during periods of low flow. In-stream water quality is often poor on the cleared plains and in urban areas.

Area:

2,225 km^2

Total storage volume:

87,721 ML

Total surface water use:

22,530 ML/yr

Development category:

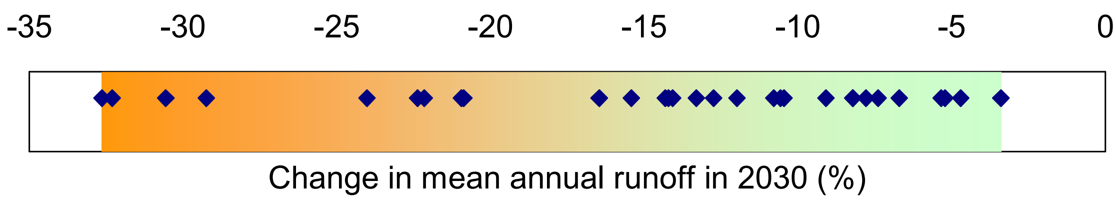
MEDIUM DEVELOPMENT

Developed yield:

45,270 ML

Mean annual runoff:

91,400 ML/yr



Barwon River

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-30%
2070	-10%	>-50%

The Barwon River Basin covers an area of 3,809 km^2. The Barwon River flows east from the Otway Ranges and the Leigh River flows south from Ballarat. The Barwon River meets the Moorabool River in Geelong. Major water storages are the West Barwon, Wurdee Boluc and White Swan Reservoirs.

Average annual rainfall exceeds 2,000 mm falling to 540 mm. Mean annual flow of the basin is 250,800 ML.

Forested catchments in the Otway Ranges supply Geelong's water and hardwood timber. The plains support agriculture and urban centres, grazing and cropping. Average annual water use of the Barwon River SWMA is 32,150 ML. Urban and industrial use comprises 89%, irrigation 10% and rural water 1%. About 45% comes from the Moorabool River Basin. Approximately 17,330 ML of water supplies Torquay, Anglesea and Geelong.

Long-term issues for water resources concern patterns of regional development, and changes in supply and demand. Water shortages are common during periods of low flow. In-stream water quality is often poor in cleared and urban areas.

Area:

3,809 km^2

Total storage volume:

78,679 ML

Total surface water use:

32,150 ML/yr

Development category:

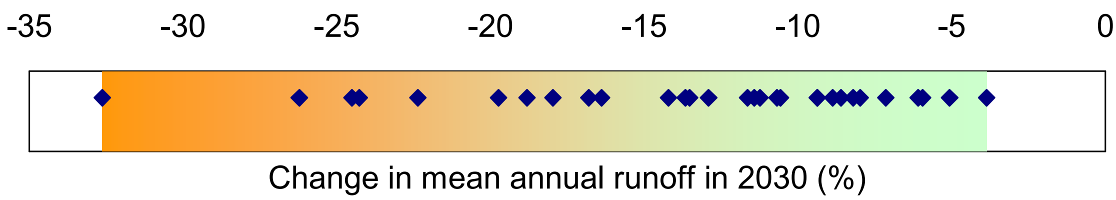
MEDIUM DEVELOPMENT

Developed yield:

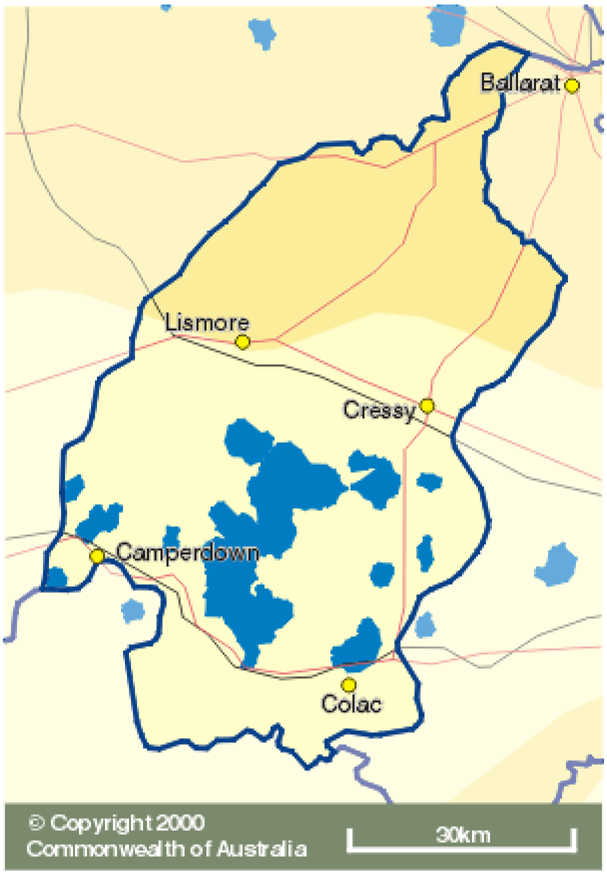
45,700 ML

Mean annual runoff:

250,800 ML/yr



Lake Corangamite



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-40%
2070	-10%	>-50%

The Lake Corangamite Basin in south-western Victoria is a closed basin covering an area of 4,081 km^2. Major streams flowing to Lake Corangamite include the Woady Yaloak River, and Narringhill, Kuruc-A-Ruc, Ferrer's, Pirron Yallock and Mundy Gully Creeks, and Gnarkeet Chain of Ponds. Dean and Baronfarook Creeks flow into Lake Colac. There are no artificial freshwater storages.

Annual rainfall ranges from about 500 mm in the north to almost 800 mm in the south. The mean annual flow of the basin is 120,500 ML.

Sheep and beef grazing dominate the basalt plains, dairying and prime lamb grazing in the south, and cropping in the north. Potatoes and onions grow on the richer volcanic soils.

Average annual water use in the Basin is 4,380 ML. Urban and industrial water use uses 83%, rural water use is 1% and irrigation 16%. All the urban and industrial surface water comes from the Barwon Basin and Otway Coast.

Long-term issues for water resources mainly concern the limited supply of surface water and reliance on importation. Dryland salinity and salinisation of lakes and wetlands are issues.

Area:

4,081 km^2

Total storage volume:

no data

Total surface water use:

4,380 ML/yr

Development category:

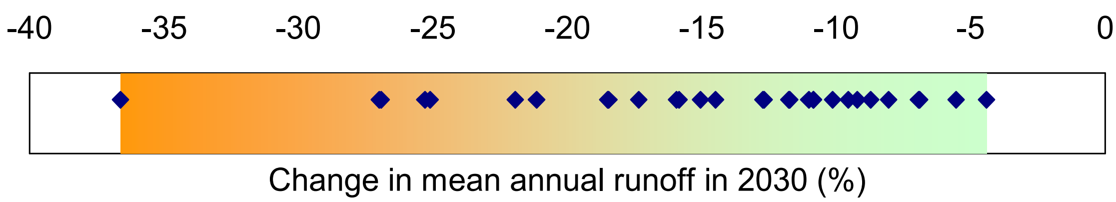
HIGH DEVELOPMENT

Developed yield:

750 ML

Mean annual runoff:

120,500 ML/yr



Otway Coast

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-30%
2070	-10%	>-50%

The Otway Coast Basin covers the southern coastal region of south-west Victoria and has an area of 3,876 km^2. The Curdies River is west of the Otways. The Gellibrand River drains the western Otways and as tributaries: Olangolah River, Kennedy's Creek and Carlisle River. Other systems include the Aire, Barham, Cumberland, St George, Erskine and Anglesea Rivers

Annual average rainfall reaches 2,000 mm in the Otways, reducing to 600 mm to the Otways rain shadow in the far east. The mean annual flow of the basin is 750,000 ML.

Approximately 60% of the basin is still covered by native forests. Dairying and cattle grazing are the principal agricultural industries, with some potato growing. Coastal tourism is significant.

Average annual water use in the Basin averages 12,180 ML - 47% for rural use, 25 % for irrigation, and 28% for urban and industrial use. Approximately 1,650 ML is imported from the Barwon River Basin for urban use and 8,820 ML is exported to the Hopkins and Corangamite basins.

Long-term issues for water resources mainly concern the limited supply of surface water in some coastal centres.

Area:

3,876 km^2

Total storage volume:

2,772 ML

Total surface water use:

12,180 ML/yr

Development category:

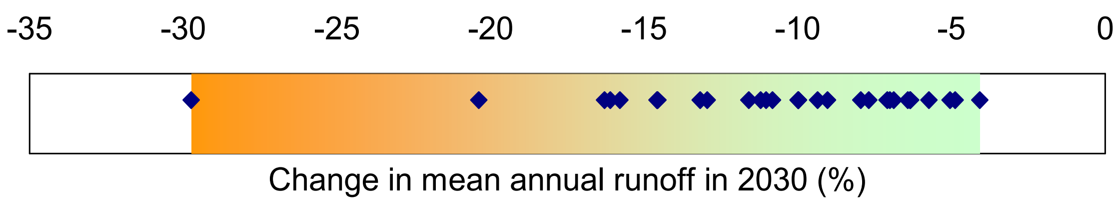
LOW DEVELOPMENT

Developed yield:

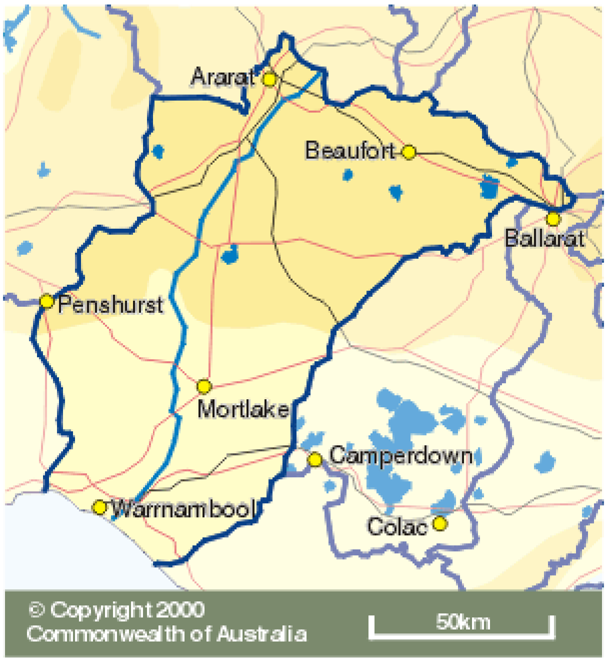
26,100 ML

Mean annual runoff:

750,000 ML/yr



Hopkins River



Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-35%
2070	-10%	>-50%

The Hopkins River Basin in Victoria's south west covers an area of 10,096 km^2. The major tributaries of the Hopkins River are Salt, Mt Emu, Muston and Brucknell creeks. The Merri River discharges to the west of Warrnambool. There are several brackish and saline lakes and no major water supply storages.

Rainfall in the south is about 800 mm per year, dropping to 525 mm in the central area and increasing to 700 mm in the north. The mean annual flow is 405,600 ML.

The Basin has been entirely cleared except for a small area of forest in the north. Wool and prime lambs, and beef grazing are important with cropping in the north. Southern market gardens produce mainly potatoes.

Average annual water use is 13,600 ML; urban and industrial use represents 53% of the total, irrigation 46% and rural 1%. About 50% of urban water comes from the Otway Coast Basin.

Long-term issues for water resources mainly concern the limited supply of surface water.

Area:

10,096 km^2

Total storage volume:

205 ML

Total surface water use:

13,570 ML/yr

Development category:

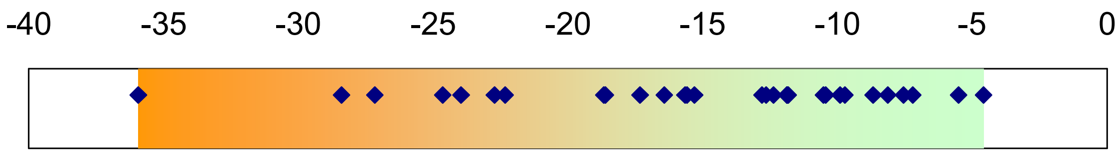
MEDIUM DEVELOPMENT

Developed yield:

10,440 ML

Mean annual runoff:

405,600 ML/yr



Change in mean annual runoff in 2030 (%)

Portland Coast

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-40%
2070	-10%	>-50%

The Portland Coast Basin ranges from east of Port Fairy to west of Portland, covering an area of 3,963 km^2. The major stream networks include the Surry River, Fitzroy River and Darlot Creek, Eumeralla River, and Back Creek and Moyne River. There are several brackish and saline lakes and no major water supply storages.

Rainfall averages about 850 mm on tne coast declining to around 750 mm in the north. The mean annual flow is 231,000 ML.

The Basin has been mostly cleared for agricultural activities, sheep for wool and cattle for dairy and beef dominating. Potatoes and orchards are grown in southeast and southwest, with some areas of cereals, vegetables and vineyards.

Of the 18,200 ML of water used in the Portland Coast Basin, 94% is groundwater. The remaining 6% is surface water and is self extracted for irrigation and rural use.

Long-term issues for water resources mainly concern the limited supply of surface water and sustainability of groundwater supply.

Area:

3,963 km^2

Total storage volume:

no data

Total surface water use:

1,100 ML/yr

Development category:

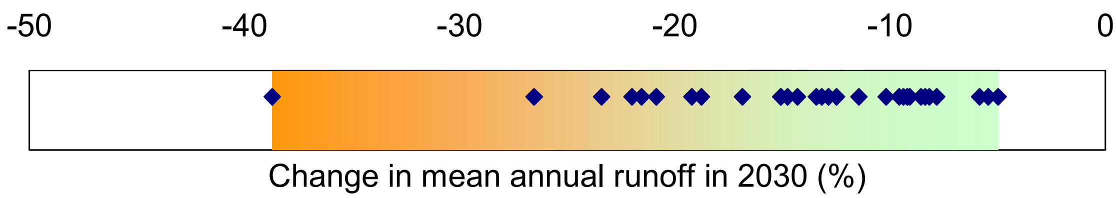
LOW DEVELOPMENT

Development category:

1,100 ML

Mean annual runoff:

231,000 ML/yr



Glenelg River

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-35%
2070	-10%	>-50%

The Glenelg River Basin covers an area of 11,988 km^2. The Glenelg and Wannon Rivers originate in the Grampians. The Glenelg flows west and south and the Wannon, south and west, joining the Glenelg at Casterton. The two major storages are the Rocklands and Moora Moora Reservoir.

The mean annual rainfall at the coast is 750 mm, declining to 550 mm towards the centre and increasing with elevation to more than 900 mm. The mean annual flow of the basin is 704,400 ML.

Most of the basin has been cleared for sheep and cattle grazing. Forested areas remain around the Grampians and in the Glenelg region. Native hardwood and softwood plantations are increasing.

Average annual surface water use is 3,960 ML, with urban and industrial use representing 51%, irrigation 44% and rural 5%. About 67,750 ML per year, is exported through the Wimmera-Mallee Stock and Domestic Supply System.

Long-term issues for water resources mainly concern the limited supply of surface water and sustainability of groundwater supply. Dryland salinity is also an issue.

Area:

11,988 km^2

Total storage volume:

256,338 ML

Total surface water use:

3,960 ML/yr

Development category:

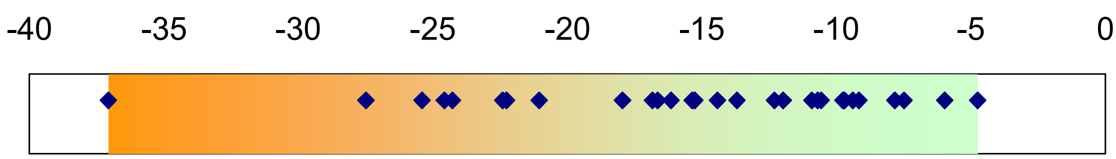
HIGH DEVELOPMENT

Developed yield:

72,770 ML

Mean annual runoff:

704,400 ML/yr



Change in mean annual runoff in 2030 (%)

Millicent Coast

Projected Percentage Change in Annual Average Runoff*

	Wettest	Driest
2030	-5%	-35%
2070	-10%	>-50%

The Millicent Coast SWMA is located in western Victoria and covers approximately 7,426 km^2 There are no perennial streams in these Basins and the sandy soils result in very little runoff. In the west, the Mosquito, Koijak, Yalla and Thomson creeks only flow after high rainfall. There are no major storages.

The towns of Edenhope and Goroke receive average annual rainfalls of 599 mm and 527 mm respectively. The mean annual flow is 4,000 ML.

Major land-uses include dryland agriculture, particularly cereal crops and sheep grazing.

Annual surface water use is approximately 210 ML, with 90% used for urban and industrial use, and 10% for rural use. The Millicent Coast SWMA relies heavily on groundwater to source demands.

Long-term issues for water resources mainly concern the limited supply of surface water and sustainability of groundwater supply. Dryland salinity is also an issue.

Area:

7,426 km^2

Total storage volume:

no data

Total surface water use:

210 ML/yr

Development category:

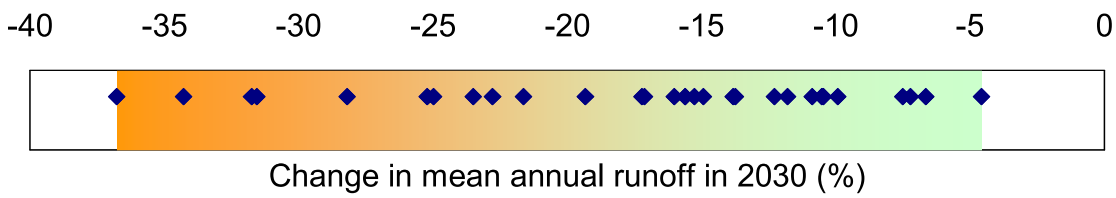
HIGH DEVELOPMENT

Development category:

210 ML

Mean annual runoff:

4,000 ML/yr



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* Rounded to the nearest 5%