Impacts of climate change and forest age on rainfall-runoff relationships for Tasmanian catchments

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Abstract Assessing the current and potential future impacts of land use and climate change on water resources is of utmost importance in Australia, where water resources are scarce and therefore need to be carefully allocated between urban and rural human consumption, agriculture and environmental flows. Located southeast of mainland Australia, Tasmania has water resources that are being impacted by various activities such as irrigated agriculture, forestry, and hydropower generation. Estimating the impacts of climate change on future water availability is crucial for the development and planning of these activities. Several projects have been carried out recently to serve as a scientific basis for future policies and decision-making (CSIRO's Tasmania Sustainable Yields and Antarctic Climate and Ecosystems CRC's Climate Futures for Tasmania projects). Runoff projections for the future are typically generated using various models, including lumped conceptual rainfall-runoff models to determine changes in runoff due to factors such as vegetation, surface retention, infiltration, evaporation, timing and magnitude of rainfall events. However, as the runoff response is based on streamflow records, some assessment needs to be made regarding the validity of currently derived rainfall-runoff relationships. The results show a statistically significant decrease in runoff coefficient for three of the four analysed catchments (Franklin River, Allans Rivulet, Davey River and Nelson Bay River) over their respective period of record. However, some inconsistency observed in some of the rainfall data shows that precaution should be taken in the interpretation of those results.

Keywords unimpacted catchments; runoff coefficient; land use; forest cover; historical records; Tasmania

INTRODUCTION

This study examined the evolution of historical runoff coefficient (proportion of rainfall that appears as runoff) for four catchments that have remained unimpacted for a sufficiently long period of record in order to detect possible trends due to climate change and/or forest ageing.

The four analysed catchments are: Franklin River, Davey River, Allans Rivulet and Nelson Bay River. The runoff coefficients were calculated for monthly, seasonal and annual time steps, using data from streamflow monitoring and rainfall stations and interpolations.

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Selection of unimpacted catchments

The first step of the study was to determine which catchments could be used to detect

trends that would not be influenced by land use changes. Fourteen relevant and potentially unimpacted catchments were listed according to the following criteria: sufficiently long period of streamflow record, and absence of logging, fire, and extractions (irrigation or hydropower generation) for the period of record.

Spatial analysis tools were then used to determine which of these catchments had no trace of irrigated agriculture, forestry or dwelling.

The results of this analysis lead to select four catchments which responded to all the criteria: Franklin River, Davey River, Allans Rivulet, and Nelson Bay River. Their characteristics are given in Table 1.

Table 1 Characteristics of the four unimpacted catchments selected for the study

Catchment	Franklin River	Davey River	Allans Rivulet	Nelson Bay River
Land use	Native vegetation	Native vegetation	Forests and native vegetation	Native vegetation and forests
Forest cover	Rainforests, eucalypt tall and low forests, other native forests	Rainforests, eucalypt tall and low forests, other native forests	Eucalypt tall forests, and a negligible patch of hardwood plantation	Eucalypt tall and low forests, and a negligible patch of hardwood plantation
Area (km²)	764	689	8.5	62

Except for Allans Rivulet, which is located on the Tasman Peninsula, the selected catchments are located in the west part of Tasmania, a mountainous region.

Runoff data

The runoff data for the four catchments were supplied by the respective owners of the streamflow monitoring stations (DPIPWE or Hydro Tasmania); details of the monitoring stations are given in Table 2.

Table 2 Characteristics of the streamflow monitoring gauges of the four catchments

Catchment	Franklin River	Davey River	Allans Rivulet	Nelson Bay River
Gauge name and number	Franklin River at Mount Fincham Track (145)	Davey River below Crossing River (473)	Allans Rivulet upstream Taranna (2216)	Nelson Bay River at Temma Road (1307)
Owner	Hydro Tasmania	DPIPWE	DPIPWE	DPIPWE
Period of streamflow record	1953-2007	1964-2007	1983-	1995-2007

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The first step was to assess the quality and the continuity of the records. Indeed, the data quality is not consistent for the whole period of record: there are some missing, estimated or interpolated days. The missing and very bad quality (quality code>45) days were eliminated. As a result, there were some gaps in the records.

For Franklin, the gaps were small (<33 days) and scattered all along the record. There were a total number of 180 missing days in the record, which represented 0.6 % of the record. Given that the missing days only represented a small proportion of the record, the impact of the missing days on the reliability of the runoff record has been considered negligible. Runoff data from the Franklin and Collingwood rivers (the Collingwood is a major tributary of the Franklin) were highly correlated (R^2=0.94),

thus the Collingwood River flow record was used to fill the missing days of Franklin River flow record. The result is a continuous reconstituted record for Franklin runoff between 1953 and 2007.

For the three other catchments, the gaps were longer (e.g. 137 days in 1977 for the Davey River, 40 days in 1996 for Allans Rivulet, 48 days in 1995 for Nelson Bay River), thus they were left blank so the records are not continuous. The smaller gaps (<10 days) of the Davey River record were filled using the data obtained from the nearby catchment Huon River (correlation of Davey River and Huon River: R^2=0.82).

Rainfall data

The main difficulty with the rainfall data was that these catchments are remote, so they do not have any rainfall stations or stations with only short periods of record.

In order for the calculation of runoff coefficients to be as accurate as possible, the data from the Patch Point Dataset (PPD) stations of the Department of Environment and Resource Management of Queensland Government or of DPIPWE stations were used. Patch Point Data are taken from observed records when they are available; any missing data are replaced with data interpolated from nearby stations to create a continuous rainfall record.

However, while these stations provide accurate point data, their distance from the catchments creates a bias as they do not fully represent the actual rainfall of the catchment. Tasmanian rainfall varies considerably over short distances due to the rugged topography. Thus the interpolated SILO 0.05° (~5km) gridded dataset of the Department of Environment and Resource Management of Queensland Government were also used. SILO rainfall data are interpolated from all nearby PPD stations and take into account parameters such as topography for each 0.05° grid cell over Australia. For each catchment, the rainfall data of all the grid cells that were at least half-included (i.e. more than 50% of their area being in the catchment) were used to calculate an averaged rainfall for the catchment. Table 3 sums up the rainfall data used for each of the catchments.

Table 3 Rainfall stations and SILO grid cells used for the four catchments

Catchment	Franklin River	Davey River	Allans Rivulet	Nelson Bay River
Nearest rain gauge name and number	Lake Saint Clair National Part (96071)	Strathgordon Village (97053)	Eaglehawk Neck Old Jetty Road (94071)	Wuthering Heights
Owner	PPD	PPD	PPD	DPIPWE
Distance from the catchment (km)	5.6	12.7	4.5	Within the catchment
Number of SILO grid cells used to calculate the average rainfall	40	30	2	2

Except for the Franklin River, the averaged rainfall with SILO data had consistent pattern and amplitude with the raw data from the stations. For Franklin, the SILO averaged rainfall was much higher than the rainfall given by PPD station Lake Saint Clair at National Park. The reason for this might be that Lake Saint Clair National Park station is located on the mountains at the east of Franklin catchment. Rainfall-bearing weather tends to come from the west in these regions, and the western

mountains (such as those in the Franklin River Catchment) have a rainshadow effect on mountains to the east (such as those in the Lake Saint Clair National Park). In order to use rainfall data that represent the actual rainfall on the catchment, the rainfall data from the 6 PPD stations around Franklin were plotted against the SILO averaged rainfall. The PPD station Gormanston (14km north-west of the catchment) showed the best correlation (R^2=0.84), and was therefore chosen for further analysis. However, it showed a higher level of rainfall (average annual rainfall=2908mm; whereas SILO average annual rainfall=2341mm over the period of record), but SILO is known to underestimate the rainfall on the west coast of Tasmania, as it is based on very limited observed data and mostly interpolated (Ling, F. et al., 2006).

Runoff coefficient calculations

Once the runoff and rainfall data were collected, the runoff coefficients for each catchment were calculated and displayed for monthly and annual time steps. For each catchment, the analysis was done twice: once using SILO averaged rainfall and once using the most appropriate nearby rainfall station. In order to try to identify the drivers of the possible observed trends, the annual runoff and rainfall were also plotted. For each record, statistical tests of Mann-Kendall, Spearman's Rho and Linear Regression were applied to determine the statistical significance of the observed trends. Mann-Kendall statistical test is among the standard procedures selected by the World Meteorological Organization for detecting trend or change in long time series hydrological data (Chiew, F. & MacMahon, T.A., 1992).

RESULTS

The trend results obtained for annual time steps are given in Tables 4a to 4d. Regarding statistical significance, when the different tests showed different results, the result indicated in the table is the one with the highest level of significance i.e. the smallest evidence against H_0=no trend.

Table 4a Calculated trends in annual rainfall, runoff and runoff coefficient for Franklin River catchment

Parameter	Rc (Rf=SILO)	Ro	Rf SILO	Rc (Rf=PPD)	Ro	Rf PPD
Trend (year^{-1})	-0.31%	-3.79 mm	+4.53 mm	-0.16%	-3.79 mm	+2.11 mm
Statistical significance	↓1%	Ø	Ø	↓1%	Ø	Ø
Runoff elasticity		-0.91			-2.51	

Rc = runoff coefficient
Ro = runoff
Rf = rainfall
↓1% = Declining trend at a 1% significance level
Ø = No statistically significant trend
Runoff elasticity = (ΔRo/Ro)/(ΔRf/Rf)

Table 4b Calculated trends in annual rainfall, runoff and runoff coefficient for Davey River catchment

Parameter	Rc (Rf=SILO)	Ro	Rf SILO	Rc (Rf=PPD)	Ro	Rf PPD

Trend (year^{-1})	+0.06 %	-1.00 mm	-2.30 mm	-0.01%	-1.00 mm	+1.90 mm
Statistical significance	Ø	Ø	Ø	Ø	Ø	Ø
Runoff elasticity		0.49			-0.64	

Rc = runoff coefficient
Ro = runoff
Rf = rainfall
Ø = No statistically significant trend
Runoff elasticity = (ΔRo/Ro)/(ΔRf/Rf)

Table 4c Calculated trends in annual rainfall, runoff and runoff coefficient for Allans Rivulet catchment

Parameter	Rc (Rf=SILO)	Ro	Rf SILO	Rc (Rf=PPD)	Ro	Rf PPD
Trend (year^{-1})	-0.79 %	-10.72 mm	-9.19 mm	-0.77%	-10.72 mm	-10.01 mm
Statistical significance	↓5%	↓5%	↓5%	↓5%	↓5%	↓5%
Runoff elasticity		2.72			2.43	

Rc = runoff coefficient
Ro = runoff
Rf = rainfall
↓5% = Declining trend at a 5% significance level
Runoff elasticity = (ΔRo/Ro)/(ΔRf/Rf)

Table 4d Calculated trends in annual rainfall, runoff and runoff coefficient for Nelson Bay River catchment

Parameter	Rc (Rf=SILO)	Ro	Rf SILO	Rc (Rf=DPIPWE)	Ro	Rf DPIPWE
Trend (year^{-1})	-0.41 %	-24.11 mm	-34.58 mm	-2.01%	-24.11 mm	+6.91 mm
Statistical significance	↓10%	↓10%	↓10%	↓10%	↓10%	Ø
Runoff elasticity		1.28			-5.71	

Rc = runoff coefficient
Ro = runoff
Rf = rainfall
↓10% = Declining trend at a 10% significance level
Ø = No statistically significant trend
Runoff elasticity = (ΔRo/Ro)/(ΔRf/Rf)

The separate runoff coefficients for the four seasons were also analysed. Although the amplitudes of the different seasons' runoff coefficients were different, notably due to higher soil permeability in winter (Blöschl, G. & Montanari, A., 2009), whenever a trend was observed at the annual time step, the trend was observed equally in the four seasons (i.e. no season was affected by that trend than the others).

The runoff coefficients, except for Port Davey River -where no significant trend appears- are decreasing with time.

For these four catchments, no general statement regarding the evolution of rainfall over Tasmania can be made: different trends are observed for each catchment. Moreover, the different results observed for the same catchment according to the

source of the rainfall data (SILO/station) indicate that some precaution should be taken when interpreting the results.

Franklin River shows surprising and unusual results. While its rainfall seems to be increasing, its runoff seems to be decreasing (though none of them is statistically significant). The decrease in runoff is consistent with declining water yields reported for the region since 1975 (McConachy, F. & Krohn, S., 2000). Moreover, further analysis of the rainfall of all the PPD stations located around Franklin (less than 20km from the catchment) showed that there is a high spatial variability of rainfall in that area, which explains the difficulty of finding rainfall data that are representative of the catchment.

Excepting the Franklin River, the positive elasticity in most cases shows that runoff patterns consistently follow rainfall patterns. However, two cases with negative elasticity (Davey River PPD and Nelson Bay River DPIPWE) underline again that precautions should be taken regarding the reliability of the data.

DISCUSSION

The observation of decreasing runoff coefficients is an unusual result for catchments unimpacted by forestry. Indeed, as older forests tend to use less water than younger ones, it could be expected to observe an increasing trend in the runoff coefficient. Different hypotheses have been put forward -and when possible, tested- regarding this observation. Some changes could have occurred in the seasonality of the rainfall -but the separate analysis of runoff coefficients for the four seasons showed that the observed trends were equally occurring in all four seasons-; in the intensity of rainfall (e.g. a switch from a small number of large events to a large number of small events could lead to a decreasing trend in annual runoff) -but the repartition of large events shows to respect an even distribution-; or in the spatial distribution of rainfall over the catchments -which cannot be tested.

There might be different causes to the unusual results -increasing rainfall and decreasing runoff- observed with Franklin River. First, rainfall in that mountainous region is subject to high spatial variability, which probably is not sufficiently represented in the interpolated SILO data. Moreover, there is an important area of karst systems at the north-west of the catchment, thus there might be some subterranean water coming into Franklin from another catchment. That might explain the high runoff coefficients and the inconsistency of the runoff pattern observed for Franklin. Lastly, evapotranspiration shows an increasing trend with time, which might contribute to the decreasing runoff.

Further analysis might need to be carried out, although the problem of data reliability might remain a limiting factor.

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