Historical trends in the flows of the Breede River

Philip Lloyd
Energy Institute, Cape Peninsula University of Technology, Cape Town, South Africa

Abstract

The Breede River is not a large river by world standards, but is the largest in South Africa's Western Province, and plays a significant part in the province's economy. Models predict that flows into it could be seriously affected by climate change. Accordingly a study was made of trends in flow over recent decades, in the hope that any trends detected would confirm, or otherwise, the prediction of the models.

Data on flows over 30 years at various sites in the Breede Valley were downloaded from the Department of Water Affairs. The data were first checked for consistency. In 2 cases there was evidence that behaviour of the flow had changed, apparently permanently, during the course of the study period (typically the variance of the flow had changed markedly at a particular point in time). The data series was accordingly truncated to make use only of the longest series of consistent records. A simple, robust technique was then employed to detect the trends. The data at each site had a log-normal distribution, and linear regression of the log-transformed data was used to detect the trend. An F-test showed that in all cases the trends were significant; in one case a t-test indicated the detected trend was of low significance, but all others were highly significant.

The results are discussed in terms of land use changes being a dominant factor in flows in the Breede River system, to an extent that should not have been ignored in attempting to use the data to predict future flows. Indeed, only one of the sites used in the study had a pristine watershed, and that showed a 14% increase in flow over the study period, contrary to the climate change predictions. There had earlier been a suggestion that climate change might be responsible for the changes in flows. It is generally recognised that climate change models cannot yet account for local climate change effects. Predictions of possible adverse local impacts from global climate change should therefore be treated with the greatest caution. Above all, they must not form the basis for any policy decisions until such time as they can reproduce known climatic effects satisfactorily.

Keywords: Breede River, runoff, trend analysis, climate change

Introduction

There is global concern over the emission of carbon dioxide and other infra-red active gases, such as methane, into the atmosphere by human activity. There is no doubt that the concentrations of carbon dioxide and other active gases ('greenhouse gases') in the air are increasing. The burning of fossil fuels is blamed. Since about 1950 the rate of consumption of fossil fuels has soared and continues to grow (Fig. 1).

The effect of increasing concentrations of greenhouse gases in the atmosphere should be to increase the average temperature, and the average temperature of the globe appears to have been increasing for as long as mankind has had reliable thermometers with which to measure the temperature. Increasing temperatures should alter the thermal balances of the atmosphere and thus be the underlying cause of climate change (see, for instance, IPCC, 2007).

However, the way in which the climate may change as temperatures increase is difficult to quantify. In an attempt to understand what might occur, large computer models ('General Circulation Models' or GCMs) have been developed which perform the necessary energy balances and couple the various physical environments involved to provide the necessary feedbacks. Some idea of the difficulty of doing this successfully may be gauged from the fact that the resolution of a typical model (HadAM3) is 2.5 x 3.5 degrees, or about 280 x 420 km at the Equator. Each grid cell is typically 1 km high, and there will be about 20 vertical levels. At this resolution many of the atmospheric features that are important for hydrology will not be fully captured by the model and will, at best, only be approximated.

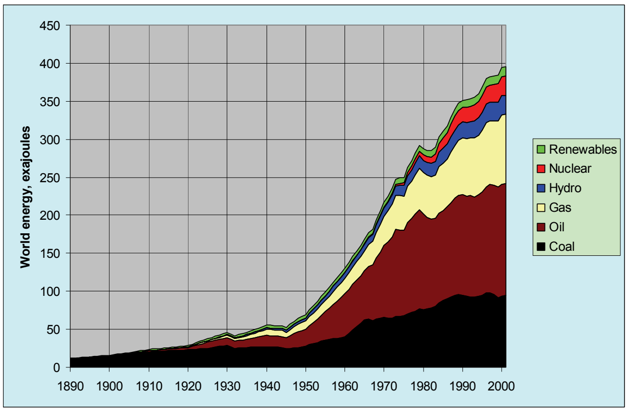

Figure 1
Growth in primary energy consumption.
Fossil energy is the sum of coal, oil and gas.
Source: International Energy Agency & BP Statistical Review of World Energy

Nevertheless, attempts to assess the possible local impacts of climate change continue to be made. A recent example was a study of future runoff in the Breede River valley (Steynor et al., 2009). A form of neural network was used to downscale

* To whom all correspondence should be addressed.
☎ +2721 460 4216; fax: +2721 460 3828;
e-mail: plloyd@mweb.co.za
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from a global climate model to the typical area of a catchment. The network was trained on historical climate data, and the climate data was linked to historical flow data at 5 stations in the Breede River valley. Thus, in principle, it was possible to link changes in the global climate model to the local climate and subsequent flow.

Three different global models were used. They were run under the A2 climate scenario (IPCC 2000). One of the models, CSIRO, could not reproduce a Mediterranean-type climate for the area. The other 2 models, ECHAM4 and HadAM, reproduced the Western Cape better, and both predicted a significant decrease in runoff, as shown in Table 1.

Table 1
Expected change in mean annual runoff from stations in the Breede River catchment

Station*	ECHAM4, % change	HadAM, % change
H1H006	-57	-33
H1H008	-53	-29
H4H017	-54	-29
H6H009	-38	-13
H7H006	-46	-22

**The identifiers are those of the Department of Water Affairs. These are the drops in flow which the models expect to occur over the next 60 years.*

It is perfectly possible to calibrate these models, because it is now ~60 years since greenhouse gas emissions started increasing rapidly. Any effects on climate will have been growing throughout this period. The historical record of flow from the stations in the Breede Valley can be interrogated for changes that may have occurred during this period, and the results compared to the predictions from the global climate change models.

Data

The data obtained was basically the same as that used in the original study (Steynor et al., 2009), but owing to archiving constraints it may not be exactly the same data (Hewitson, 2009; Steynor, 2009). However, this should not affect the results in any significant way.

Data for the various stations were downloaded from the Department of Water Affairs website (DWA, 2009) as text files and imported into Excel for analysis. The records downloaded are given in Table 2. Note that, whereas Steynor et al. (2009) chose to examine data only up until 1999, it was decided in this case to use the latest available data. The longer the baseline, the more reliable is the estimation of any trend in the data.

The data are associated with quality codes. Only those data with codes 1, 2 and 60 were accepted for further processing,

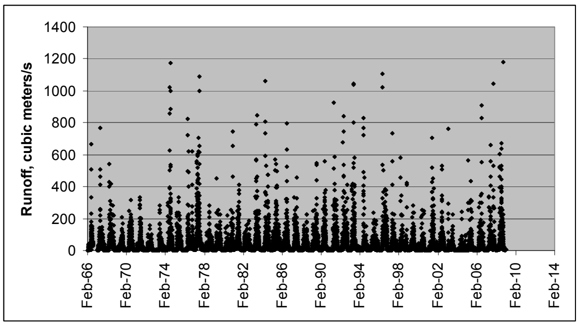

Figure 2
Distribution of data, Station H7H006

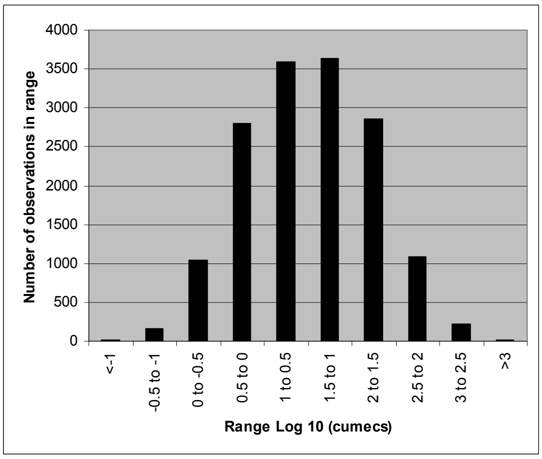

Figure 3
Distribution of log-transformed data, Station H7H006

and no-flow values were removed. These removals numbered less than 500 records per 15 000 data points. The distribution of the data was then examined. Figure 2 shows the raw data for H7H006.

The data are clearly not normally distributed. It is not possible to take a meaningful average from such a distribution, because there will be a large difference between the mean and the median. In the case of H7H006, the median is 10.342 and the average 36.175 m^3/s. Accordingly they were transformed into the log domain, and there were normally distributed, as Fig. 3 shows.

The data are well represented by a log-normal distribution, with a median of 10.342 and a mean of 10.319 (when transformed from the log domain).

The remaining data was checked in the same way. Two stations were found where the nature of the distribution changed during the period examined. This is illustrated for H1H006 in Fig. 4.

Table 2
Details of the flow stations, their watersheds and the data recovered

Station	Name	Area, km²	Latitude*	Longitude*	Data start	Data end
H1H006	Witbrug	753	32°25'18"	19°13'06"	16/04/1950	11/05/2009
H1H018	Haweqias	113	33°43'24"	19°10'33'	27/02/1969	14/05/2009
H4H017	Le Chasseur	4336	33°49'05"	19°41'41"	30/04/1980	18/02/2009
H6H009	Reenen	2007	34°04'32"	20°08'44"	10/05/1964	17/02/2009
H7H006	Swellendam	9842	34°03'57"	20°24'15"	16/03/1966	17/02/2009

** The co-ordinates were checked. Station H6H009 is actually 34°04'46"S 20°08'40"E*

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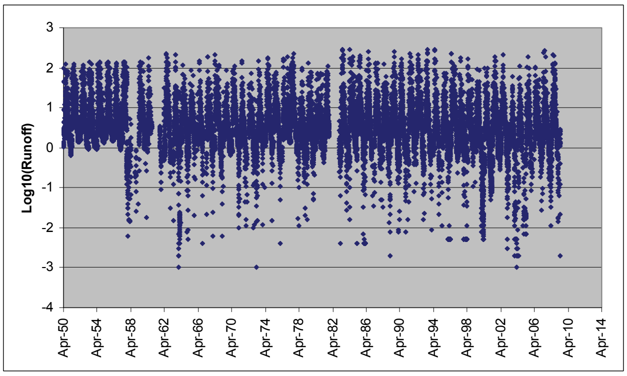

Figure 4
Log-transformed data for Station H1H006

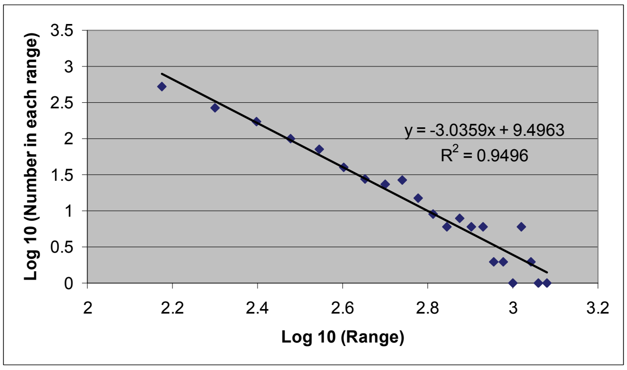

Figure 5
Number of samples in each range, for ranges of flows between 0-50, 50-100 etc, Station H7H006

The distribution of the pre-1958 data is visibly different from that of the post-1960 data. Every statistical test showed that the 2 populations had different characteristics. It is suspected that some form of abstraction was taking place, so that the minimum flow dropped by up to 3 orders of magnitude after 1960. There was also a very significant gap in the data at about 1980, although the populations on either side of the gap had similar statistical properties. The early data was therefore not included in the analysis.

Station H6H009 also showed a similar marked difference between its pre- and post-1978 data, so the pre-1978 data was also omitted. Station H1H006 is in Mitchell's Pass, and there was no identifiable event around 1958 which could be identified as causing the change. There is no record of a change in the methods of recording the flow, which might be a source of this type of change However, Station H6H009 is below Theewaterskloof Dam, which only came into operation around 1978, so this is most likely to be the cause of the change in flow which is observable in the record.

Analysis

The log-transformed data were analysed by linear regression. Lloyd (2009) has discussed in some depth the use of linear regression with large data sets containing several sources of noise such as seasons. The linear regression effectively computes the local mean everywhere in the sample population, and the variance of the mean of the population, s_m^2, is far smaller than sample variance s^2, because $s_m^2 = s^2/(n-1)$ where n is the size of the sample. Thus even though the variance of the individual sample is very large, as it clearly is in data such as that in Fig. 4, the variance of the mean of any set of a thousand or more samples can be very small. With 12 000 to 17 000 samples in the population, there are many sets of a thousand samples possible, the mean of each of which will have a very small variance.

Thus a trend is defined as the way in which the local mean varies with time. This is estimated by the regression, the slope of which gives the trend very robustly. Two tests of significance were employed. In the first, an F-test was applied to the regression of flow vs. time. In the second, a t-test was used to compare the mean of the 1st half of the sample set with the mean of the 2nd half. It was assumed that the variances of the 1st and 2nd half were approximately equal, and this was a good approximation for 3 of the full sets. However, it was also the 1st sign that something was amiss with the full data sets for H1H006 and H6H009 as described above. Once truncated, they were well behaved under this test.

A final test used the untransformed samples sorted by value into sets of equal range, and plotted as the logarithm of the number of samples vs. the range, as shown in Fig. 5.

In every case but one, a statistically significant straight line resulted. Its extrapolation gave a good estimate of the peak flow that might be expected.

Results

The results of this analysis are given in Table 3. The 2nd column gives the period over which the trend analysis was conducted.

Table 3
Results of analysis

Station	Date	Median flow m³/s	% change	Statistical tests F	Statistical tests t	Peak flow m³/s	Comment
H1H006	May-80	3.40	-54.4%	>99.99	>99.99	485	Data between 1950 and 1980 from different population
	May-09	1.55					
H1H018	Mar-69	1.99	+14.6%	97.8	98.1	313	
	May-09	2.28					
H4H017	May-80	13.41	-10.9%	99.8	>99.99	1 287	
	May-09	11.95					
H6H009	May-78	10.02	+0.2%	>99.99	>99.99	[1 397]*	Data between 1964 and 1978 from different population
	May-09	10.04					
H7H006	Feb-66	9.69	+13.3%	99.2	NS	1 343	
	May-09	10.98					

** In this case the data did not yield a significant regression such as that shown in Fig. 5.*

This was shorter than the full length of the data record for sites H1H006 and H6H009 because some of the earlier data from these sites was clearly from a different population, and the data set was truncated as described earlier. The 3rd column gives the 'median' flow, i.e. the most likely flow. It is **not** the same as the average flow, because the data are log-normally distributed. The 4th column gives the percentage change over the period of the analysis. For instance, at site H1H006, in May 1980 the median flow was 3.40 m^3/s, and by May 2009 it had fallen to 1.55 m^3/s; 1.55/3.40 = 0.456, so the fall was 1 – 0.456 = 0.544 or 54.4%. Columns 5 and 6 show the results of the statistical tests. In each case the value given represents the probability that the trend found does **not** arise from random effects.

Discussion

Comparison of the results for the changes in flow that have occurred over the past 40 years, shown in Table 3, and the predictions of what might occur in the next 60 years, shown in Table 1, indicates significant differences. The question is what might cause a change in flow. Steynor et al. (2009) hypothesized that temperature changes in the global climate would cause a significant drop, but this seems unlikely, because there has been an increase in temperature over the period of the present study, and a number of the measuring stations have recorded significant increases in flow. There appears to be no valid reason to suppose that, if temperature change is indeed a driver for flow, the direction in which it drives should suddenly reverse.

One difficulty that has to be faced, and which Steynor et al. (2009) apparently did not consider when training their downscaling model, is changes in the watershed rather than in the temperature. We have already seen that the flow at Station H6H009 on the Riviersonderend tributary almost certainly changed when a major dam was constructed upstream. The fact that the flow barely changed over the present study period may be a tribute to effective management of the impoundment more than to any climatic effects.

The flow at Station H1H006, which is situated at the base of Mitchell's Pass, may similarly have been affected by changes in the Ceres valley over the period of study (the Koekedouw Dam came into operation too late to have much influence). Station H4H017 is well below Worcester's Brandvlei reservoir, and receives flow from both the upper reaches of the Breede and the Hex Rivers. The growth of the grape industry in the Hex River valley, and the associated development of many moderate-sized impoundments, must have affected the river flow adversely at this point. Also, of course, H4H017 would have felt the effect of the decreased flow from H1H006 – both flows dropped by about 2m^3/s over the study period.

Similarly H7H006, below the confluence of the Breede and the Riviersonderend, must have been affected by a high degree of abstraction, because flow should be approximately the sum of H4H017 and H6H006, and in fact it is less than either.

This leaves H1H018 in Du Toit's Kloof as the only Breede tributary studied which has had minimal development in the catchment area during the study period. It has shown a significant increase in flow. Temperature change could have had a beneficial effect – it seems most unlikely that temperature change could have had the negative impact estimated by Steynor et al. (2009), because that would require some other factor to have had a major positive effect, and no such factor is apparent – the watershed is effectively pristine.

The discrepancies between this study and that of Steynor et al. (2009) may be a result of different quality checks or not accounting for water resource management changes such as that identified in Fig. 4.

A further effect was the level of correlation of flows between the stations. Account was not taken of the fact that H1H006 and H1H018 were upstream of H4H017, or that H4H017 and H6H009 together were the principal sources of H7H006.

Steynor et al. (2009) appear to have assumed that each station was independent. Once it was clear that there was a high degree of long-term cross correlation between the stations, it became obvious why two of the models were able to find that all stations moved in the same direction under the supposed climate change forcing.

A further statistical problem was the authors' failure to recognise the need to take into account the distribution of the data. They appear to have used average values as their measure of flow, unaware of a serious degree of high bias when averages are used with logarithmically distributed data. This alone could readily have led them to a false conclusion.

These are all problems with the runoff data sets employed by the authors. A further problem was that of linking flow to rainfall. Rainfall data were not employed, but a weather model, the 'National Centres for Environmental Prediction reanalysis' data, was used because of 'the lack of contiguous observed data relating to atmospheric state.' This appears to be a standard method for avoiding problems with downscaling from general circulation models, but it cannot escape the criticism that it replaces one model with another. Instead of rainfall, it employed (Steynor et al., 2009) 'the geopotential height and the specific humidity at 700 kPa' as predicted by the model. They were chosen because they 'reasonably characterise the general atmospheric state related to rainfall.' Note that there is no evidence in support of this assertion. Nevertheless it was claimed (Steynor et al., 2009) that 'Using a rainfall-related synoptic state was more accurate than using model-derived precipitation data because of the high level of uncertainty in the parameterisations used to derive precipitation data from atmospheric models.' Again, there is no evidence for the claimed superior accuracy, but there was a valuable admission that the models do a poor job of predicting rainfall. It is contended that the uncertainties that the authors describe in their approach are probably sufficient to raise major questions about any output from their study. Modelled data is used instead of real data; unsubstantiated claims are made about accuracy and links between parameters; and the geopotential and the specific humidity are used as a proxy for rainfall without any demonstration of the linkage between the factors.

As a final step they studied lags between rainfall and flow, and came to the conclusion that 1 day sufficed to account for all lags. This seems most unlikely. Recall, for instance, that Station H6H009 on the Riviersonderend tributary is below the large Theewaterskloof Dam, and that the distribution of flows was such that it seemed likely that releases from the dam were carefully controlled. In this case the lag between rainfall and flow could be very large indeed – if there were any correlation at all. This is not quite the case for Station H4H017 below the Brandvlei Dam, because Brandvlei is significantly smaller than Theewaterskloof, and the catchment area over twice as big. So some lag would be expected at H4H017, although significantly longer than 1 day. There are no significant impoundments between H6H009/H4H017 and H7H006 so a 1-day lag is not unreasonable.

The difficulties of applying General Circulation Models to local climates are well known. In its revised Summary for

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Policy Makers in the Fourth Assessment Report, the IPCC (2007) said:

'Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger, making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings and feedbacks also make it difficult to estimate the contribution of greenhouse gas increases to observed small-scale temperature changes.'

If this is true of temperature, it is even truer of precipitation.

Conclusions

Examination of river flows over the past 43 years in the Breede River basin shows that changes in land use, creation of impoundments, and increasing abstraction have primarily been responsible for changes in the observed flows. However, one site examined has a relatively pristine watershed, and its flow has increased significantly. The only hypothesis to explain this increase is the beneficial impact of temperature change.

The claims by Steynor et al. (2009) that climate change is likely to reduce flows in the basin in the future have been found to be without foundation. They are based on a series of hypotheses that are unsubstantiated, and use data that were not scrutinised carefully. Alternative hypotheses were not evaluated, so that, for instance, the impact of the construction of a large impoundment on the Riviersonderend River, obvious in the record of the flows, was overlooked. The phenomena that they observed have clear physical bases, and it was not necessary to invoke climate change to explain them. Note that this is not to say that climate change may not play a role, merely that the argument for a climate change effect is not substantiated by their evidence.

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