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ORIGINAL ARTICLE

Use of climate scenarios to aid in decision analysis for interannual water supply planning

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Abstract This work addresses the issue of climate change in the context of water resource planning on the time scale of a few years. Planning on this time scale generally ignores the role of climate change. However, where the climate of a region has already shifted, the use of historical data for planning purposes may be misleading. In order to test this, a case study is conducted for a region, the Australian Capital Territory, where long term drought is raising concerns of a possible climate shift. The issue is cast in terms of a particular planning decision; the option to augment water supply in the next few years to hedge against the drought persisting. A set of climate scenarios are constructed for the region corresponding to the historical climate regime and to regimes where progressively greater levels of change are assumed to have already taken place (5%, 10%, 20% reductions in mean rainfall). Probabilities of the drought persisting are calculated for each of the scenarios. The results show substantial increases in the probability of the drought persisting for even moderate reductions in mean rainfall. The sensitivity of the decision to augment supply to the scenario results depends ultimately on the planners tolerable thresholds for the probability of the drought persisting. The use of different scenarios enables planners to explore the sensitivity of the decision in terms of their risk tolerance to ongoing drought and to their degree of belief in each of the scenarios tested.

Keywords Drought management · Climate scenarios · Climate change · Water resources · Decision analysis

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1. Introduction

There is a growing history now of the use of weather and climate information to aid in water supply planning decisions. On short time scales in the range from hours to days, outputs from dynamical weather models are provided as inputs to hydrological models, primarily for the purpose of flood forecasting (Krzysztofowicz, 2001; Jasper *et al*, 2002). On long time scales of order several decades we are often concerned about potential climate changes (Arnell *et al.*, 2001). In that case, climate scenarios are developed, based on climate models and other sources, for projecting uncertainty in future water supply (Gleick, 1989; Risbey, 1998). In between these time scales are the seasonal (several month) and interannual (several year) time scales. On seasonal time scales, forecasts are produced from both statistical models (Chiew *et al.*, 2003) and increasingly from dynamical weather models (Shukla *et al.*, 2000) for use in water resource and agricultural planning. The interannual time scale is something of a lacuna at the present time. It falls outside the scope of weather and seasonal models, but is too short a time scale for climate scenarios based on greenhouse climate changes. Thus, planning on this time scale tends to make use of neither weather forecasts nor climate scenario information. Rather, one typically assumes that the climate is more or less stationary on this time scale and that historical rainfall series can safely be used in characterizing hydrological responses.

The purpose of this paper is to explore whether climate scenarios have any role to play at the interannual time scale. In doing so, we can also begin to explore the margin of safety for the assumption that use of historical climate series (stationarity) suffices on this time scale. That is, how much does the climate need to change, or have changed, before the stationarity assumption might lead to misleading expectations for planning over the next few years? These issues are explored through a case study of water supply planning for the Australian Capital Territory (ACT), which is located in the southeastern corner of Australia. This case is described following an outline of drought issues in southern Australia.

2. Drought context in Australia

Drought is an irregular, but persistent feature of Australia's climate. While the continent has always been drought-prone (MacKellar, 1993), more recently, concern has arisen about possible changes in drought regimes as a result of greenhouse climate change (Karoly *et al.*, 2003; Risbey *et al.*, 2003; Nicholls, 2004). This concern was fueled by the extreme drought that covered much of Australia in 2002, but follows on the heels of the long running decline in rainfall in the southwestern corner of Australia (IOCI, 2002). In that region, rainfall has declined by about 15% over the past several decades (see Figure 1), leading water resource managers to assume that the reduced rainfall is now the new norm for planning purposes (Sadler, 2000). In the southeastern corner of Australia, rainfall totals have been below normal for the past eight years. Water management authorities throughout southeastern Australia have naturally been curious to know whether the relatively short term decline in rainfall there could be the beginnings of a longer decline similar to that faced by their counterparts in the southwest. This would have major implications for their short and long term management operations, since southeastern water authorities are already facing low storage levels and water restrictions.

The cause of the rainfall decline in southwestern Australia is the subject of ongoing research (IOCI, 2002), but will be difficult to establish unequivocally. It may be a natural decline, or it may be associated with changes in greenhouse gases and/or ozone (Karoly,

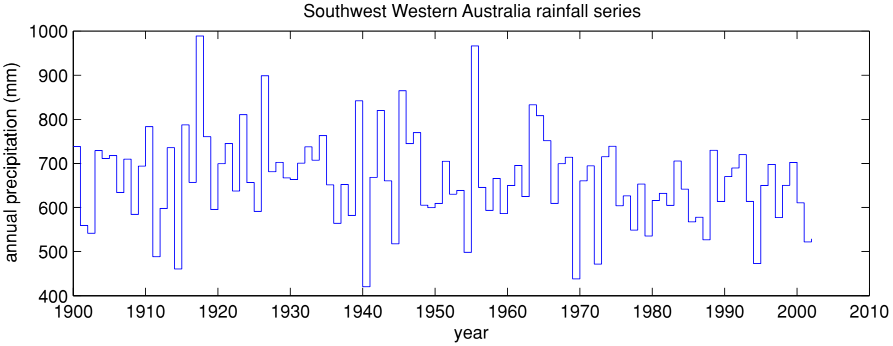

Fig. 1 Rainfall time series for the south west of Western Australia. Annual rainfall data from Australian Bureau of Meteorology

2003), or land use changes (Narisma and Pitman, 2003). The number of storms passing through this region has declined in recent decades (Simmonds and Keay, 2000). Though storm tracks fluctuate naturally, there is concern that this is consistent with the poleward contraction of southern hemisphere storm tracks posited by Hartmann *et al.*, 2003 and others. That contraction is said to occur in conjunction with an ozone-greenhouse induced cooling of the lower stratosphere in high southern latitudes. If the storm tracks were to contract polewards in southeastern Australia as well, this could yield a longer term reduction in rainfall in the region. Such a shift may even be underway, though it is not possible to establish that yet without a longer record.

One way to study a longer rainfall record is to use climate models. Models can't substitute for the real thing, but may provide some insight into the odds of obtaining a rainfall fluctuation such as observed. We analysed precipitation output for the southwest of Western Australia (WA) from a 1000 year run with the CSIRO climate model (Hirst *et al.*, 2000). The histogram of annual rainfall for the 100 year observed record and 1000 year climate model record is shown in Figure 2. The shape of the histogram is reasonable for the model, but is displaced toward weaker rainfall totals relative to observations, as is typical for climate models. We can get some indication of the frequency characteristics of the model by comparing the power spectrum of rainfall data in the model and observations. Figure 3 shows the power spectra for 100 years of data from each. The model's power spectrum matches the observations quite well over this period, with only a small reduction in power at the lowest frequencies. This gives us some confidence to use the model as a proxy for the real data set. To be sure, the model underestimate of low frequency power implies that it would produce an underestimate of the likelihood of obtaining long periods without rain by chance.

Precipitation time series generally exhibit substantial autocorrelation and are often modelled with an ARMA process (Box and Jenkins, 1976). Owing to Wold's Theorem, any covariance stationary process can be de-trended to produce a stationary ARMA process. A trend analysis of the climate model 1000-year series did not reveal any trend, and a time series analysis of the series exposed a stationary ARMA model. As a consequence, we fit an ARMA process to the climate model 1000-year series and used that to calculate the odds of obtaining a run of years with mean rainfall some specified amount below the long term mean. In order to match the conditions observed in southwest WA we set the level at 10% below the long term mean. The results are shown in Figure 4, which indicates how the probability of obtaining a sample mean 10% below the long term mean changes as the length of the sample changes. In the case of southwest WA, the drop in mean has been sustained for about the

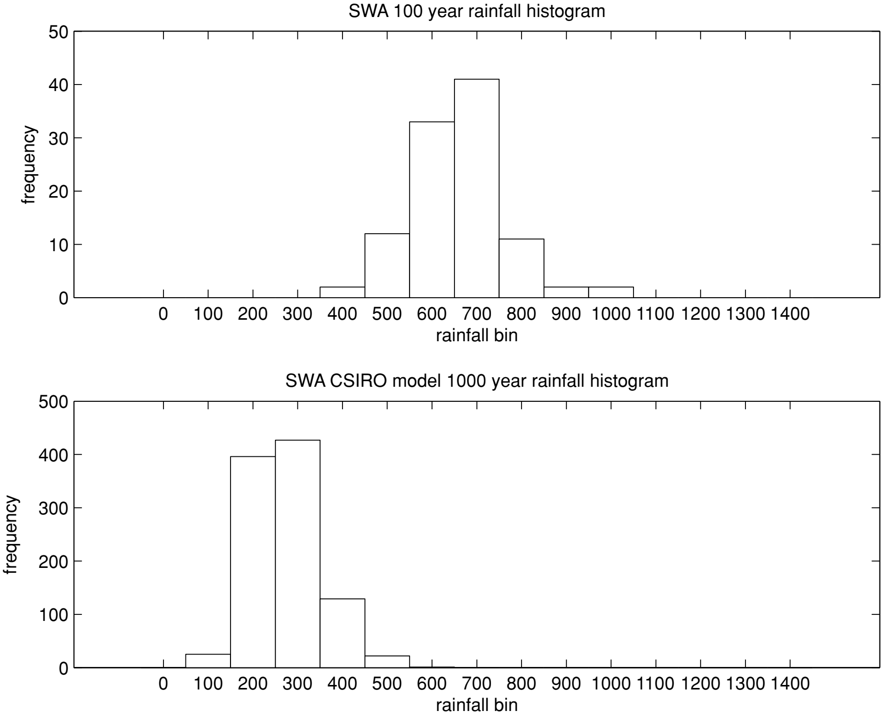

Fig. 2 Histogram of annual rainfall for south west of Western Australia for (a) 100 years of observational data (b) 1000 years of climate model data. The histogram measures the number of years in each rainfall bin. Units of each bin are mm/year

past three decades. From the climate model series we see in Figure 4 that this corresponds to a probability in the vicinity of 2 in a 100. That is, there is about a 2% probability in the model of obtaining a 30 year drop in the mean of this size by chance. These are small odds, but not zero. It would be dangerous to infer that the same odds apply to the real world, though it does help to begin thinking about the rough order of probability. A drop in rainfall such as observed in southwest WA could have occured by chance, but the longer that drop persists, the less likely that is. That is why more and more attention is being given to possible climate change explanations, and why there is concern that the same thing could occur in the southeast of Australia.

3. ACT case

Our case study region is the Australian Capital Territory. The water supply system for the ACT is managed by ACTEW Corporation (ACTEW, 2004). The ACT water system is currently experiencing low inflows (Figure 5a) and storage levels and has implemented water restrictions and a number of demand management programs. The low water levels are associated with the ongoing eight year drought in southeastern Australia. The rainfall series for the ACT region (where the catchments are located) reflects that drought and is shown in Figure 5b. In the short term, ACTEW face a decision on whether and how to augment existing supply as a hedge against continued drought years. Some of the short term options

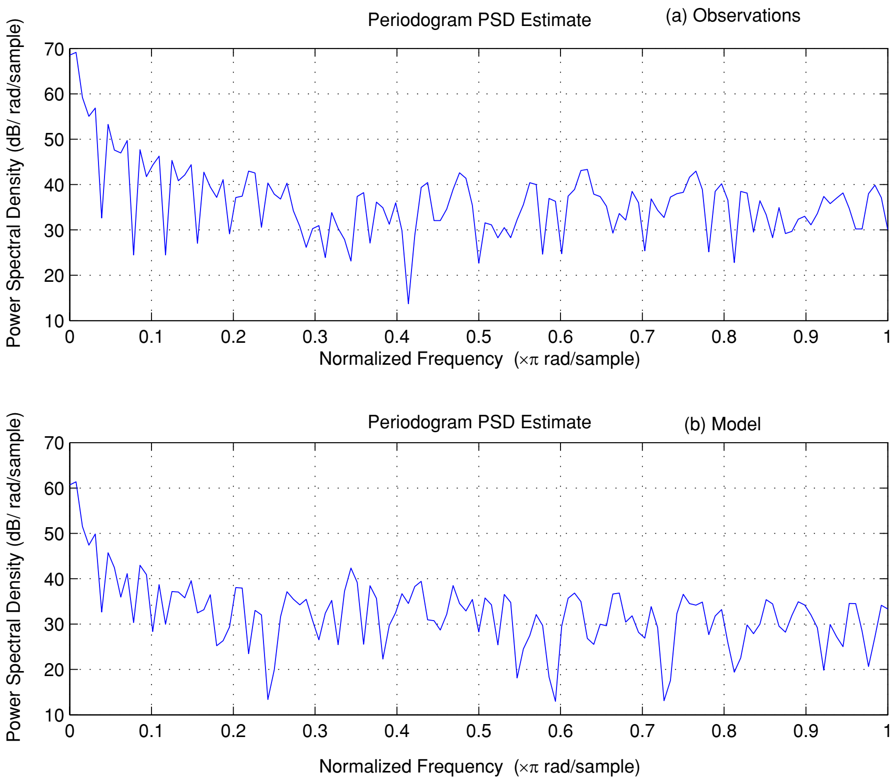

Fig. 3 Power spectrum of annual rainfall for south west of Western Australia for (a) 100 years of observational data (b) 100 years of climate model data

include new water treatment facilities to utilize water from an existing dam (Lower Cotter Dam), pumping water from the Murrumbidgee River, and more severe usage restrictions. Over the longer term it seems that additional supply will need to be procured to match growing population and other changes. ACTEW have investigated a number of options to augment long term supply, which include: constructing a pipeline to transfer water from a large dam (Tantangara Reservoir) in the neighbouring state of New South Wales, enlarging an existing dam (Cotter Dam), and constructing a new dam (ACTEW, 2004). These longer term options require from a half decade to a decade from planning to fruition for planning and environmental impact studies, design work, site investigations, and construction. Because of this delay and the ongoing drought, plans for shorter term contingency options take on greater importance.

The focus of this paper is the short term decision that covers management of the system over the next few years before longer term options start to become available. On this time scale the critical issue is whether the current drought would likely continue, necessitating use of the options to augment short term supply: pumping water from the Murrumbidgee or constructing new water treatment facilities. These options have their costs, and of course, one would like to avoid them if the drought were to end. However, since these options also have lags associated with their implementation, if they are not selected soon, then ongoing drought would lead to further and deeper water restrictions (ACTEW, 2004). This is an outcome they would like to avoid.

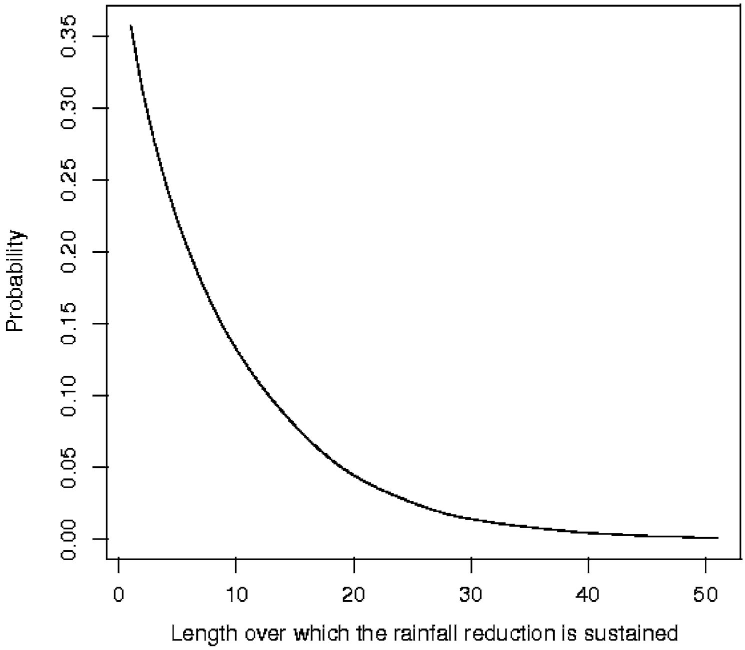

Fig. 4 Probability of obtaining a 10% drop in mean rainfall for the south west of Western Australia as a function of the length in years over which the drop in mean rainfall is calculated. Results are based on ARMA fit to the CSIRO model 1000 year rainfall series

In order to get a better idea of this possibility and to aid in their decision process, ACTEW (and others) have asked the meteorological community what the chances are that the drought will continue. There is no simple answer to this question. However, the question may be more tractable and usefully answered if we recast it in terms of the kinds of issues facing the water managers. Over the next few years the system managers have the option of exercising their shorter term contingency plans and would like to know what conditions they'll face over this period. Over this time frame, we can recast the question to make it quantitatively tractable as follows: what are the odds that two of the next three years will be significantly drier than normal? If the next few years continue to be dry, this would lead to ongoing severe water restrictions (stage 3 or greater). In that event, it would be desirable to have exercised the contingency plans. If one waits to act though, the contingency plans will not be nearly as efficable. Thus, we need to form some expectation now about the likelihood of continued drought and assess that against the costs and benefits of implementing the contingency plans or not.

In assessing the odds that dry years will continue, one must define precisely what a 'dry' year is. For this application, the operators of the system are concerned about avoiding a situation where severe water restrictions (stage 3) are in place for too long. The system is currently in stage 3 restrictions and would most likely continue to stay there (or get worse) with a prolongation of the recent rainfall/runoff regime. Over the past seven years the inflow to the system has decreased about 50% in association with a rainfall decline in the region of about 10%. A rough rule of thumb is often given that runoff declines are at least twice rainfall declines – and may be up to a factor of 5 (Chiew and McMahon, 2001) as appears to be the case here. With this rule of thumb, a 50% decline in runoff would correspond to a reduction

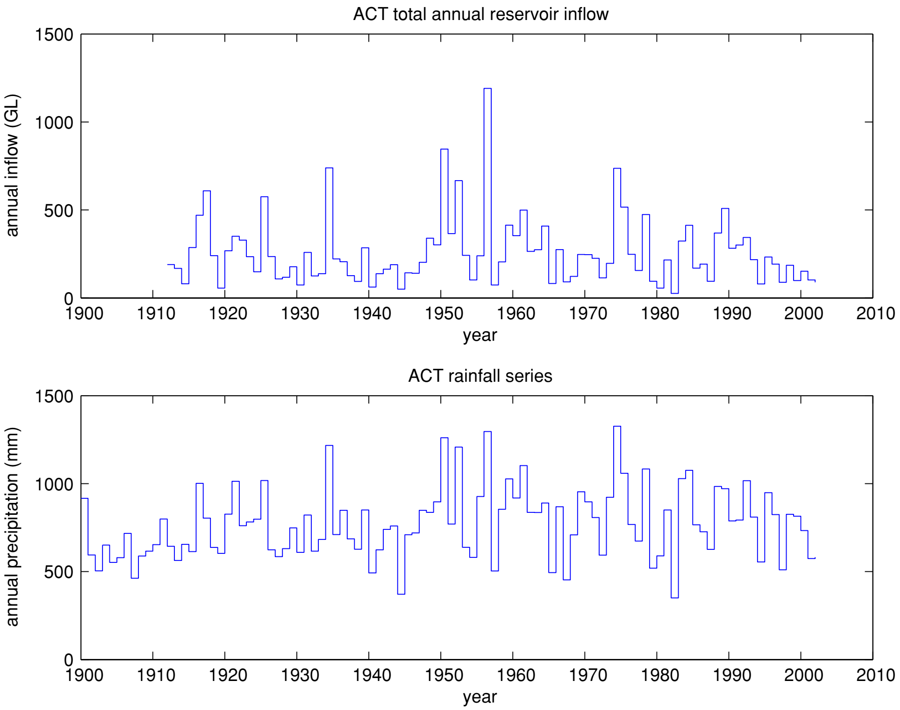

Fig. 5 ACT annual system inflow and rainfall. The upper panel shows inflow to the ACT reservoir system. The lower panel shows annual rainfall for the ACT

in rainfall from between 10% (factor 5) to 25% (factor 2). For the purposes of this exercise we have selected both the 10% and 25% rainfall reductions to correspond to moderate and severe dry years respectively. The 'moderate' dry year is typical of the current drought and is already leading to water shortages in the region. It is therefore probably a severe enough definition of dry years to invoke the contingency plans. The more extreme definition of a 'dry' year (25% reduction) would be a very substantial reduction (if maintained) and would almost certainly lead to further stage 3 restrictions (and worse) – since the current stage 3 state was attained with the milder 10% rainfall decline. A 25% decline corresponds to about one standard deviation reduction from the long term mean for the region. We employ this definition as well to give some idea of the sensitivity of results to the definition of 'dry' year, bearing in mind that the severe dry year is more extreme than needed to invoke the contingency plans.

4. Climate scenarios

The standard way to calculate the probability of dry years occurring in the immediate period is to use the long term record of rainfall for the region. Thus we obtained a long term high quality rainfall data set for the ACT (Lavery *et al.*, 1997). The data contains rainfall observations from a collection of stations in the ACT and is broadly representative of ACT rainfall, though cannot perfectly duplicate the actual rainfall in the ACTEW catchments. The ACT record is based on one hundred years of rainfall observations (Figure 5b). While this is a long record, the difficulty in using it to calculate the odds of a continuation of dry years in the ACT is that we don't know whether the climate of the ACT is stationary or not. From the series alone we can't tell whether the recent run of low years is a natural fluctuation, or whether it is perhaps the beginning of a steady or abrupt climate change. Based on the 100 year series, the odds of getting a drop in rainfall of 10% in any period spanning 7 years (as we've seen in the recent seven years) is about 1 in 5. That is, such fluctuations can occur quite naturally. However, there are also reasons to project steady or abrupt rainfall declines in the region, particularly in light of the recent abrupt rainfall changes in southwest WA. These possibilities should be allowed for in addition to the stationary climate assumption. We can derive scenarios for each of these possibilities as follows.

Stationary climate: The stationary climate scenario assumes that no climate change is taking place. Therefore the 100 year series is taken to be representative and the odds of getting 2 dry years in the next 3 can be calculated directly from the series.

Slow, steady climate change: In this scenario the ACT rainfall series can be interpreted to reflect a slow decline (with random fluctuations) over the past several decades. This scenario is consistent with steady rainfall reductions such as those given in climate model climate change simulations (CSIRO, 2001). That decline corresponds to a drop in rainfall by up to about 5% in the CSIRO ensembles or in the mean of the observed series over recent decades. We created a scenario with a 5% drop in mean rainfall by reducing all rainfall totals in the ACT series and recalculating the odds of getting 2 dry years out of 3.

Abrupt climate change: In this scenario, the recent drought is assumed to reflect an abrupt drop in the mean of the rainfall series to a lower level from which it is not expected to recover. Such a change seems to have occured in the SW of Australia in recent decades and there are concerns that the drought in the SE may follow the SW pattern. One mechanism postulated for such a regime change is the trend to an enhanced polar vortex apparently associated with ozone decreases in the Antarctic stratosphere (Hartmann *et al.*, 2003). These changes may be moving storm tracks southwards, away from southern Australia (Karoly, 2003). The recent rainfall drop in the ACT corresponds to about a 10% drop in the mean. Assuming this to be effectively permanent, we created a scenario with a 10% drop in mean rainfall by reducing all rainfall totals in the ACT series and recalculating the odds of getting 2 dry years out of 3.

Large climate change: We have added a fourth climate scenario that depicts much larger climate change in the region. In this case we set the rainfall reduction at 20%. This is twice as large as the recent reductions in the region, but is included to provide a more extreme scenario. Though extreme, sustained local reductions of this size have been approached in parts of the southwest of Australia.

Note that while the term ‘scenario’ and the scenarios themselves make reference to future climate, the scenarios are intended to describe the *current climate* of the ACT region. In the third and fourth scenarios it is clear that an abrupt change is assumed to have taken place such that the rainfall now follows a new regime with reduced mean. In the second scenario a slow steady change is assumed to have been underway for some time and is approximated for the purpose of projecting the next few years as if it were an abrupt change representing the change so far. The important point is that the scenarios apply to the present period. The reason we can have a diversity of scenarios for the present is that we don't know what rainfall regime is now in place without the benefit of hindsight or better causal understanding of the processes governing rainfall in the region.

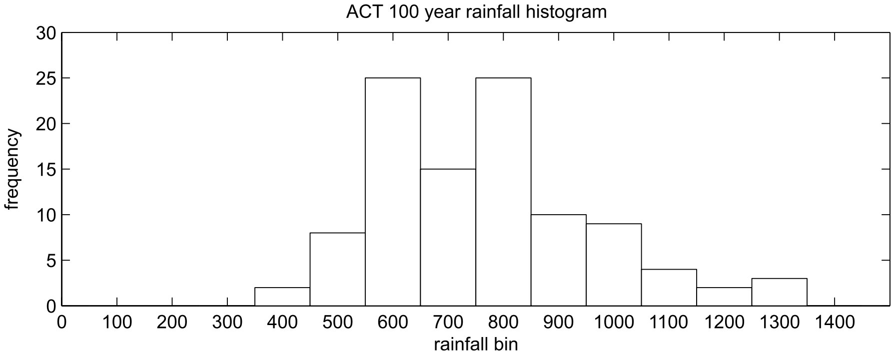

Fig. 6 ACT rainfall histogram based on 100 years of annual rainfall data. The histogram measures the number of years in each rainfall bin. Units of each bin are mm/year

The probabilities of getting a particular number of dry years in a specified period were calculated for each of the scenarios above (0%, 5%, 10%, 20% reduction in mean precipitation). The calculation of probabilities from the rainfall series can be done in a variety of different ways, depending on the structure assumed in the data. These issues are described in the following section. The method of creating the scenarios assumes the changes in rainfall have already taken place, and reduces the mean of the distributions by the specified amounts, preserving the ratio of the variance to the mean. We created them this way because our focus is on changes to mean rainfall. We have not examined possible changes in variability of the rainfall distribution here. Rind *et al.*, 1989 and others have argued for possible increases in variability of the rainfall distribution under climate change scenarios. The distribution of annual rainfall for the ACT based on the past one hundred years is shown in Figure 6. The distribution has a short tail on the low rainfall side. Any shift in the distribution that filled in that tail would be of particular concern, since that would imply more extreme dry years. We are not in a position to evaluate that possibility at this point, though that is the kind of climate surprise that would be most troubling.

5. Scenario probability analysis

The four climate scenarios described above yield four variations of the original ACT rainfall time series — an unaltered series and three others where each years rainfall total has been reduced by the specified percent. The first method we use to calculate the probability of obtaining 2 dry years out of 3 in each scenario is based on an ARMA model fit to the data. Fitting an ARMA model assumes that the data are stationary and that the errors in the model fit to the data are normally distributed. We detrended the ACT rainfall data and performed a Shapiro-Wilk normality test (Shapiro and Wilk, 1976), which does not reject normality for the data ($p = 0.2$). A seasonal ARMA(1,1) model with period 3 was fitted to the data. A normality test on the residuals of that model is more strongly indicative of normality ($p = 0.35$). We then employed the ARMA model to calculate the probability of obtaining 2 dry years out of 3 for each of the scenario series. The calculations were performed on the original data, and on detrended forms of the data. The results show little difference between the two. The results were also calculated by taking account of the correlation structure in the data and by assuming independent observations. Again, the results are fairly similar in both cases. We report results below for the undetrended data with the correlation structure taken into account.

In a second series of calculations we assumed no structure in the rainfall data and calculated probabilities using a simple Monte Carlo approach. This has the advantage of not relying on normality or any other structure being present in the data. However, it does not take into account the likely presence of autocorrelation in the series in calculating the probabilities. While use of the ARMA method seems well justified here, we present results using both methods to provide some indication of the uncertainty in the results due to the assumptions made about the underlying structures in the data. Results from both methods are shown in Table 1

The results show substantial increases in probability of continued dry years as the effective mean rainfall in the region decreases. The chance of getting 2 moderate dry years in 3 has increased to 50% for the scenario where rainfall has already declined by 10% (indicative of the current drought). This increase is from a baseline of about 30% chance of 2 moderate dry years in 3 for the unchanged climate scenario. The results for moderate dry years are relatively insensitive to the method of calculating probabilities (ARMA or Monte Carlo). For severe dry years there is more sensitivity to the method used to calculate probabilities, though the same general picture emerges of large increases in the probability of dry years when the rainfall has declined by 10% or more.

We employed four different scenarios above to represent the current state of the ACT rainfall regime. The first question is whether it matters for the operational decision which scenario is used. That is, is the decision sensitive to choice of scenario? We don’t know exactly what threshold probability the decision is sensitive to, but we can explore consequences for a range of values. If the decision to develop alternative supply hinges on a likelihood of immiment dry years of greater than about 1 in 100 then it is not sensitive to which scenario is used, since all of the above scenarios yield probabilities greater than that. The same is true for a threshold of 1 in 10 for the moderate dry year definition. For this ‘dry’ definition the threshold needs to be greater than 3 in 10 chance before the decision is sensitive to climate scenario. Thus for example if the decision hinged on a likelihood of continued dry greater than 0.5, then one would not invoke contingency plans unless believing the abrupt change or large change scenarios. For the severe dry year definition, the odds of continued dry change quite dramatically (by a factor of 4 to 20 for the two probability methods) depending on which scenario is representative of current rainfall. In summary, whether the scenario matters depends on the precise decision threshold of the planners. However, given the large changes in odds of dry year runs as a function of scenario, it seems that for many practical decision thresholds the choice of scenario will be important.

Table 1 Probability of dry years for each of the specified reductions in mean rainfall in the ACT. The first number given is taken from the ARMA model and the second number in parentheses is from the Monte Carlo calculation. The definitions of moderate and severe dry years are given in the text

	Stationary climate drop mean 0%	Slow change drop mean 5%	abrupt change drop mean 10%	Large change drop mean 20%
2 moderate dry yrs in 3	0.29 (0.36)	0.39 (0.45)	0.50 (0.52)	0.75 (0.82)
2 severe dry yrs in 3	0.08 (0.02)	0.11 (0.13)	0.16 (0.23)	0.34 (0.41)

Table 2 Weighted climate scenarios and the weighted odds of getting 2 dry years in 3. The first column of results for the weighted odds is for the ARMA probability calculations and the second column in parentheses is for the Monte Carlo calculations

Stationary climate weight	Slow change weight	Abrupt change weight	Large change weight	Weighted odds moderate dry	Weighted odds severe dry
0.9	0.1	0.0	0.0	0.30 (0.37)	0.08 (0.03)
0.6	0.3	0.1	0.0	0.34 (0.40)	0.10 (0.07)
0.3	0.3	0.3	0.1	0.43 (0.48)	0.14 (0.16)
0.1	0.3	0.5	0.1	0.47 (0.51)	0.16 (0.20)

Given that the choice of scenario does potentially matter, how do we discriminate among them? Unfortunately, there is no rigorous way to place weights on the different scenarios. However, that doesn't mean that we don't have any information about their relative likelihoods. Since precipitation is so variable and it is difficult to pick out climate change signatures, one might normally expect higher odds for the no change scenario than the abrupt change scenario – unless one had compelling reasons to expect a change. On the other hand, there are plausible reasons to expect changes and it would be a brave person that wouldn't give any weight at all to the climate change scenarios. The next question to consider is whether it matters precisely how the scenarios are weighted. We have carried out a sensitivity analysis for a range of different weighting combinations as shown in Table 2.

The table shows how the odds of attaining dry year runs increase as the weighting shifts from the stationary climate scenario to the climate change scenarios. Whether one is sensitive to the scenario weights depends critically on the threshold probability. For the moderate dry run case, if the odds of dry runs required to initiate contingency plans are less than about 0.3, then one is indifferent to the scenario weightings as they all yield likelihoods greater than that. Conversely, if the odds must exceed about 0.5 in order to initiate contingency plans, then one is again insensitive to the scenario weights as they all yield probabilities lower than that (assuming that the large climate change case is always weighted fairly low). In the middle range between these levels (0.3–0.5) the decision depends on the weighting. For some thresholds (around 0.3) it is clear that even if you allow only modest odds for the climate having changed, the threshold will be exceeded. In that case you wouldn't need to worry too much about precisely what the weights are. One knows that the threshold will be exceeded for any modest expectation of underlying climate change, so it is probably worth acting.

The point of a weighting exercise like this is to show the outcomes for a variety of expectations about whether climate has changed so that the decision maker can identify where they are situated in the table given their decision threshold and beliefs about the likelihood of change. Where they are insensitive to the weights put on scenarios, there is no need for them to deliberate much further about climate change for that particular decision. Where they are sensitive, it illustrates how climate change may matter and how the decision is not well served by a reliance on the stationarity scenario alone.

6. ACT decisions

The scenario probability analysis in the preceding section provides a basis to address the short term planning issues for the ACT raised in Section 3. The short term options to augment supply identified by the ACT water planning authority (ACTEW) included: construction of new water treatment facilities to utilize water from an existing dam (Lower Cotter Dam), pumping water from the Murrumbidgee River, and more severe usage restrictions.

With the passage of a year and a half since this research commenced, we can now report what ACTEW actually did in response to the situation described in Section 3. In effect, they chose to implement all three of the available short term contingency options. They upgraded pumps and completed a water treatment plant to utilize poorer quality water from the Lower Cotter Dam. They also built a new pump station to transfer water from the Murrumbidgee River (ACTEW, 2005). The Lower Cotter Dam project is already operating and supplying water, while the Murrumbidgee transfer has been tested but not yet sourced (ACTEW, 2005). Further, they also sought permission to implement some permanent water restrictions, which have now come into effect. The permanent restrictions are not as severe as some of the temporary measures invoked to counter the drought. The declaration of permanent restrictions follows a trend toward permanent restrictions introduced in other Australia states in the drought-effected southeast of the country.

The decision by ACTEW to invoke the short term drought contingency plans has been vindicated in as much as the drought has continued in this region (Watkins, 2006), with another year of below average rainfall in the ACT (ACTEW, 2005). The fact that ACTEW implemented all three contingency plans suggests that they took the likehihood of continuation of the drought fairly seriously. They clearly did not plan on a resumption of normal rainfall and flows over the contingency period. In terms of our scenario analysis, either they gave moderate or higher weights to the scenarios where the climate has changed, or else they gave low weights but are risk averse in their planning. Though we can't be sure of the relative contributions of these factors, published reports and consultation by ACTEW shows that they were concerned about the drought and had reasonable expectations that it could continue. Thus, they implicitly gave at least modest weights to the change scenarios described in Section 4. Given that, the decision to augment supply by implementing the contingency measures follows given the need for only moderate levels of risk aversion. For moderate (or higher) weights on the change scenarios the probability of getting critical dry years rapidly approaches 0.5. At this level of probability one doesn't need to be very risk averse to decide that invoking the contingency plans is the best course of action.

The decision to augment supply would have been reinforced by other factors as well in this case. A bushfire in 2003 burnt most of the forest cover in the major catchment of the system, thus compromising runoff and water quality. The timing of this event with the need to make short term drought contingency plans would have added impetus to the decision to augment supply. Further, the measures taken to augment supply were relatively modest in terms of cost and could be implemented fairly quickly. They are also compatible with longer term plans to develop more reliable supply. Thus, a convergence of factors likely contributed to the decision to implement all three contingency options. An awareness of the potential for a continuation of dry years was only one of these factors. However, the fact that this was part of the mix underscores the importance of including scenarios that take into account the possibility that the climate of a region has already changed. This may change the odds enough to influence even short term contingency planning.

7. Conclusions

We set out here to explore whether climate scenarios have any role to play at the interannual time scale. In particular, we asked how much does the climate need to have changed before the stationarity assumption might lead to misleading expectations for planning over the next few years? On the basis of this case study the answer seems to be that climate scenarios do have a role to play. Further, relatively small changes in rainfall regime can lead to significant changes in the odds of dry year runs that may impact short term water planning decisions. For example, in the ACT region, the stationarity assumption (no climate change) gives expectations of a continuation of preponderant dry years (2 in 3) of about 0.3. If on the other hand we assume that mean rainfall in the region has already dropped by just 10%, the odds jump up to about 0.5. For a 20% drop in rainfall mean the odds are around 0.8. Given these increases in dry year likelihoods, it seems imprudent to plan solely on the basis of the long term climate record (stationarity) in situations where there are plausible reasons to be concerned about a continuation of drought regime – as in southern Australia.

Whether one is actually sensitive to these changes in likelihoods of drought persistence depends critically on the decision being made. In this case, the decision to augment short term supply entails costs which might be unnecessary if rainfall in the next few years is normal to high, but will be necessary if it stays low. This has led planners to ask what the odds are that the drought will continue. If the odds are high, they will act, and if low, perhaps not. The precise level at which they set the odds of drought needed for action is key to setting the degree of sensitivity to any potential climate change that might have occured. In this case we saw that (for the moderate dry run definition) if the threshold of continued drought is set lower than about 0.3 odds, then there is no sensitivity to the actual scenario as they all yield higher odds. For drought thresholds higher than 0.3 there will be some sensitivity to the choice of scenario and it does matter what is assumed about climate change.

These conclusions are based on a definition of ‘dry’ years for the ACT of 10% (and 25%) reductions in rainfall, and we tested specifically runs of 2 ‘dry’ years in 3. We chose these levels to try to match outcomes of relevance to the planning decision of whether to augment supply in the next few years or not. The 10% reduction in rainfall mirrors that which has occurred recently and is already stressing the system and leading to severe water restrictions. A continuation of this level of reduction is therefore probably severe enough to merit invoking the contingency plans. We also tested a more severe dry year definition of a 25% reduction in rainfall. This changes the odds accordingly, though the same general sensitivity to choice of climate scenario is apparent.

We examined critical dry year sequences here as 2 dry years in 3. We can of course extend the analysis to any specified number of dry years in a specified period. Whatever set of sequences is tested, the important point is that the sequences should be set to match the desired operational criteria (avoidance of prolonged stage 3 restrictions in this case). While the results will clearly change in the details for other definitions of dry runs and dry years, the general sense of the results should apply more generally for other sequences and definitions which are matched to roughly the same operational criteria. That is, the results illustrate the fallacy of claims that climate change can be safely ignored in the short term. Even current decisions pertaining to the next few years of operation may need to take climate change into account if the underlying climate statistics at the location have already undergone a shift. For very modest changes in mean rainfall (10%), there are significant changes in the likelihood of drought persistence in the ACT. Such changes may be abrupt (as in southwest Western Australia) or they may have been gradual. These changes can have a big impact on the statistics of extreme events in current (and future) periods compared to expectations based on the historical record.

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