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Climate Change, Water Flows and the Environment

Bryson Bates

Paper prepared for presentation at the “Water For Irrigated Agriculture And The Environment: Finding a Flow for All” conference conducted by the Crawford Fund for International Agricultural Research, Parliament House, Canberra, Australia, 16 August 2006

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SESSION: FUTURE WATER AVAILABILITY AND IMPROVED AGRICULTURE

Climate Change, Water Flows and the Environment¹

BRYSON BATES

Email: bryson.bates@csiro.au

Introduction

I will discuss how we should view some climate change impact assessments, some recent findings regarding rainfall, and one-off trends.

I will describe global climate models (GCMs) that are used to produce climate change scenarios, and consider the uncertainties involved in these and some of their limitations. I will discuss planning for climate change, not just from the perspective of farmers but also from the perspective of infrastructure managers — for example, a water supply manager who might be considering changing operational rules in an existing water supply system or expanding that system. I will also include snapshots of some river basins around the Asia–Pacific region and some climate change projections. When I was preparing for this presentation — that included reading the *Fourth Assessment Report* of IPCC — I was amazed at the lack of good and reasonable studies in the area.

Finally I describe some of the knowledge gaps and offer my conclusions.

BRYSON BATES is Director of CSIRO's Climate Program. He served as a Lead Author for the Second, Third and Fourth Assessment Reports of the *Intergovernmental Panel on Climate Change*. His research interests include hydro-climatic extremes, downscaling numerical climate model simulations and the effects of climate forcing on rivers. He is an editor for the international journal *Climate Research* and an invited member of the Steering Committee for International Meetings on Statistical Climatology. He held the position of Visiting Research Scientist at the Earth Institute of Columbia University from 2002 to 2003, and was the research manager of the Indian Ocean Climate Initiative from 1998 to 2004.

Some cautionary notes

One thing to be aware of when looking at this subject is that maps of the globe showing reductions in runoff are heavily based on the ability of GCMs to simulate the baseline climate and runoff. As a hydrologist I can tell you that not all of them do a very good job, at least in parts of the world that I am familiar with.

Most of the detailed studies focus on climate and surface water resources in USA and Europe; Australasia comes in a very poor third compared to those two. In the developing world the situation is much worse. Even in developed countries, only a small number of studies have considered the feasibility and effectiveness of adaptation measures in the context of specific water supply systems. There is not a lot of information around. Another important factor relevant to the balance between water availability and demand, particularly in the Asian Pacific region, is that changes in population and economic development will have a significant role, as well as climate change.

Recent findings — rainfall and runoff trends

Trends in climate are not uniform around the globe. A recent paper in *Nature* (Gedney *et al.* 2006) presented data from rings in juniper trees that essentially show that the twentieth century is the wettest period in the last one-thousand years in northern Pakistan. In other parts of Asia (northern and central areas) there are signs of upward trends in rainfall, while in eastern and south-eastern areas

¹ This text was prepared by the editor from the record of the presentation.

there are no emerging trends at all. In China, however, there is certainly evidence of drought areas increasing in the north, but not in the north-west. More locally, there is drying trend across southern and eastern Australia, while conditions in the north-west are becoming wetter.

Gedney *et al.* 2006 were trying to ascertain the contributors to current rainfall and runoff trends. I will refer only to Asia. On the right-hand side of Figure 1 there are columns for all possible contributing factors — climate alone, aerosols alone, the effects of increasing CO₂ on photosynthesis by plants, and changes in land use.

On the left-hand side of the diagram there are two hatched columns: these show the situation over the whole study period, 1901–1994. The next two show the situation post-1960. It seems counter-intuitive, but there has been a reduction in observed rainfall but an increase in observed runoff.

The climate signals do point towards a decrease in rainfall, but you can also see a positive contribution from aerosols. There is also a sizable contribution from plants. Studies reported in hydrological literature, from people doing impact studies on climate change, frequently ignore changes in plant behaviour. Any improvements in water use efficiency in plants because of increased CO₂ are rarely captured in these analyses.

In this part of the world the ‘Asian brown cloud’ has become significant. It is a cloud due to pollution, about 3 km thick; covering the entire Indian sub-continent and certainly moving into eastern and southern Asia.

Associated with aerosols is the subject of ‘global dimming’ that has been getting press for quite some time. In Australia and in China studies show that pan evaporation over the last few decades has been going down. However, if you look at that data very carefully, at least in the Australian context, in the last five or six years it is starting to go back up again. There is a lot of argument about the value of pan evaporation, but it is actually evaporation that matters. There is also a growing school of thought that aerosols in the atmosphere have hidden global warming — that we should have seen more of a signal than we actually have. There is increasing evidence that that signal was large, but in fact it has been waning since the 1980s. Aerosols are in the atmosphere for only a year or two, but we need to start talking about greenhouse gases, like carbon

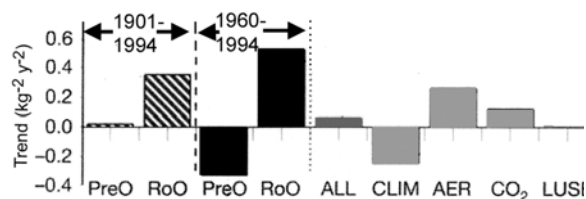


Figure 1. Attribution of runoff trends, Asia. ‘PreO’ = precipitation observed; ‘RoO’ = runoff observed; ‘All’ = modelled runoff incorporating all contributing factors; the four grey columns on the right indicate the contribution of the individual factors (Gedney *et al.* 2006).

dioxide — this will remain in the atmosphere for 50–150 years and its effects are cumulative.

A very small number of studies indicate that aerosols in the atmosphere due to human activity have sustained the North Atlantic circulation, which is very important in keeping the climate of north-eastern USA and western Europe fairly benign. Some recent CSIRO work points to aerosols as being the cause of rainfall increase in north-western Australia.

Global climate models (GCMs)

Global climate models are very large American models that have to be run on very fast computers. They involve three-dimensional computational grids. They try to simulate the fluxes of energy and water through the atmosphere and the oceans, across the land surface and through the cryosphere. Some of the later models include an interactive biosphere as well. These models do a good job at simulating climate on a global scale, but at the regional scale — and the definition of regional is quite critical here, whether you’re talking about south-eastern Asia or the south-western corner of Australia — they are certainly not yet capable of simulating climate.

Uncertainties are significant

In assessing the impacts of climate change on water supply, uncertainty in the projections of precipitation is a dominant factor. However, very good methods have been developed — in Australia but in other countries as well — for using information from large models and scaling it down for use in crop models or water supply models.

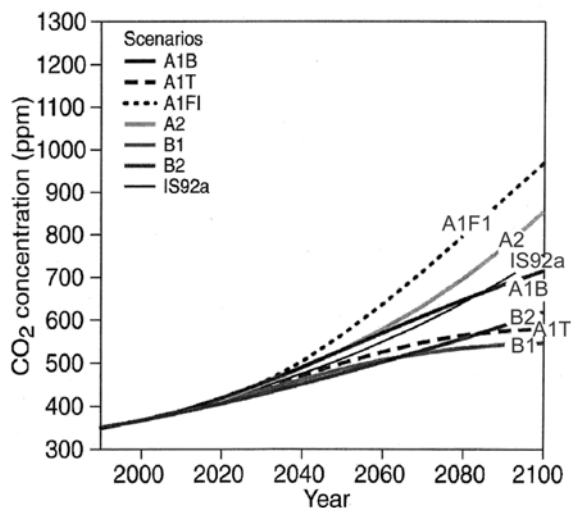


Figure 2. CO₂ concentrations suggested by a range of scenarios (IPCC 2001)

Uncertainties are inevitable when dealing with climate change over a time frame of the twenty-first century. There is uncertainty in the climate model itself; there is uncertainty in our hydrological models; and there are uncertainties in the greenhouse gas emission scenarios that are put out by the IPCC. In Figure 2, on the right, further out towards 2100, the uncertainties in the projection certainly grows. This is because of uncertainty about future social, technological, political development. If you were a farmer, however, you would probably be looking at the portion of that diagram around 2010–2020, and you can see there is very little difference in the scenarios at that time. It is basically the uncertainties in the climate and hydrological models that would concern you.

If you were a planner for major infrastructure you would be out more in the 2050s, and you can see that at that time the differences in the emission scenarios start to come into play. These aren't all of the scenarios — they are only a sub-set. I will refer again to the some of these scenarios later.

Modelling at a regional scale

A number of climate scientists around the world are now assessing the ability of GCMs to simulate climate over smaller spatial regions. Figure 3 compares four models, very highly regarded in Australia, for their ability to simulate climate when applied at a much smaller scale — an area of south-western Western Australia of about 600 × 600 km.

The figure actually shows what are called 'mean sea level pressure anomalies' (MSLPs) — that is,

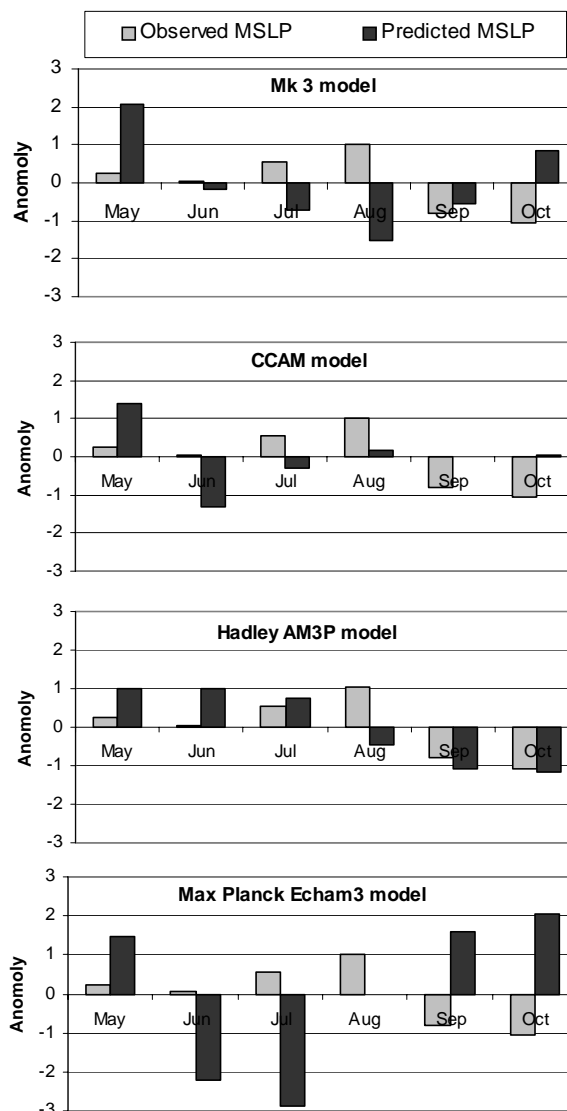


Figure 3. The results of an attempt to predict mean sea level pressure anomalies (MSLPs) for south-western Western Australia using four different models

the variation around the mean. If the model is doing well the black boxes would match up with the grey boxes and would be capturing the seasonal signal. Only one model does that very effectively — the third one down, which happens to be the UK model. The fourth set of results are those of the Max Planck model, which does not look encouraging. And yet from the climate scientists point of view, these models aren't really that far apart. The Hadley Centre model would probably be up in the top one or two, and Echem would be about fourth or fifth among about 20 climate models. And yet there is this large difference in their performance at this regional scale.

The effects on storm runoff was examined in the Stirling catchment in south-western Western Australia, using the same models. Again the Hadley model, after down-scaling, worked very well in reproducing the seasonal cycle in that region. However, the errors in the water balance results of the Echem model are quite large, of the order of a hundred percent. Thus even though these models are regarded as being good in terms of their climatology, they're not very useful in terms of hydrological assessment. The Hadley model is very good, the Echem (Max Planck) one not so good.

Planning for the future

Projections of climate and freshwater resources

Given the above background, how on earth do we plan ahead? Climate systems are highly non-linear — when disturbed they don't come up with a proportionate response. In fact a very famous ocean scientist once said, 'If you nudge the climate system it is capable of a violent response' — hence the term non-linear. It is also very noisy; when you take observations there are errors in the observations, there is a great deal of inherent variability that can only be described by statistical methods. And there is also an element of chaos, in that things like El Nino prefer to be in one state or the other rather than a neutral position. Our knowledge of this system is certainly not complete.

It is not possible to predict whether or not there will be 10 mm of rainfall in Canberra on 29 June 2050. That is absolutely impossible. What we're trying to do is something very similar to a game of Two-Up, which Australians would be familiar with. You throw two coins up in the air, and a lot of bets are made as to whether there will be two heads, two tails, or a mixture of the two. If we are starting a game, it is impossible to predict with any reliability what the result will be on the one-thousandth toss — if we last that long! But we know the probability of two heads is about 25%. So we can get ourselves in the ballpark here. I say about 25%: it is exactly 25% if the person throwing the coins is doing it fairly and if the coins are unbiased. We know that's probably not quite true. So there are some error bounds around that, and exactly the same with climate change scenarios. We don't have perfect knowledge; we don't have perfect models and we don't have perfect data. But

we can however give you an idea of what the ballpark might look like.

Although in this part of Australia we are going through an extended drought, our future climate will still produce both wet and dry periods. This variability, however, will be super-imposed on continued warming unless we start really cutting our greenhouse gas emissions. Rainfall will depend on what happens to the major rainfall generation mechanism in this part of the world. There is evidence that at least one example of these, the mid-latitude westerlies, are already changing across southern Australia.

In some of the high-end projections, the climate change signal is large relative to natural variability. If we go along the business-as-usual path, we will see a very strong ethnogenic signal in climate in future decades.

In the Asia-Pacific region, warming will be greatest in central and northern Asia. The intensity and frequency of heat waves in eastern Asia will increase, and runoff will increase in the high-altitudes and wet tropics and decrease in the mid-latitudes and dry tropics. Heating of the atmosphere changes the nature of the water cycle; the atmosphere has a higher-moisture holding capacity; the risk of both floods and droughts will increase. There will be changes in the seasonality of river flows, particularly in areas where snows are the major contributor to runoff — and these results seem to be the same regardless of which of the GCMs are used. In the coldest regions around the planet, spring runoff will increase, while in lower regions that do have snow winter flows will increase.

In many parts of the world rainfall intensity will increase, and this will lead to increased soil erosion unless it is managed. Increased intensity of floods and droughts will have adverse effects on water quality. Increases in sea level will impair water quality of coastal aquifers and wetlands, especially in low-lying coastal regions. And there will be changes in many parts of the world in the balance between water supply reliability and water demand.

Studies of major river basins

The Yellow River

In the Yellow River basin there is no strong evidence of any precipitation trends over the last few

years, but temperature — particularly minimum temperature — has increased (Fu *et al.* 2004; Yang *et al.* 2004) (and the same is evident in Australia). All of the GCMs that were used in a recent study (Nijssen *et al.* 2001) predict that, about 20–40 years out, there will on occasions be a significant decrease in precipitation falling as snow and reduced stream flows due to increased temperature and evaporative demand.

The Yangtze River

In the Yangtze River basin there is some evidence of increased precipitation, and certainly a temperature increase (Wang *et al.* 2001). I find the type of projection (Guo *et al.* 2002) undertaken in this basin very dissatisfying as is based on a factorial experiment — rainfall will be varied by 10%, evaporation by 10% and so on. If the hydrological cycle is tweaked hard enough it will respond, but there is no guidance as to what is a reasonable change. You may end up with estimates that a one-degree temperature increase will reduce run-off by 36–39%: is this likely?

The Murray–Darling

In the Murray–Darling Basin (MDB), the last five years have formed the driest such period on record. Droughts across Australia have been getting hotter since 1973, although there doesn't seem to have been any less rainfall through these droughts. Snow depths at the few places we have long-term observations are decreasing. The Murray–Darling Basin Commission, CSIRO, the Bureau of Meteorology and other parties have formed the South Australian Climate Commission which will examine climate issues facing this basin, both in the present and in the future.

Projections (Beare and Heaney 2002) suggest that substantial reductions in runoff are likely:

- 2050: –10 to –19% (scenario B1) or –14 to –25% (scenario A1)
- 2100: –16 to –30% (scenario B1) or –24 to –48% (scenario A1)

Projected agricultural costs are US\$0.6B (scenario B1) to US\$0.9B (scenario A1).

The Murrumbidgee

Figure 4 shows the impact of climate change on the Murrumbidgee River catchment. We down-scaled one GCM run and tried to compare the present to 2050. Using the A2 scenario — a fairly

high scenario — we compared the consequences of raising the present-day atmospheric carbon dioxide concentration to about 1.7 times that concentration. That led to an 8% rainfall decrease, which doesn't seem very high, and an 0.9°C increase in maximum temperature. The figure, however, shows a 'flow duration curve' in which the flow data is ordered by magnitude and assigned a probability. The flow duration curve for the future climate — particularly at the high end — falls noticeably below that of the current climate. It indicates a 45% reduction in the highest 50% of the flows. So not only are we talking about a runoff reduction, but most of the reduction is taking place in the high flows.

The Mekong

I could find only one projection of climate change for the Mekong, where the situation (2025 and 2045) seems to be fairly complex (Nijssen *et al.* 2001). The study suggests:

- increases in temperature will be uniformly distributed throughout the year
- precipitation increases during the monsoon season, decreases during the dry season
- runoff and evaporation increase in months with increased precipitation
- much of the increased precipitation in the early part of monsoon will be used to replenish soil moisture storage.

Knowledge deficits

Figure 1 illustrates one of the knowledge gaps to which I have already referred: the response of vegetation to rising CO₂; climate change and nutri-

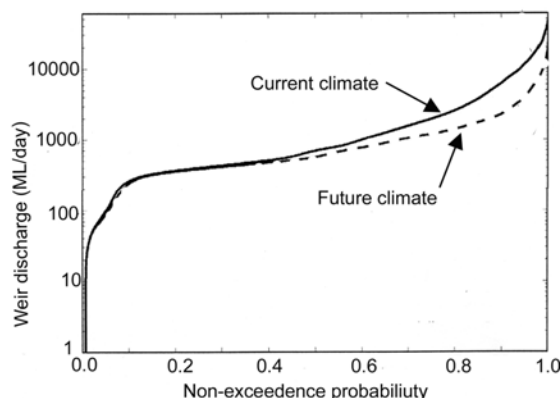


Figure 4. Flow duration, Murrumbidgee River at Maude Weir. 'Future' = Scenario A2, 2050 (CO₂ up by 1.7), 8% less rainfall, 0.9°C increase in maximum temperature, 45% reduction for highest 50% of flows (Viney *et al.* 2003)

ent availability is completely underdone here.

In water supply catchments with mixed-species forests, the likely response of the forests is uncertain. We expect that in the early parts of the 21st century the efficiency of water use by vegetation will increase, but that will be contingent upon what happens to rainfall and temperature. The big prerequisite is available nutrients. If nutrients are limiting, there will not be an increase in water use efficiency and runoff will not increase. Most studies don't seem to take that into account at all, or to use only crude rules of thumb.

It is not so much the changes in the mean climate that are going to undo us, but the changes in variability and extremes. Decision-makers have paid far too little attention to extremes and relevant space and time scales, but there is a move to increase research in those areas.

Ground-water resources were mentioned in the second and third *Assessment Reports* as an area that needs to be researched. Water quality is another one, particularly in relation to soil erosion, low flows, algal blooms and effects on aquatic ecosystems. Most of the latter are already subject to intrusion by evasive species — weeds, foreign fish, etc. — and most of the habitat is either destroyed or compromised. It is certainly fragmented.

We also need to start considering the detection and attribution of change in behaviour and health of water resources — some little work has been done, but not a great deal. We need more powerful methods to characterise hydrological uncertainty, including short-term vagaries.

Looking out 10–20 years, we need a much better idea of hydrological systems to make a reasonable assessment of impacts of climate change. In this country at least, the cost of impacts — with or without adaptations — is not being estimated. We don't really know, with reasonable certainty, what climate change holds for us in terms of the impacts.

At a national level there are two schools of thought: either 'we'll all be ruined', or 'our living standards will be compromised but only slightly', but really the jury is still out. We are really missing 'integrated regional assessments' — many of the impact studies that are done focus simply on one issue: on water or on wheat or on rice. Several different groups may study different things in the same basin without working together. In the Mur-

rumbidgee, what happens to water affects farmers, but it also affects the environment, it affects water supply for towns. If we start afforestation — putting more forests in the headwaters of the Murrumbidgee — there will be less runoff. All these things are interconnected, and if we are worried about the sustainability of our economy and our society we need an integrated approach.

Conclusion

We know from the palaeolithic record that our climate system has changed in the past. There is certainly evidence of it changing now. We expect through the IPCC process to track change in the future.

There is some debate about the extent to which humans are affecting the current climate. Most creditable scientists believe that the human footprint is already evident, and that its effect is increasing. Some people are saying we shouldn't make adaptations until we have what they call full scientific certainty — knowing everything we need to know to make a decision. There are very few of us, however, who at any point in our lives when we have had to make a critical decision have had a full set of information, and this is no different.

If we wait for full certainty, there are several important considerations. One is that it may never come, because we are dealing with a system we don't know completely, and our models will never be able to fully simulate the climate system. Another is, if we do wait, by the time we accept that we have a problem it might be too late to do anything sensible. Regardless of whether you believe in ethnogenic climate change, or human-induced climate change if you want to call it that, you do need to measure the risk. In this part of the world — southern Australia — at least, we've already got dry conditions at the present time. If we really adapt our society to such dry conditions now, life will be a lot easier in the future.

References

- Beare, S.C. and Heaney, A. 2002. Climate change and water resources in the Murray–Darling Basin, Australia: impacts and possible adaptation. *World Congress of Environmental and Resource Economists*. Monterey, California, 24–27 June 2002. Conference paper 02.11, ABARE Canberra, ACT. 33 pp.

- Fu, G., Chen, S., Liu, C. and Shepard, D. 2004. Hydroclimatic trends of the Yellow River Basin for the last 50 years. *Climatic Change* **65**, 149–178.
- Gedney, N., Cox, P.M., Betts, R.A., Boucher, O., Huntingford, C. and Stott, P.A. 2006. Detection of a direct carbon dioxide effect in continental river runoff records. *Nature* **439**, 835–838. <http://137.122.14.197/Bio4900/c10.pdf>
- Guo, S., Wang, J., Xiong, L., Ying, A. and Li, D. 2002. A macro-scale and semi-distributed monthly water balance model to predict climate change impacts... *Journal of Hydrology* **268**, 1–15.
- IPCC (International Panel on Climate Change) 2001. Climate change 2001: impacts, adaptation and vulnerability. Contribution of Working Group II to the *Third Assessment Report of the Intergovernmental Panel on Climate Change*. http://www.grida.no/climate/ipcc_tar/wg2/ (accessed April 2005).
- Nijssen, B., O'Donnell, G.M., Hamlet, A.F. and Lettenmaier, D.P. 2001. Hydrologic sensitivity of global rivers to climate change. *Climatic Change* **50**, 143–175.
- Viney, N., Bates, B., Charles, S., Webster, I., Bormans, M., and Aryal, S. 2003. Impacts of climate variability on riverine algal blooms. In: International Congress on Modelling and Simulation, MODSIM, 14-17 July 2003, Townsville, Australia.
- Wang, G.X., Li, Q., Cheng, G.D. and Shen, Y-P. 2001. Climate change and its impact on the environment in the source regions of the Yangtze and Yellow Rivers in recent 40 years. *Journal of Glaciology and Geocryology* **23**, 346–352.
- Yang, D., Li, C., Ni, G. and Hu, H. 2004. Uncertainty of the water resources assessment in the Yellow River Basin. *Journal of Hydrology* **192**, 211–232. <http://www.wrrc.dpri.kyoto-u.ac.jp/~aphw/APHW2004/proceedings/JSC/56-JSC-A640/56-JSC-A640.pdf>