Combined Pressures and Climate Change Impacts on the Victorian Water System and Possible Responses

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EXTENDED ABSTRACT

The impact of various climate change scenarios has been modelled on the water system of all the river basins across Victoria. Importantly, this analysis has been undertaken in combination with calculations of scenarios of Victorian demography, land-use and electricity generation. We employ a detailed physical account of these sectors using the Victorian Regional Stocks and Flows Framework (VRSFF).

The results from the collection of scenarios in VRSFF show the significant impact that some climate scenarios may have on the water system. For example, if predictions of high climate change eventuate and major dam levels are maintained to support urban and rural water use, then our work shows that many of the 29 major river systems in Victoria will be significantly stressed, some dropping to less than 1/3 of their usual flow by mid to late this century. Factoring in possible yearly variations in climate means these river systems, such as the Thomson River and the Murray River entering the neighbouring state of South Australia, may intermittently stop flowing.

We also explore potential climate change mitigation and adaptation options, which may also have negative impacts on water security but may be preferable to the alternative of not mitigating. In one scenario, reducing CO_2 emissions from electricity generations to 50% of 1990 levels (i.e., not quite reaching a 60–90% target) by 2050 requires per capita consumption rates of goods and energy to be decreased from about 2.0% per year to 0.4%, while also increasing brown coal station efficiency by 25% and replacing most brown coal stations with low or near-zero emission technology, such as biomass, wind, and gas. This scenario produces the lower curve in Figure 1.

This analysis clearly indicates the importance of combining technological options with reduced consumption for achieving proposed reductions in greenhouse emissions to avoid dangerous climate change. It also indicates the substantial extent of the change required, especially in terms of avoiding a "rebound" effect if energy end-use efficiencies are proposed as a means of reducing consumption.

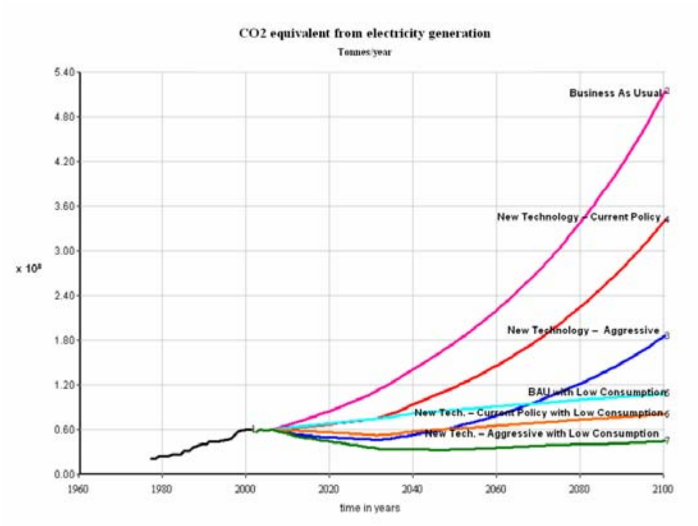

Figure 1. CO_2 emissions from electricity generation for different scenarios. The three upper curves at 2100 all involve continued per capita growth in material and energy consumption of 2% pa. The lower three curves assume 0.4% pc pa.

1. INTRODUCTION

Management of water resources throughout large areas of Australia has become a major challenge in recent years. Serious drought has occurred for several years throughout eastern Australia from Queensland in the north, through NSW, to Victoria in the south. These conditions have affected agricultural production while also impacting significantly—perhaps for the first time—the water security of Australia's major urban areas where the vast majority of Australians live.

The discussion of these water constraints has involved a wide range of views about causes and possible responses. These include comparison of rural versus urban water use, the dependence of electricity generation on water (and vice versa), and the contribution of possible climate change to reduced water availability.

In this work of the Water for Healthy Country flagship in CSIRO, with support from the Victorian Department of Sustainability and Environment, we have studied the interactions between demography, land-use, electricity generation, water demand and supply systems, and include the effects of climate change. This work incorporates and complements Victorian government policies, such as "Our Water Our Future" (DSE, 2004). It uses "Stocks and Flows Framework" (SFF) physical accounting simulations to create and analyse scenarios of the interactions across Melbourne and Victoria.

2. STOCKS AND FLOWS SIMULATION DESCRIPTION

A SFF consists of a simulation framework, a calibration framework, and a collection of data sets. It is designed to trace the physical aspects (tonnes, litres, joules, hectares, etc.) of a system, over an observed history, and for different simulated future scenarios over the long-term.

The Victorian Regional Stocks and Flows Framework (VRSFF) is an accounting framework that represents physical interactions between sectors of the economy and environment in Victoria. There are several major components to the VRSFF and these are inter-related: demography; land-use; electricity requirement and production; and water supply and demand.

Demography is a key driver of economy and its requirements. Detail on other non-urban land-uses is available from the complementary national framework, Australian Stocks and Flows Framework (ASFF) (Poldy 2000). The Victorian consumption of materials and energy was derived from the ASFF using Victorian data components where available or scaled data. These flows drive the physical Input-Output calculation of the basic industry sector in the VRSFF, with particular attention paid to electricity generation capacity (West 2007a). A number of data connections are subsequently made from the above components to the water account of the VRSFF (Turner 2007a), since demography, land-use (West 2005a) and electricity production influence water demand and supply.

Sectoral calculators within ASFF model the dynamics and transactions of physical stocks. Many drivers may influence outputs in compound and complicated ways but not involving 'complex' feedbacks. This makes the outputs of the framework explicit and tractable and also allows the framework to be open to input from other models and expert knowledge.

2.1. Historical Reconstruction

There are several important benefits associated with the historical calibration of the ASFF and VRSFF. The most obvious benefit of historical calibration is providing starting values for parameters used in the scenarios, but also the current direction and rate of change of the physical economy. A very important feature involves creating the age structure of stocks, such as the stock of agricultural land, buildings or electricity generation plant.

Another function of the calibration is to verify the structure of the framework i.e., confirm that its relationships and parameterisation is working as expected. The framework is operated over the historical period in precisely the same manner as for scenarios. As a result of the calibration process, the observed historical data is reproduced identically over the history period. The calibration of the electricity modules and the water account have been described in more elsewhere (Turner 2007b, Baynes 2007), and for the demography and land-use modules in (West 2005b).

This section outlines the calibration of a key variable in the VRSFF associated with the climate system, namely the evapo-transpiration of rainfall. Other climate related variables (also in the water account modules) are calibrated using the processes described elsewhere (Baynes, 2007, Turner, 2007b)—they are evaporation of water from open water storage, and water use intensities, particularly residential outdoor and irrigated agriculture.

Historical rainfall and stream flow data for each major catchment are taken from the *Rainman Streamflow 4.3+* database (Clewett 2003). Having incorporated yearly rainfall data we then calibrate the evapo-transpiration (ET) and runoff rates using observed data on Mean Annual Runoff (MAR) for each water region (DWR, 1989). The way the volume of precipitation is ultimately distributed in each catchment is different because of geography, geology and land use.

The general process is to distribute total rainfall on the surface of a water region into ET, runoff to surface waters, and groundwater in such a way that the calculated runoff to surface waters reproduces the MAR. For all Victoria (DWR, 1989):

Rainfall (100%) ≈ ET (84%) + MAR (15%) + Groundwater Infiltration (1%)

We have elaborated on this, disaggregating each variable in the above equation by location, by land uses at that location, including off hard surfaces of developed land as storm water. The latter is directly linked to a development history or scenario represented by the 'land use state' variable which is calculated in a separate part of VRSFF.

The water balance calculations assume 1% distribution to groundwater (which is reasonable based on available information and the purposes of the VRSFF for strategic long-term analysis)—knowing rainfall and MAR data allows ET to be imputed for each catchment and over historical time. These calculations effectively embed the information about land use and geography in the values of ET for each catchment area. The order of magnitude of ET may be compared with the values for combined 'in stream losses to groundwater infiltration and ET' reported in the *State Water Report 2004-2005* (DSE, 2006). Calculated ET and runoff rates for land-uses can be significantly different. The data are important factors for calculating subsequent river flows and the effects of scenarios that may involve land-use change and climate change. This calculation is combined with a host of other calibration calculations, such as water extractions, discharge rates and storage levels (Turner, 2007b, Baynes, 2007).

Confidence in the calibration process is provided by good comparison between observed data not used in the calibration and simulated results. A significant example is the simulated historical flow of the Murray River, which follows from many natural and human processes along the river network, shows a decrease from more than 10,000 GL/yr to about 5,000 GL/yr at the end of the historical simulation.

3. SCENARIOS EXPLORED

Scenario "hierarchy"

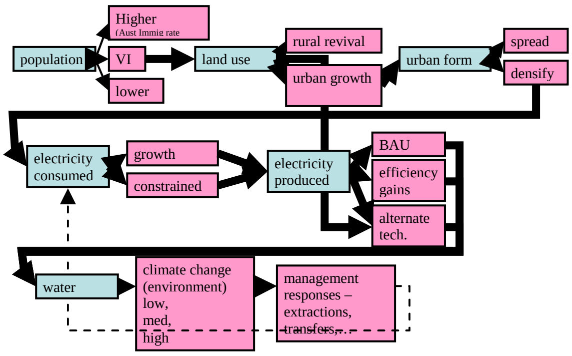

Figure 2. Schematic diagram of the series of factors (blue boxes) and possible alternative settings of those factors (pink boxes) that form the scenarios studied.

The scenario approach is to incorporate a series of factors that effectively explore the implications of compounding possibilities encompassing policy, behaviour, technological and environmental options (see Figure 2). Some alternative scenarios are also presented to give an understanding or insight into the sensitivity of the simulations and role of uncertainties.

The scenario outcomes are not predictions; they are intended to help identify the key driving forces behind the physical outcomes and to stimulate further exploration and review of underlying assumptions. Some key scenario settings relevant to this paper include:

- Victoria in Future (VIF) demographic projections—by 2050 Victoria's population grows to approximately 6.7 million;
- two alternative growth rates—2.0% per capita per annum and 0.4% pc pa—of consumption in material and energy;
- electricity production by a variety of power plant technologies, including aspirations for efficient brown coal power, gas combined cycle and renewables;
- low, medium and high climate change scenarios described below.

3.1. Climate scenarios

The climate change scenarios, for each SWMA, are the upper, median and lower rainfall and runoff projections taken from a CSIRO report for the DSE (Jones and Durack, 2005). Low, medium and high climate change scenarios correspond respectively to average global temperature increases by 2050 of 0.8, 1.5 and 2.2 °C above 1990 temperatures respectivley. In addition to decreasing rainfall under climate change there are significant increases in evapouration rates. The combination of rainfall and evapouration changes leads to substantially higher decline in surface water runoff in the calculations of climate change impact (Jones and Durack, 2005).

Each projection was based on an average of the preceding 40 year of historical records. We have used individual projections for each SWMA. These general trends can be made more sophisticated by adding an estimated inter-annual variation in rainfall. Inter-annual variation in historical rainfall was used to generate some measure of climate variability in future years. These results will be indicative only since currently there is insufficient scientific understanding of these changes.

4. RESULTS

This section examines the implications of several climate change scenarios on river flow and major surface storage. It also looks briefly at a possible adaptation and mitigation responses to climate change to provide comparisons with impacts on the water system if no action is taken.

4.1. Impacts of Climate Change

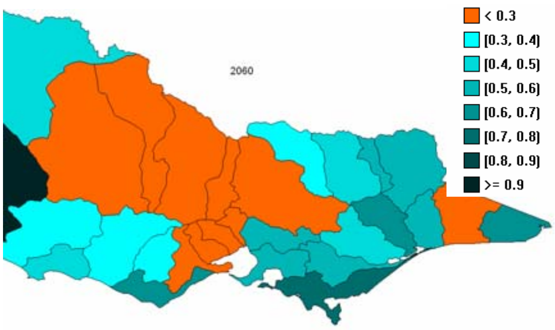

Figure 3. River flows relative to historical averages 2060 in Victorian water regions. The scenario assumes high climate change.

Substantial impacts occur on surface water flows to rivers and wetlands, e.g., .in Figure 3. This map depicts at 2060 the impact on river flows for a high climate change scenario, assuming that major water storage are maintained at steady levels. Other strategies can be explored. The map displays river flow relative to historical average flows in each water region. A relative river flow level of 30% or less (shaded orange) of the historical average was used to indicate when the river flow out of the water region had potentially reached a stressed level.

By 2060 ten out of the twenty-nine river basins are showing signs of substantially reduced river flows. By the end of the century almost all river basins of the entire state are below 30% flow. The outcome for the medium climate change is less dramatic but still substantial. For a medium climate change scenario (that is otherwise the same as for the scenario in Figure 3), a similar pattern of impacts occurs some 3–4 decades later than for high climate change.

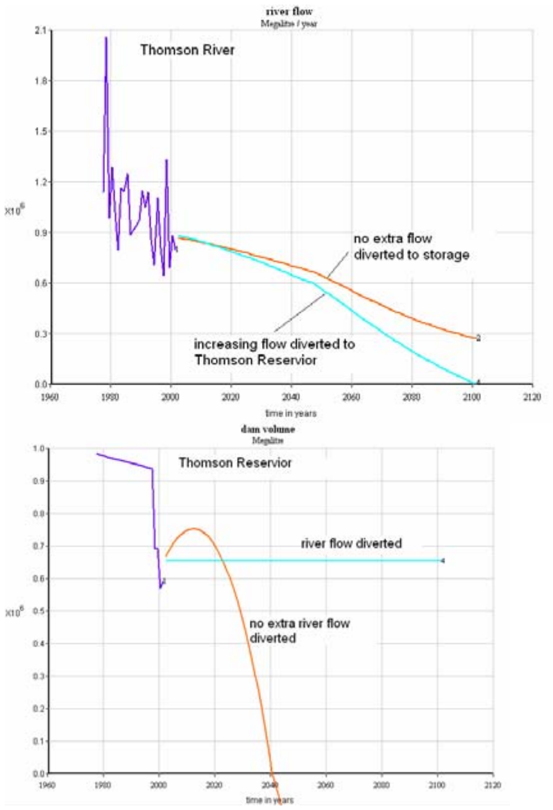

Figure 4. Thomson River flow (top) and Thomson Reservoir levels (bottom) under a high climate change scenario (2.2 °C change at 2050). Two alternative management scenarios are shown, one where the proportion of river flow diverted to the Reservoir is kept constant. The other shows the Thomson Reservoir held constant by drawing on increasing diversions from the Thomson River.

Given the importance of the Thomson River for supporting a vast proportion of the Victorian population, the effect of alternative water management in the Thomson Region is shown in more detail for high climate change scenarios in Figure 4. The graphs show both river flow and storage levels under alternative water management options.

One management option is to continue diverting the same proportion (as at the end of the history period) of the Thomson River flow to the Reservoir. In this case, the Reservoir level initially increases, but subsequently falls to zero by about 2040 and 2055 in the high and medium climate change scenarios. This is primarily due to decreasing river flow, though increased evapouration from the Reservoir and increasing demands for water also play a role. While river flow decreases, it is not as substantial as the decrease under the alternative management option explored here.

The other simple management option is to seek to maintain storage levels by changing diversions from river flow. In this case, for both high and medium climate change it is possible to maintain the Thomson Reservoir at relatively secure levels (about 50% of capacity) throughout the simulation period i.e., to 2100 by drawing increasing proportions from the Thomson River. In the medium climate change scenario river flow is reduced somewhat (about 25%) by 2100 relative to the previous management option. However, in the high climate change scenario the flow of the Thomson River is severely compromised by the latter part of this century. It is also evident that beyond 2100 the river flow would not be sufficient to continue maintaining the Thomson Reservoir.

The situation for Lake Eildon (a key irrigation supply) and the Murray River exiting this water region also appears serious. Under medium climate change Eildon can be maintained at relatively high levels, however the average flow of the Murray (leaving IV5) is reduced to about 30% of natural flow by 2100. High climate change results in insufficient river flow to the extent that Eildon runs dry by about 2080. The implications of this outcome have not been explored further in this study.

Exploration of water futures and management options can be made more sophisticated by adding an estimated inter-annual variation in rainfall. Such analysis shows twin challenges for water system management. First, near or mid-term trends (up to several decades) may be masked by the large annual variations typical of Australia's climate. Second, these large variations can effectively advance critical events (such as rivers not flowing) by several decades. In combination, these features mean that the real challenges may not be perceived in time if "adaptive" management based on real- or near-time data is used without long-term scenario analysis.

4.2. Possible Responses to Climate Change

The analysis above shows how the impacts of medium and high climate change scenarios dominate the sustainability of Victoria's water future—to the extent that scarcity of water may substantially threaten economic activity and environmental flows across much of Victoria sometime beyond mid-century. Such high climate scenarios were previously thought to be at the extreme range of probability but are progressively being considered as increasingly possible given recent updates in global CO_2 emission trends—which are tracking on the worst case scenarios—and climate impacts which have accelerated faster than expected.

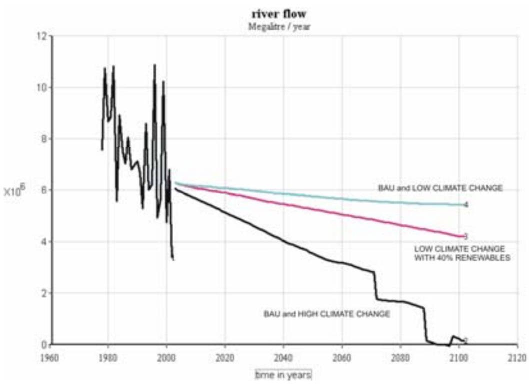

Figure 5. River flow in the Murray River at the South Australian border. The scenario of 40% of new energy generation coming from renewable biomass causes some decrease in the river flow (from the upper blue curve to the pink curve) because of changes in run-off; this is compared with possible future river flow scenarios such as the high climate change scenario shown in the lower (black) line.

Given the potential severity and the growing likelihood of the impacts described, it is worthwhile exploring options that might avert the key pressures. Obviously, effective GHG mitigation must be global in the sense that a sufficient number of national contributions are made. The first option involves a form of carbon sequestration, while the second revisits the potential for reducing CO_2 emissions within Victoria. Both are compared with a BAU growth in electricity consumption and a low climate change scenario (see the upper curve of Figure 5).

The basis for the first option of mitigating CO_2 involves substantial areas of cropland (~40%) converted to forests for biomass production (DSE report). The biomass could be burnt for electricity production with steam turbines, resulting in net carbon emissions that are near neutral. However, this approach is likely to also result in progressive reductions of river flows, by about 18% in 2060 (see the middle curve of Figure 5), due to higher ET rates of forests compared with crop land. This result assumes that it is part of a global mitigation strategy. While such reductions in river flow are significant, the scenarios developed here show that river flows may be diminished more significantly if mitigation of climate change is not pursued globally with strategies such as the biomass scenario.

In comparison, the reduction in Murray River flow by 2060 is about 50% assuming a high climate change scenario results from insufficient local and international attempts to lower GHG emissions (see the lower curve of Figure 5). Similarly, under a medium climate change scenario, the river flow is reduced by a greater volume than the combination of large biomass production and low climate change. Therefore, in a risk management approach based on the information analysed in this study it appears better to ensure climate change is mitigated even if the mitigation results in some environmental impacts. Of course, if a global mitigation strategy is not implemented, then the Victorian biomass strategy described above would result in the worst case reductions of river flow, greater than 50% by 2060.

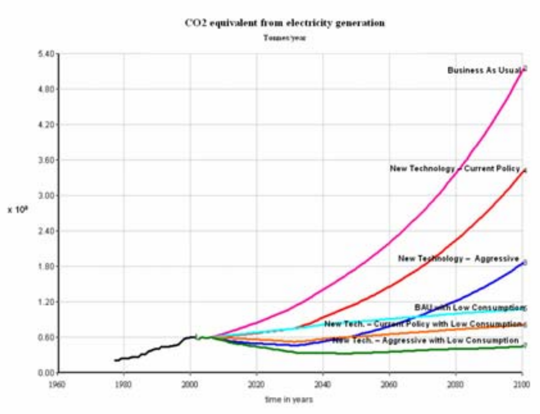

Figure 6. CO_2 emissions from electricity generation for different scenarios. The three upper curves at 2100 all involve continued per capita growth in material and energy consumption of 2% pa. The lower three curves assume 0.4% pc pa.

Another alternative mitigation option is to reduce greenhouse gas emissions. Electricity generation scenarios (presented elsewhere (West 2007b, Turner, 2007b)) provide insight into the feasibility of cutting CO_2 emissions from stationary energy sources. Over the long term (to 2100) the most effective strategies for reducing CO_2 emissions involve cutting growth in electricity consumption in combination with aggressive technological change (Figure **6**).

If growth in end-use consumption is not curbed then CO_2 emissions continue to increase in the long-term (three upper curves at 2100 in Figure **6**). This true even when aggressive technology is introduced, such as 25% increase in brown coal power efficiency and a switch steadily to 90% electricity supplied from a mix of gas combined cycle and renewables (labelled 'New Technology – Aggressive in Figure **6**). While this scenario produces an initial marginal decrease in CO_2 emissions for a couple of decades, growth in demand for electricity inevitably overtakes any of the technological savings and emissions rise steadily.

In comparison, if growth in end-use consumption of materials and energy is held at 0.4% per capita per annum then CO_2 emissions are substantially reduced (three lower curves at 2100 in Figure **6**). Even when no change is made to the way electricity is produced in Victoria i.e., predominantly by brown coal, the eventual emission rate at 2100 is limited to less than double current rates. When low growth in consumption is combined with the aggressive technology scenario, CO_2 emissions reduce most rapidly and remain at relatively low levels—by 2050 the emissions are about 50% of the 1990 levels (lowest curve in Figure 6).

5. DISCUSSION

The analysis focused on technology that is currently commercially available and demonstrated. Potential carbon geo-sequestration may provide a means to substantially reduce CO_2 emissions, assuming that economic and environmental viability are established such as the stability and size of the reservoirs.

A significant caveat relates to the assumption of the possibility of maintaining low growth rates in end-use consumption, as in the 0.4% pc pa scenarios. It is flawed to propose that total end-use of electricity could be reduced simply by increasing efficiencies in those end-uses, such as lighting, machinery, and by insulating building envelopes, for example. Such improvements typically lead to lower total prices paid by consumers for the (electrical) services delivered, and consequently the savings are available for expenditure elsewhere in the economy. This typically stimulates growth in the overall economy and therefore generally requires increased energy production—an example of the “rebound effect”. Any such rebound resulting in additional energy use and associated CO_2 emissions have not been incorporated in the scenario calculations.

Rebound would not occur if the financial savings are used in ways which do not contribute to economic activities involving energy, or if the lower end-use consumption was achieved simply by less per capita demand for goods and services, rather than efficiencies. Clearly, such approaches would involve substantial change to the fundamentals of current economic structure.

6. CONCLUSIONS

We have integrated climate change impacts on the water system of Victoria with interactions of demographics, land-use, and electricity generation using linked Stocks and Flows Frameworks. A set of scenarios were used to examine the effects of simultaneous driving factors. The scenarios included low, medium and high climate change (associated with global mean temperature increases by 2050 of 0.8, 1.5 and 2.2 °C above 1990 temperatures respectively).

Climate change impacts (for high and medium scenarios) appear to be the most significant factor among the set of drivers for future water security in Victoria. Of course, this might not have been the case if the past trajectory of water use had not already placed the water system as close to critical levels as it is now. Results indicate severe water shortages across many river basins of Victoria by mid-century for high climate change, and end-century for the medium scenario. Options for managing such problems appear limited.

Another response explored here involved alternatives for mitigating CO_2 from electricity generation (as part of a potential global programme). This showed the importance of reducing end-use consumption of electricity, without a rebound effect, in combination with aggressive technological change.

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