Forecasting lower Murray River salinity under climatic uncertainty and reduced dilution flow

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Introduction

The lower portion of the River Murray, South Australia (SA) has received increased attention during 2007 as the region has received its lowest inflow in 50 years. Whilst the annual average inflow is approximately 4800 GL, last year SA received just 1470 GL. Compounding the issue of low inflows is the ongoing problem of river salinity in the region. As a result of native vegetation clearing and irrigation drainage return, saline groundwater inflows have been increasing in the last decades. Consequences include diminished irrigation, reduced yield, deteriorated drinking water quality and damaged floodplain health through salinisation.

As is true elsewhere (the Colorado River Basin, part of Pakistan), increasing river and floodplain salinity along with increasing water scarcity under drought conditions represent a major natural resource management challenge. This article reports on research underpinning the Lower Murray Landscape Futures (LMLF) Project. LMLF is a futures scenario modelling exercise to identify biophysical and socio economic outcomes of management options for the region whilst accounting for the uncertainty of climate changes and its impact on water allocation, flow variability, and hydrological parameters such as water table levels and evaporation rates on the floodplain. The project involved an integration of biophysical and economic models to determine the salinity, biodiversity and economic impacts of land and water management actions. It included nine biophysical and socio-economic processes in order to model basin water availability, irrigation economics, catchment runoff and water management, groundwater salinity processes, floodplain health, river salinity, salinity damage and salt interception, and regional socio-economic impacts (Connor et al., 2007). Because many biophysical processes in the region have large time lags (decades to century) the models developed aimed to provide long-term evaluations of future management actions.

The focus of this article is the integration of groundwater, floodplain salinity and surface water salinity models into one integrated tool. The interception of groundwater by floodplains is one of the key processes considered in the modelling tool. Groundwater that passes through the floodplain can be lost by evapotranspiration if the water table is within the vegetation rooting zone. As salt is not removed by the evapotranspiration process, it accumulates in the soil profile but can be subsequently flushed by flooding. This leads to considerable time delays between when salt enters the floodplain from the highland to when it finally reaches the river, a process often referred to as floodplain attenuation of salt loads. The degree of attenuation has been well studied and documented for the South Australian portion of the Lower Murray. The extant analyses show that attenuation can range from 0-67 % in South Australia, but averages around 30 % (Overton and Doody, 2007). The degree of attenuation at any given location requires location specific data on groundwater inflow rate, floodplain width, floodplain aquifer depth and permeability, evapotranspiration rate, and wetland and river heights (Holland, et al. 2005).

A significant challenge for the LMLF project was the lack of detailed floodplain data for Victorian portion of the river. However, to estimate the salinity impacts of changing land use, estimates of floodplain attenuation are needed. Therefore, the objective of this paper is to discuss how floodplain attenuation in Victoria was modelled with sparse data. In addition, the paper reports on key findings that arose from integrated scenario analysis accounting for groundwater flow and floodplain salt and water balance.

Methodology

The concentration of salinity in the River Murray is driven by three main effects (i) increasing/decreasing saline groundwater inflow at the floodplain edge, (ii) floodplain salt attenuation, and (iii) changes in flow that influence the level of salt load dilution under climate change scenarios. Also, there is a need to incorporate uncertainty into predictions of changes in salt load and river salinity because: (i) river system planning involves long planning horizons (e.g. several decades), (ii) accurate long-term projections are generally difficult to make, and (iii) there are inaccuracies in data measurements and model parameters. Therefore, an appropriate estimation of floodplain attenuation and groundwater flux into the river is required that enables efficient forecasting of salt load and river salinity changes under uncertain conditions. Our analysis was based on three key components:

1. The estimation of river salinity resulting from changes in groundwater flux/salt due to future changes in land use and irrigation management practices in current and future years.
2. The estimation of the floodplain attenuation factors (FAF) accounting for the differences between estimated groundwater salt loading rates and observed river salinity. In South Australia this involved application of pre-calibrated models. For Victoria this involved using more simple approximations than the calibrated groundwater models because of the sparsity of floodplain data. Both essentially involve inferring FAF based on the differences between the estimated salt loadings and the observed salinity. One of the models used to infer the Victorian salt load is the Landscape to River model (L2R model developed in LMLF project see Connor et al., 2007); the other is EM1, the Eastern Mallee model version 1 (Aquaterra, 2006).
3. The conversion from salt loads to river salinity concentration, after accounting for floodplain attenuation. This involved the regional river authorities' river operation model, MSMBIGMOD (Murray Darling Basin Commission, 2007) for the year 2000. This involved estimation of river salinity for flows consistent with the benchmark case (1975 to 2000) and for flows consistent with reduced water allocation under climate change. MSM-BIGMOD is a combination of two models. MSM is a monthly simulation model used for modelling flows based on operating rules for storages, irrigation demands, water resource assessment and water accounting. BIGMOD is a daily flow and salinity routing model used prior to the adoption of MSM-BIGMOD for daily flood operation.

Results

Salinity impacts of reduced dilution flow with climate change

Three climate change scenarios were developed in the LMLF project (see Connor et al., 2007). Whilst the results of these climatic scenarios are projections only, they represent potential examples of mild, moderate and severe climatic conditions within the Murray-Darling Basin. There were clear differences in predicted river salinity between the different climate scenarios (Figure. 1). Two trends were evident, with salinity increases in a downstream direction and with lower inflows. However, under mild and moderate climatic conditions, the average yearly river salinity is under 800 EC at Morgan (the management target for drinking water) over 25 years. However, weekly salinity variations exceeded the 800 EC threshold in the lower part of the system at times by average 16% at Morgan (baseline case) with the concentration effect while for the moderated climate scenario this limit is exceed by 36% of the time. These predictions were for the current level of salt interception by saline groundwater pumping and diversion along the river, no changes in irrigation efficiency, and baseline conditions for the MSM-BIGMOD model. On the other hand, under the severe climate scenario, the large reduction in runoff (63% of current) would result in a chronic exceedence of the 800 EC salinity threshold at the South Australian border and particularly at Morgan.

Estimated floodplain attenuation in the Victoria Lower Murray

The average calculated floodplain attenuation factor from the two feasible methods for the Victorian section of the River Murray (reach by reach) suggests that floodplains store anywhere between less than 1% to 65% of the calculated groundwater fluxes (Table 1). Knight et al. (2002) has indicated that the degree of attenuation can also vary significantly within a lock reach. Comparing test of calculated future river salinity resulted from L2R model after attenuated by estimated FAF with salinity Audit (Murray-Darling Basin Commission 1999) indicate that our estimated FAF reasonably represent the real system (see Table 2). Relative to the salinity audit, our results are consistent within SA but slightly overestimate river salinity in Victoria. This over estimation is most likely the result of the less accurate salt load estimates available for the Victorian section of the river and the uncertainty involved.

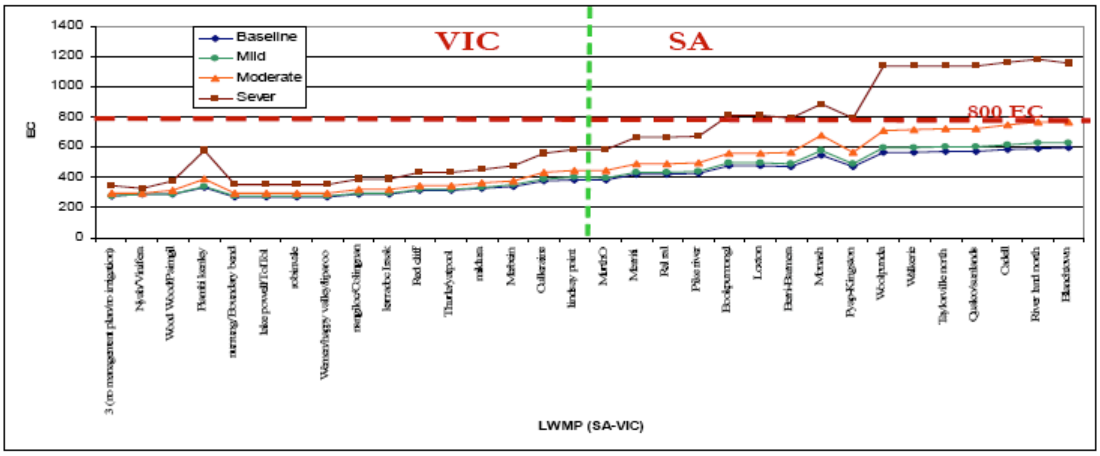

Figure 1 Salinity trend under different climatic conditions, assuming current groundwater baseflows

Table 1 Floodplain attenuation factor per river reach River reach FAF-calibrated River reach FAF-calibrated

River reach	FAF-calibrated	River reach	FAF-calibrated
Nyah-Narrong	64 %	Lock 11-Lock 9	35 %
Narrong -lock 15	53 %	Lock 9-Lock 8	0 %
Lock15-Colignan	60 %	Lock 8-Lock 7	0 %
Colignan Nangiloc	50 %	lock 7-Lock 6	32 %

Table 2 River salinity estimates for 2000, 2020 and 2050 and comparison with the salinity audit

Stations	L2R			Salinity audit		
	2000	2020	2050	2000	2020	2050
Swan hill	295	298	323	270	270	310
Mildura	376	386	452	360	400	450
Renmark	420	467	520	400	480	550
Morgan	580	623	790	570	670	790

Salinity impacts of combined groundwater salt load growth and reduced dilution flow

Salt load reductions were estimated for two adaptive management strategies: (i) reduced irrigation area in response to less available water, and (ii) more efficient water use in response to higher water prices (Figure 2). There are clear variations in salt load for different irrigation efficiencies. Salt loads were reduced under increased irrigation efficiency and, in turn, river salinity was reduced when water prices were higher.

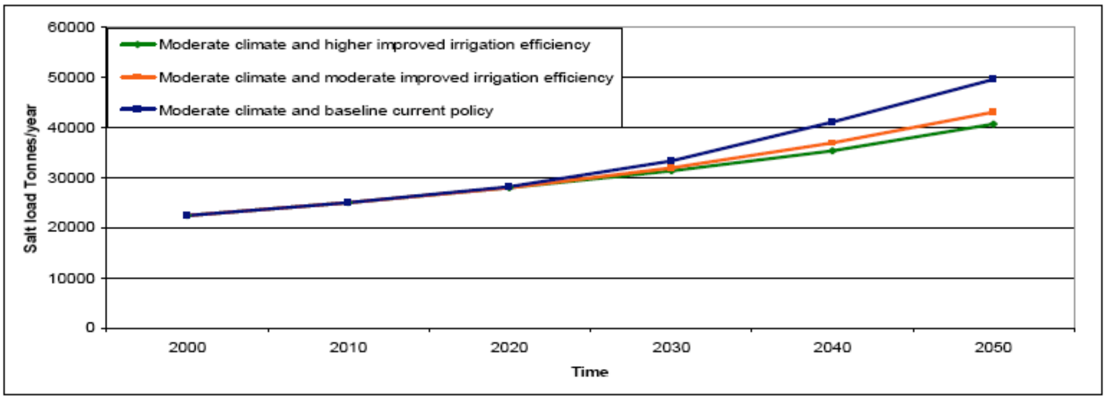

Figure 2 Salt load under different irrigation efficiency

However, the combined effect of groundwater salt load (which can be controlled by policy options that reduce groundwater flows to the floodplain and river) and reduced dilution flow (which can only be controlled by changes in flow management that effect dilution) leads to increase river salinity at Morgan over 50 years (see Figure 3). In summary, the combined effect is greater than the individual effect. These results should be treated with considerable caution, particularly the floodplain attenuation factor and its impact on river salinity. Also, there are many uncertainties which can affect this analysis' outputs. We do not assert that our results are perfect; however, they represent the probable outcomes at the time of analysis based on the data and information available. There is a potential for refinement in the future when more information about floodplain attenuation processes is known.

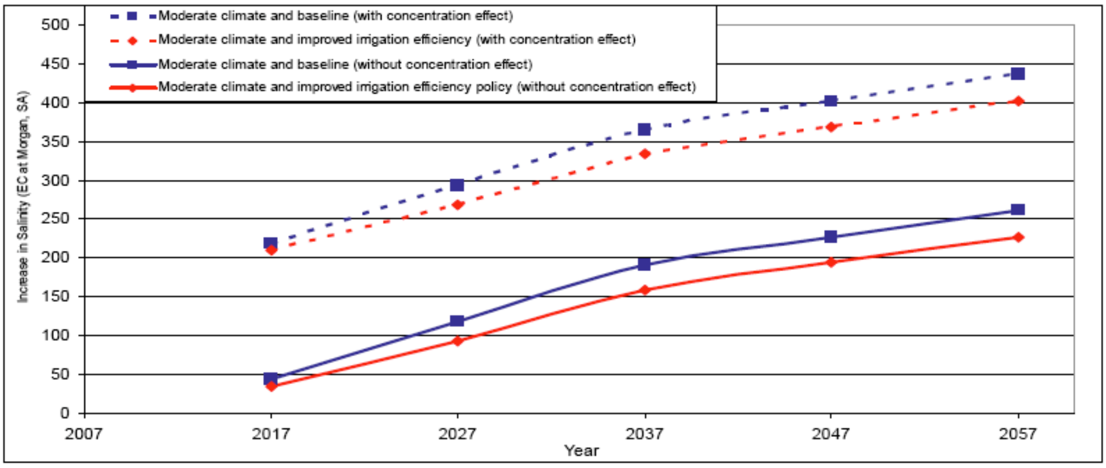

Figure 3 Salinity trend under combined effect (groundwater salt load growth and reduced dilution)

Conclusions

The system analysis carried out in this paper showed that: (i) a large fraction of salt in the Victorian section of the River Murray is stored in floodplains (this has significant implications for floodplain heath), (ii) reduced dilution flows due to climate change could significantly increase river salinity over the next 25 years, (iii) salt load growth is changed accordingly to increase/decrease of groundwater flux/salt (resulted from changes in policy, irrigation management, floodplain attenuation factor and legacy of history effect), and (iv) the combined effects of salt load growth and reduced dilution flow on river salinity are greater than their individual contributions. These results have important implications for the assessment of floodplain health in the region and on the policy options that could be considered to mitigate the anticipated rise in river salinity over the next 25 to 50 years.

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