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Finding a sustainable balance in the water food nexus – Socio-economic transformation in an agricultural catchment

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Abstract: Increasingly the competition for water between food production and the environment threatens the viability of agricultural communities. This paper focused on this water-food-environment nexus in the Murrumbidgee River Basin, Australia, and how it contributed to the evolution of the regional economy and changing demographic patterns. Paradoxically, against expectations, changes in water management favouring the environment coincided with falling unemployment and increase in average regional income, despite a decline in agriculture. To understand this, and to explore how the competition for water played out in the Murrumbidgee Basin, we develop and use a socio-hydrologic model that explicitly considers bi-directional feedbacks between human and water systems. The modelling shows that in response to widespread ecosystem degradation, community sentiment forced new water management policies that favoured ecosystems which inevitably led to reductions in agriculture production. In response, the basin economy reorganized through sectoral transformation to the manufacturing and service sectors, improved agricultural practices, and out-migration of basin residents. The sectoral transformation was facilitated by capital available for investment in manufacturing and service sectors with knock-on impacts on population dynamics and unemployment. Collectively these contributed to a sustainable transformation of the basin economy. The study shows how transformation of the basin economy and demographics mitigated potentially adverse economic outcomes and enabled society to cope with water management decisions that favoured the environment. The dynamics outlined here highlight the adaptive capacity of people and movement of capital in a free economy, supported by appropriate strategies and funding, to cope with water stress.

Key words: socio-hydrology, irrigation, ecosystems, water management, employment, sectoral transformation

1. INTRODUCTION

Water plays a key role in economic development, particularly in agricultural economies. Rising human population has heavily impacted the hydrological cycle and in many places, water resources are being adversely affected in terms of both quantity and quality and fresh water resources have depleted. In addition, climate change further exacerbates both water supply and demand. Increasingly this issue is becoming further compounded as awareness of water scarcity and food security rise with increasing population (Gleick and Palaniappan, 2010) and with climate change (Jiménez Cisneros et al., 2014). Increasing water use in agriculture inevitably reduces the share available for ecosystems, leading to its degradation, and in places where ecosystem services are valued by humans, community sentiment turns adverse. Water management decisions made that favour ecosystem sustainability can, however, impact a region's economy, employment, and population, especially in agriculture centred economies. The potential for conflict is self-evident as different users of water attempt to maximize their benefits at the expense of others. Kandasamy et al. (2014) depicted this tension in the form of a pendulum that swung from a situation that favoured agricultural water consumption to one that favoured environmental water use.

In this paper, we hypothesize that even though water restrictions did in fact impact agriculture, various sectors of the wider basin economy also adapted, leading to sustainable economic transformation of the region even as tangible environment protection was implemented. This study attempts to discover the complexities which resulted in these observations and how the catchment adapted to cope with water stress. We carry out data analysis and detailed socio-hydrologic modelling to mimic and explain how the complex interactions and feedbacks between various subsystems of the human-water system within the Murrumbidgee basin that may have given rise to the observed phenomena, considered here as emergent dynamics, and to facilitate scenario testing to further our understanding. We examine the co-evolutionary mechanisms through which humans responded to the reallocation of water and the changing norms and values that inspired this, how theses impacts translated to the remainder of the basin economy and society, how they reorganised to cope and to explain the changes in terms of detailed process insights of the system.

2. MODEL AND PARAMETERIZATION

In this study the human-water dynamics is explored using a conceptual model that explicitly utilizes a socio-hydrology framework. This model (Figure 1) consists of the following sub-models: water availability (labelled a in Figure 1); agriculture (b); environment health (c); manufacturing and services (d); technology (e); and human population (g). Each of these sub-systems was coupled to mimic their co-evolution over time and in order to facilitate this coupling, two link-models are employed. The operation of the model and model equations was explained in Roobavannan (2017a,b).

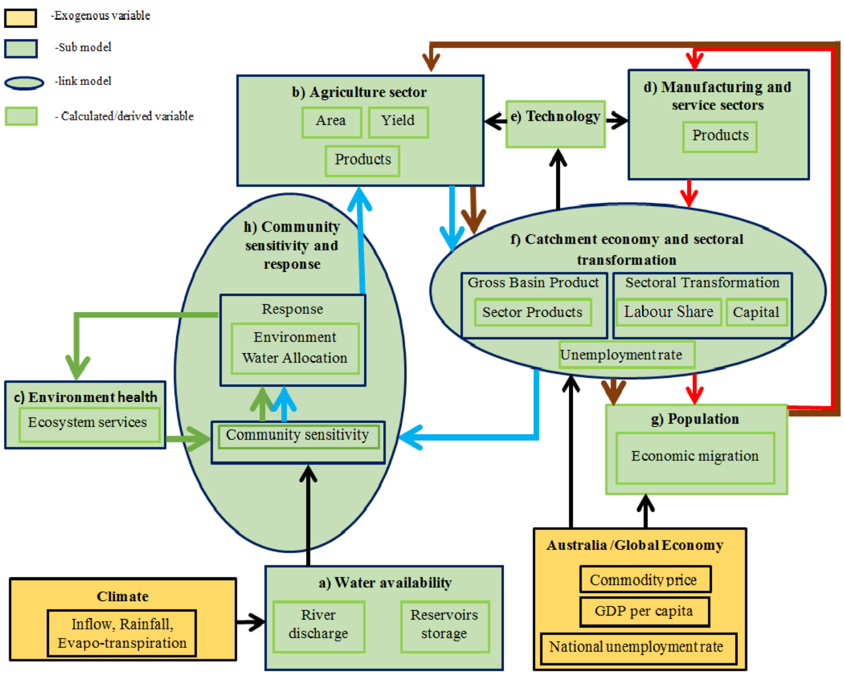

Figure 1. Socio-hydrology conceptual framework for Murrumbidgee.

3. MODEL INPUT DATA

3.1 External drivers

Two groups of data are input to the model as external drivers and they are related to the climate and to the Australian or global economy (Figure 1). The input data used in the model is summarized in Table 1. Hydro-climatic drivers of the model are inflows from the Snowy Mountains hydroscheme that flow into the Blowering Dam and into Burrinjuck Dam, and rainfall and evapotranspiration data. Gross domestic product per capita of Australia (GDP_t), national unemployment rate (Ua_t), the rate of return to capital (r), and price of crops (cp_{it}) cultivated in the basin, are the economic drivers of system.

3.2 Parameters, initial data and variables

Parameters are constant values that are used in equations in the various sub-models (Figure 1). Initial data are the values at the first time-step and are used to initiate the model computations. Values at subsequent time steps are updated based on model calculations. The values of variables are model calculated even at the first time-step. Some variables are compared against available observed data to gauge the fit of the model (see results and discussion).

3.3 Simulation period and time-steps

Model simulates the coupled dynamics from 1976 to 2012 where coupled dynamics and thresholds are apparent. The availability of detailed data for external drivers and for calibration of the model limited the simulation to the 1976-2012 period. The model was run on time-steps of one year. Data to calibrate the model was available on an annual basis. The storage in dams in catchment are calculated daily based on daily rainfall and inflows. Water allocation (Wa_t) was calculated on a monthly basis to account for seasonal cropping patterns.

4. MODEL SIMULATION RESULTS

The CEST link-model (Figure 1 link-model f) translates the impact of community inspired cuts to agricultural water allocation and the contraction of agriculture across to the rest of the basin economy. Central to the operation of the CEST link-model is the accumulation and growth of capital (Eq. 19-20, S1; Roobavannan, 2017a). The capital creates employment in the economic sectors of the basin and subsequently production is created from this. Unemployment is calculated based on the size of the labour force.

4.1 Basin sectoral transformation

During the period of cuts to agriculture water (1995-2010) sectoral transformation occurred from the agriculture sector to the manufacturing and service sectors (Figure 2a, b). Here the sectoral transformation is demonstrated by the growth in employment in manufacturing and service sectors and the post-1995 decline in the agriculture. Figure 2a shows the number of employees in the agricultural sector, and the manufacturing sector and service sector. Figure 2b shows the employment share in agricultural sector (Na_t), manufacturing sector (Nm_t) and service sector (Ns_t). The correlation with observed data in Figure 2a were $r^2 = 0.99$ (manufacturing and services) and 0.75 (agriculture) and in Figure 2b were $r^2 = 0.83$ (Nm_t), 0.83 (Ns_t) and 0.79 (Na_t).

The employment share of agriculture was strongly influenced by land under cultivation, which is determined from water allocation and allows calculation of Na_t. The employment share of the manufacturing and services sector depends on capital (K_t) (Figure 2c) and consumption (C_t) in these sectors. Figure 2c shows the capital (K_t) accumulated from the difference between the production (discussed in the next section) and consumption. The employment share of services and of manufacturing are then determined.

Sectoral transformation was occurring even before 1995. Figure 2a shows that employment growth in manufacturing and services was faster than agriculture (Figure 2a). The growth of the manufacturing and service sectors compounded the accumulated capital (K_t) and enhanced growth of employment in these sectors. Meanwhile the diminishing availability in land and water resources constrained growth in employment in the agriculture sector. Employment was further impacted by improved agricultural practices (mechanisation, technology improvements, corporate farming practices, etc.).

Post-1995, the sectoral transformation was more rapid as employment growth in manufacturing and services grew while agriculture employment declined (Figure 2a, 2b). Figure 2c shows the capital growth continued to rise post-1995 from the continued growth in production in manufacturing and services. Employment demand in manufacturing and services (Dm_t) continued to grow. A lower demand for agriculture employment (Da_t) meant lower competitive demand for labour, a growing employment share in manufacturing and services (Nm_t, Ns_t). The growth of employment in the manufacturing and service sectors supported the viability of the basin economy during a period of agriculture contraction. Later, after 2010, the breaking of the drought, and the availability of more water resulted in a rise in agriculture employment.

4.2 Basin economy and production

Figure 3a shows the gross basin product per capita ($GBPc_t$) which is based on the sum of the production in the three economic sectors. The production in the three sectors is shown in Figure 2c. Data on $GDPc_t$ for the Murrumbidgee is not available and in its absence the median household income (MHI) is shown. In developed countries MHI is generally higher than $GBPc_t$ as it includes contributions not in the later (e.g. superannuation, workers' compensation, child support, etc.).

Initially, $GBPc_t$ grew steadily. The introduction of the government water reform in 1995 and the subsequent drought saw the $GBPc_t$ decline which fell annually till 2002 and the Murrumbidgee was in recession for 7 consecutive years. The $GBPc_t$ did not recover pre-1995 levels until 2004. While the drought did not break till 2010 and while irrigation water allocation declined during this period the $GBPc_t$ did not similarly decline. The $GBPc_t$ reached a low in 2000, and except for the period of 2008-10 when the drought was extreme, generally increased. It was in 2009 that Australia felt the economic impact of the global financial crisis. The increase in the basin economic production may be attributed to sectoral transformation from agriculture to manufacturing and service sectors and to diversification in agriculture.

4.3 Population dynamics and human migration:

The population changes by natural means (births, deaths) and by migration into/out of the basin. Figure 3b shows a continuous increase in population between 1976-1995 before slowing till the late 2000s. The fit with recorded population data was $r^2 = 0.96$.

In/out migration is explained by considering the operation of the attractiveness state variable (Figure 2, sub-model g). Attractiveness is a human behaviour state variable similar to community sensitivity which captures human preference to stay in the basin or migrate to the outside considering economic ($GBPc_t$, unemployment) and resource (land and water) gradients. The attractiveness of migration (Figure 3c) to the basin was positive up to 1997, albeit generally declining. The composite effect of unemployment, gross production, the availability of land and water resources was still conducive to net migration.

After 1995, the attractiveness of the basin to in-migration (Figure 3c) dramatically fell and was predominantly negative due to economic recession and resource constraints leading to out-migration. Out-migration countered natural population growth giving a slower population growth.

4.4 Unemployment

Figure 3d shows the unemployment in the Murrumbidgee. Pre-1995, attractiveness to the basin was positive (Figure 3c), driven by agricultural potential and expansion of manufacturing and service sectors. While cumulative in-migration and basin population rose, so did unemployment (Figure 3d). In effect, the addition to the basin labour force through natural growth and in-migration exceeded labour demand. This observation parallels the Todaro paradox (Todaro, 1976) where job creation in a region leads to increased unemployment due to factors such as in-migration. This rise in unemployment could also in part be explained by technological advances and improved practices which increased productivity and reduced the need for workers. Nonetheless, humans motivated to migrate by attractiveness signals (in herd-like behaviour) were always more likely to do so in a manner that overshot the potential that existed (Bikhchandani et al., 1992; Todaro, 1976).

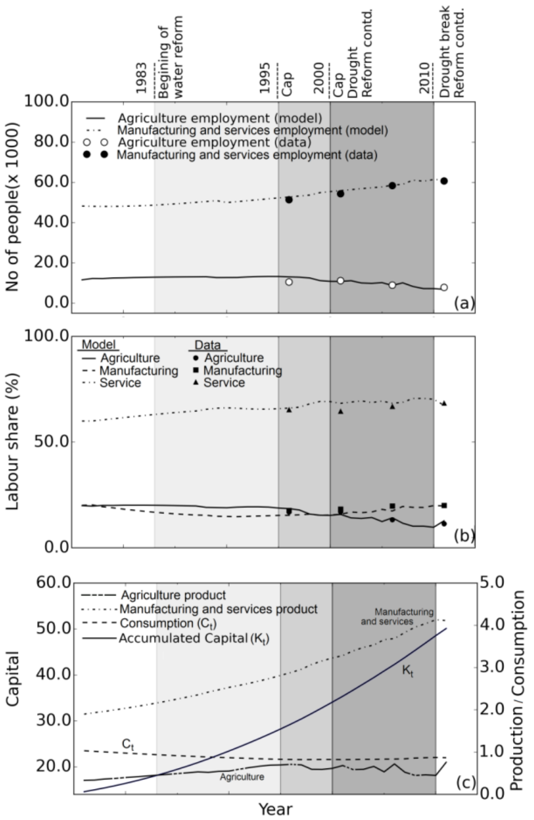

Figure 2. (a) basin employment, (b) labour share, and (c) accumulated capital (K_t), consumption (C_t) and production in Murrumbidgee

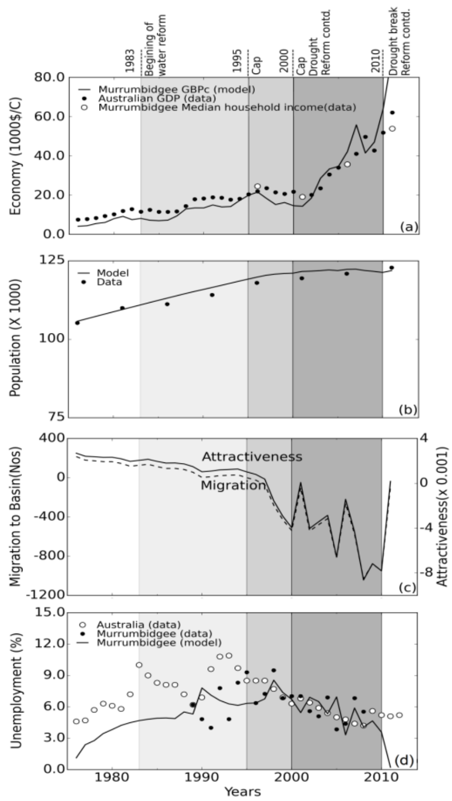

Figure 3. (a) Australian GDP_t and Murrumbidgee $GBPc_t$ (b) basin population, and (c) attractiveness of migration, and basin migration (d) unemployment rate in the basin and in Australia.

Paradoxically post-1995, unemployment actually fell (Figure 3d). The peak in unemployment (in 1997) lagged the cuts to water allocation (in 1995) by 2 years, in part reflecting the inertia of enterprises to immediately retrench workers in a period of transition from a temporary cap in water allocation in 1995 and to a permanent cap in 1997 (not foreshadowed in 1995). After 1995, the economic wellbeing and future potential of agriculture was bleak. Between 1995-2002, the Murrumbidgee was in recession (Figure 3a). At this time Australia's GDPc was rising and from 2003 rose sharply largely in response to Australia's mining boom. Unemployment in the rest of Australia was falling (generally since 1993) and was lower than in the Murrumbidgee for many years after 1997 (Figure 3d). Basin attractiveness was negative (Figure 3c), and to enhance their economic wellbeing, some people moved to the manufacturing and service sectors (Figure 2a, b) while others migrated to regions outside the basin where prospects were better (Figure 3c). Unemployment declined even as net basin population was stagnant (Figure 3b) contributed to by out-migration. In Australia, the mining boom attracted many workers from regional areas, including the Murrumbidgee. Moreover in the Murrumbidgee, youth unemployment is reasonably low, with most leaving to find work elsewhere (Wilkinson and Montoya, 2012). Out-migration and sectoral transformation helped the basin to cope with water stress.

These population dynamics that contributed to a fall in the basin's unemployment appear counter-intuitive and not self-evident without the benefit of the socio-hydrologic analysis presented here. The unemployment rate and the preceding discussion on population dynamics and basin economy leading to it frames the discussion and illustrates the complex dynamics in terms of composite changes in the economic sectors and their relative production, workforce within the basin and population migration, and natural population growth. The CEST link-model was able to translate the impact of community inspired cuts to agriculture water allocation and the resulting contraction in agriculture across to the basin economy, employment, and population dynamics in a manner consistent with what historically happened in the Murrumbidgee Basin. It tracked the dynamics and feedback between the various variables, captured the co-evolution of the complex system and allowed an understanding of what occurred.

5. CONCLUSIONS

This paper has focused on the water-food-environment nexus being played out in the Murrumbidgee River Basin located in south-eastern Australia and which contributed to the evolution of the regional economy and changing demographic patterns. It used a coupled socio-hydrologic system model, which considers the bi-directional feedbacks between human and water systems, with explicit consideration of increased wealth, technological changes, and community sensitivity to environmental degradation, sectoral transformation, and population movements, and used it to explore how the competition for water between humans and the environment impacted on the catchment economy and demography. The model captures the feedbacks, internal dynamics and thresholds resulting from the changes in water management, which was well correlated with what actually occurred in the Murrumbidgee. The dynamics was arbitrated by the 2 link-models.

In the Murrumbidgee agriculture first expanded with abundant land and water resources. The growth in prosperity and the corresponding accumulation of capital naturally led to growth in manufacturing and services. Expansion of agriculture with the harnessing of more water inevitably degraded the environment. Community's sensitivity to the environment increased. In this instance, the CSR link-model determined the impetus for action towards more environment-centric measures and water reallocation for the environment as community sensitivity passed through critical sensitivity threshold. The model captured the initial community sensitivity to agriculture expansion, subsequent reversal in sensitivity with depleting water resources, the decline in agriculture and collectively simulated the pendulum swing in this complex system.

The dynamics triggered by the change in community sensitivity and the impact on water allocation and agriculture production were translated across the basin economy by the CEST link-model. The link-model simulated the accumulation of capital, the employment generated from this and the production in each of the three economic sectors of the basin. The model showed that the basin adapted to the economic stress through sectoral transformation to the manufacturing and service sectors, increased production in these sectors, changes in employment, including the paradoxical observation in the unemployment rate, and the out-migration of residents to regions outside the basin where prospects were better. Diversification of agricultural cropping and improved water use efficiency slowed the decline of agriculture production. These changes enabled the basin economy to cope and transform without collapse. The water reforms made to mediate the competition between humans and the environment impacted agriculture therefore did not translate to economic contraction and high unemployment as was feared earlier. The model showed how such contraction was averted, leading to a sustainable transformation of the region's economy even while tangible environment protection measures were implemented. These changes are counter-intuitive and not self-evident without the benefit of the socio-hydrologic analysis presented here.

This type of socio-hydrological model is a useful tool that can assist in the debate of the future of the agriculture industry in the Murrumbidgee. It can also contribute to more sophisticated water management. The information and insights that the socio-hydrologic model provides can be beneficially inform how communities could transform in response to water reallocation, and to open up different adaptation pathways.

Around the world, fresh water crisis is imminent due to growing human populations, exacerbated by climate change. The present modelling study can guide other water stressed regions where competition for water between different users is taking place. Further, more comparative studies can further understanding of why water management in some basins fail (e.g., Aral Sea, Lake Urmia), and can help define the role of economic transformation in water management decisions and help a region's economy to transform itself.

The structure of the socio-hydrologic model used here has been tailored to the Murrumbidgee in terms of the type of economy, role of government, type of administration and level of support, the role of the community and it's valuing of the environment. For example in the Murrumbidgee, crop diversification leading to better returns and lower water requirements was enabled by water trading. This may not be possible elsewhere without the kind of reforms that the government instituted. More such models need to be developed for other coupled human-water systems in different localities and jurisdictions to learn and identify what is unique and what is generally applicable and to determine relationships between variables that may be valid more universally. In this way more generic coupled human-water system models could be developed for universal applications. This is left for further research.

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