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Hydrology and Earth System Sciences Discussions

Interactive comment on "Socio-hydrologic modeling to understand and mediate the competition for water between agriculture development and environmental health: Murrumbidgee River Basin, Australia" *by* T. H. M. van Emmerik et al.

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General comment

"In the paper, the authors proposed a framework to model the human-river system by coupling five sub-system: hydrology, population, ecology, irrigation and environmental awareness, and used the Murrumbidgee River system downstream of Wagga Wagga as a case study. It's an interesting and ambitious paper. However, the method, data used, results and conclusions presented in the paper are not publishable materials."

We respect the opinions of the reviewer. For whatever is worth, we will provide additional perspectives on the rationale for this work, and the methods adopted. Hopefully, this clarification might overcome some of his misgivings.

This paper presents a new modelling framework within the emerging science of socio-hydrology (SH). SH aims to model human-water coupled system as a whole, rather than only looking at the hydrologic cycle or water-economics. First of all, socio-hydrological modelling of the kind of presented is a new activity: most of the models that have been presented so far have been developed for general systems, not for real places. This poses many challenges, including the ones the reviewer is raising. However, the model that is presented here is viewed more as learning and diagnostic tool, to try and understand the observed human-nature system dynamics, and not as a predictive tool. As we already address in the paper, this is akin to a test of a hypothesis.

Of course more fundamental research is required to determine relations between state variable that are generally valid. This paper presents a first step in finding the latter. Based on an intuitive approach, relations, feedback mechanisms, initial conditions were tested to see how reality can be described. Clearly, the next step is to transfer the developed model framework to different areas in order to discover more generally valid rules that can be applied in all human-water coupled systems. In this paper, we do not claim to have achieved this, for now we are satisfied to show for the first time how such a framework can be used in an actual case study.

Detailed comments

"Modeling approach: The five state variables representing the sub-systems are related. However, they are acting in different spatial and temporal scales, for example, the environmental awareness is very broad, and is effected by national and international environmental campaigns, and can't be modelled as the degree of wetland stress."

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We do not understand the reviewer's point here. The state variables we use are reservoir storage, irrigation area, wetland storage, and population size are modelled in lumped fashion at the scale of the basin and at annual timescale. This is clearly stated in the paper: there is no discrepancy in scales. So we do not agree with the comments of the reviewer.

The reviewer specifically mentions environmental awareness, implying there is a scale discrepancy. We agree, however, that environmental awareness is only partly endogenous, a reflection of environmental degradation both within the basin and outside (including in the wetlands downstream). There certainly is an element of more broad regional and even national community awareness that is also affected by the diminution of the relative importance of agriculture in the national GDP. This we have already acknowledged in the paper.

However, at this stage of SH modelling one has to simplify a very complex system to a degree where modelling is at all possible. In this case, wetland stress was selected as a measure of environmental degradation. One can view it as a lumped variable that averages several factors; environmental damages and measures taken by individuals, motivated groups or governments. Even with the simplification the model does produce dynamics that to some extent mimics reality. Based on this, future research can go in more depth and add more refinement to certain modules (e.g. environmental awareness).

"Population dynamics are mainly affected by the State and Commonwealth policy, and are not the result of available resources (water and land). In addition, the human settlement change within the system (as described as moving downstream/upstream) contributes very little to population dynamics."

The establishment and development of agriculture were no doubt a result of State and Commonwealth policy and investment (such as the soldier settlement scheme, food security and dam storage and irrigation infrastructure). The key is that human

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settlement followed opening of the land and the construction of reservoirs and other irrigation infrastructure: without water and land people would not have populated the area. This is precisely the assumption made in the modelling.

Agriculture enterprise in the Murrumbidgee was not without difficulty and despite many setbacks, eventually over time took hold. The establishment and agriculture's continued growth, provided the opportunities and impetus for secondary industries (e.g., food processing) and services within growing communities. The increasing prosperity of the agriculture enterprise led to further population growth and expansion. This led to intensification of agriculture in the established areas and movement out to more marginal areas. We had sought to capture this, albeit simply, in our model.

"These variables, in particular, technology, can't be modeled as internal within the same system. On contrast, many of the endogenous variables such as technology should be external drivers."

We have assumed (justifiably) that Australia is a free market based economy where adoption of technology at any scale is an individual choice. In the context of basin scale socio-hydrology, it is strongly influenced by the decision-making of stakeholders within a basin, such as farmers. A contrast to such an economy is a centrally planned one (for e.g., former USSR) where it is often implemented by a central planning agency. If the adoption of technology is an individual choice, it stands to reason that it is indeed an endogenous variable. In cases of production activities, such as agriculture, it possibly depends on a profit maximizing motive of agents such as farmers and therefore on basin scale production. Pande et al. (2013), in this special issue, have theoretically shown that level of technological innovation/adoption is directly linked to Gross Basin Product if the former depends on individual decision making.

"One of the two drivers, discharge at Wagga, is not an appropriate forcing. Discharge at Wagga was determined by the Water Share Rules endorsed by the Water Minister - a decision based on water requirements from agriculture, domestic water supply and environmental needs. It should be an internal variable, at least in normal years."

First of all, water Share Rules are a recent construct in more recent times based on licencing of water extractions from rivers and did not exist for a greater part of the model period from 1910 onwards. It is pertinent to note that licencing of water was freely undertaken to the extent that by the 1990s the water resources were significantly over-allocated. It is only since the 2000s that steps were initiated to have the water sharing match available water.

Secondly, and more importantly, the majority of water in the Murrumbidgee is allocated to agriculture. The overwhelming majority of agriculture enterprise, and where most of the water allocated to agriculture is used, is located downstream of Wagga Wagga. While not strictly speaking a forcing function it suffices for the simplified model we intended.

"On what assumption did the authors select the initial conditions for the five state variables? How did the authors select the thresholds? What are the calibration procedures - the degree of freedom is obviously large?"

The setting of initial conditions: back in 1910 agriculture was assumed to start from scratch. Therefore initial conditions for reservoir storage and irrigation area were just zero. There was no environmental degradation, and environmental awareness was also assumed to be zero. For simplicity, we assumed a notional initial population size of 5000 people.

The thresholds used in the model were considered as parameters. Calibration was done manually, using time series of irrigation area, population size, reservoir storage capacity expansion and water extraction. Even then, we were not endeavouring to exactly match these observed time series. Instead we were only attempting to mimic the observed general trends, in order to test hypotheses on the reasons for the observed pendulum swing (Kandasamy et al., 2014).

In our model there were two components that were calibrated. We calibrated the constitutive relations. At this stage in the development of SH, general applicable governing equations and constitutive relations between the various modelled state variables have yet to be determined. Therefore, we chose to run the model using several mathematical shapes of constitutive relations. The model is definitely complex and with many parameters indeed comes a large degrees of freedom. It is acknowledged that many parameters can be chosen within a parameter space that makes physically sense (e.g. natural population growth, catchment area, runoff coefficient). We are currently embarked on the development of more detailed models based on the conclusions of this paper, and the kind of analysis that the reviewer envisages will be carried out as part of that modelling study.

Reviewer #2 has also raised similar concerns about the identifiability and parameter uncertainty: we will provide a more detailed analysis of the sensitivity of the parameter values in response to both reviewers.

"Data: Where are the data (fig 6) come from? Is it true that over 50% of water allocated for rice production? Does the population - irrigation area relationship show pendulum swing?"

The graph in Fig. 6 was taken from Kandasamy et al. (2014), based on data on (1) storage (NSW State Water Corporation), (2) Population in MRB (ABS, 2013b), (3) irrigated area in MRB (ABS, 2013a), irrigation flow utilization in MRB (DWR, 1989; ABS 2013a; State Water Corporation). We did not include these references in this paper, as they have been presented in the paper by Kandsamy et al. (2014), who clearly provided evidence for the observed pendulum swing. We will expand slightly the description of these figures so the readers are aware about the data background behind these figures.

Hafi et al. (2005) indicates that 51.7% of irrigation water in the Murrumbidgee Irrigation Area was allocated for rice in 2000-01 (this reference will be added to the revised

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manuscript). The ratio between population and irrigated area (irrigated area/cap) also shows a pendulum swing, and this is presented in Fig. 9.

Final comments: We thank the reviewer for his critical comments. We believe that the clarifications we have made address his main concerns. We will work these clarifications into the revised manuscript in due course.

References

The following references will be added to the revised manuscript:

ABS: Australian Bureau of Statistics, available at: http://www.abs.gov.au/ (last access: May 2013), 2013a.

ABS: Australian Yearbook, Australian Bureau of Statistics, available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf (last access: May 2013), 2013b

DWR: Water distribution operations in irrigation areas and districts of NSW, New South Wales Department of Water Resources, Gutteridge, Haskins & Davey, Sydney, 1989.

Hafi, A., Beare, S., Heaney, A. and Page, S, Water Options for Environmental Flows, ABARE eReport 05.12, prepared for the Natural Resource Management Division, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, November, 2005.

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