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Discussions

Interactive comment on "Socio-hydrologic drivers of the Pendulum Swing between agriculture development and environmental health: a case study from Murrumbidgee River Basin, Australia" *by* J. Kandasamy et al.

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Specific comments We thank the reviewer for the comments provided. We address the specific comments raised.

1) Reviewer Comment: This work is of strong interest to those studying water management. However, the Introduction lacks references or acknowledgements of other works that also seek to understand human-hydrologic systems more holistically (for example, see references listed below). While these others studies were not conducted

on the Murrumbidgee basin itself, appropriate referencing would not only lend support to those working on similar issues, but would also provide references to additional reading material for those interested in learning more about the broader issues being addressed by this paper. Scholz, J.T. and B. Stiftel, 2005. Adaptive Governance and Water Conflict: New Institutions for Collaborative Planning. Resources for the Future. Richter, B.D. et. al, 2013. Tapped out: how can cities secure their water future? Water Policy. 15(3):335-363.

Author response: Thank you for this suggestion. The references suggested by the reviewer will be incorporated and referenced into the Introduction section of the paper to give a broader perspective beyond the Murrumbidgee and Australia, and incorporating human hydrologic systems.

2) Reviewer Comment: Much emphasis is placed on the differences in the system state over the last century (p.7204-7205, lines 20-4) with a schematic of the basin's current complexity displayed in Fig 2. However, without presenting a simple system for comparison, the "enormous" complexity (p.7204, line 23) is not apparent. The authors might consider modifying Fig 2 to include a schematic of a simple system (e.g., an overview of what the system looked like 100 years ago) to better illustrate their point.

Author response: We agree. At present, a description of the simple system for comparison is given in the first 2 paragraphs of section 3.1. Additionally, a reference to these texts will also be made when figure 2 is first introduced. Finally, a comparison will be made based on the system in the past (as per your suggestion), relative to it at present (as currently shown in Fig 2).

3a) Reviewer Comment: The authors' use of the term "pendulum swing" implies that the system might once again fall (swing back) to management schemes which are detrimental to overall ecosystem health. The implications of the "swing" are relevant to the model proposed at the end of this work and therefore warrant some discussion.

Author response: This is an excellent suggestion, and an important point. The fact the system may in fact "swing back" is the impetus behind development of socio-hydrology model so a more complete understanding might be developed that will guide system managers to develop policies with a more sustainable trajectory. More discussion on this will be added in the revised manuscript.

3b) Reviewer Comment: Fig. 3 seems to be a visual representation of the hypothesis rather than a "result", particularly since none of the supporting data has been discussed at the point where it is first referenced (p.7205, lines 8-10).

Author response: While we understand and accept this valid interpretation, this is perhaps the consequence of showing the change in key indicators and explaining the pendulum swing in the different eras ahead of the presentation of the supporting data. In the revised paper, Figure 4 will be mentioned together with Figure 3 to better link with the supporting data.

4) Reviewer Comment: One of the primary goals of this paper is to use quantitative data to establish where and why different "eras" of management occurred. The authors could better achieve this goal by grouping the data in Fig 4 to highlight certain system drivers and responses for emphasis. For example, if the data were grouped by system type (agricultural vs. environmental), the reader would find it easier to see the important correlations between trends in analogous system variables at given times (e.g. as the volume of stored water for agriculture increases (Fig 4a), the downstream flows to important environmental systems decreases (Fig 4f)).

Author response: Thank you for this excellent suggestion. We will adopt it in the revised manuscript. The order in Figure 4 will be rearranged to effect this. For eg. Figure 4a and b show the rise in agriculture infrastructure giving rise to agriculture production (Figure 4c (previously 4d), where rice is used as a surrogate) and consequently leading to a rise in population (Figure 4d, previously 4c) as supporting industries and services in the local area develop. Figure 4e shows the rise in water utilisation leading to the decrease in rivers flows (4f). In recent times, the later has reversed (Figure 4g - previ-

ously 4h)) due to environmental water buy backs (Figure 4h - previously 4g)), though the quantities are still small. However, we submit that it is not possible to completely form distinct groups as the impacts are interlinked, e.g. the drop in population (4d) is partially caused by the overall drop in the agriculture share of economy (4h - previously 4g) due to local effects (4b). Similarly, the fall in agriculture production (4c - previously 4d)) in recent times is linked to environmental water buy backs (Figure 4h - previously 4g)), subsequent change in water utilisation (4e) and a reduction in irrigated area (4b).

5) Reviewer Comment: While the text-based narrative provides much evidence in support of the hypothesis proposed, it is not clear how some of the data in Fig 4 relate to these ideas. Fig 4a, 4b and 4h seem to be excellent examples of data that support the evolution of different "eras", showing distinct trends during different time periods. Other examples, however, seem less convincing. While the agricultural share of GDP (Fig 4g) helps paint the broader picture, this lends little direct support to the emergence of Era 4 (p. 7213, lines 15-18), since there seems to be little if any difference between the share in Era 3 vs. Era 4.

Author response: As mentioned earlier, the drop in population (4d) was partially caused by the overall drop in agriculture share of economy (4h - previously 4g) as it was by local effects (4b). The diminishing role of agriculture in the Australian economy (Figure 4g), which combined with the changed community attitudes towards the environment strengthened the Commonwealth government's hand enabling it to put in place a $12 billion national water reform package which "swung the pendulum" towards the environment. While it is true that agriculture declined continuously since the 1950s and since the 1980's there seemed little change (in Era 3 vs. Era 4), social and political sentiments (green vs farm lobby) swung over that period of time to the environment, albeit gradually over the last 30 years.

6) Reviewer Comment: Quantitative information on specific examples of problems (e.g. soil salinity, environmental flows) and responses (e.g. Salt Interception Schemes, numbers of participants in the green lobby) plainly identified within the text would provide

more substantial support to the analysis. The authors might consider either providing clearer explanations for inclusion of the current data, or incorporate new data that directly supports the key points of the narrative, especially if additional data could show analogous changes in the two systems. This analysis heavily emphasizes the large cost (p. 7216, lines 23-24, p. 7217, lines 15-17) of the "pendulum swing". Yet, quantitative evidence for these costs is not obvious in this analysis. For instance, it would be very interesting to see the estimated amount of government expenditures on agricultural modifications vs. environmental rehabilitation over time. While all necessary data may not be available, inclusion of some quantitative information on the dollar amount spent over time on, for example, built irrigation infrastructure, water license purchases, environmental mitigation (wastewater treatment plants, salt interception schemes, fishways), etc. would lend more weight to the idea that these transformations were, indeed, costly. Similarly, the lack of quantitative evidence for changes to the environmental system also weakens the arguments made by the authors. Given that two of the biggest environmental problems faced within the basin were soil salinity (p. 7209 lines 14-23) and salt water intrusion (p.7209, lines 8-13) efforts to include quantitative evidence of these "environmental costs" would significantly benefit this work.

Author response: Some of the evidence and data that depicts the environmental degradation and the subsequent attempts at remediation is described in the following paragraphs:

The overall investment of in-stream infrastructure associated with the storage and diversion of water from the Murrumbidgee River based on 2011 replacement costs is in the order of $2800M. (State Water, 2008). Off-stream infrastructure was developed first by government through the NSW Water Conservation and Irrigation Commission were later transferred and owned by the Murrumbidgee Irrigation Limited (MI) and the Coleambally Irrigation Co-operative (CIA). MIL operates over 3,500 km of supply channels, and 2,160km of drainage channels with an asset replacement cost of over $500M (MI, 2011). CIA operate infrastructure to the value of $133M (CICL, 2011). On-farm ir-

rigation infrastructure in the Murrumbidgee region is estimated in the order of $1,600M (Meyer, 2005).

Before the introduction of rice farming in the 1920s, the groundwater watertable in almost all of the MIA was about 20 m below the surface. In 2001 the watertable for around 85 percent of the MIA was within 2m of the surface. In 1987, it was estimated that 96,000 ha were affected by saline soils and 560,000 ha had watertables within 2m of the surface, with the latter rising rapidly in many areas (MDBMC 1987, 93). Unless mitigated, by 2040, 1.3 million ha of irrigated land are expected to be salinised or waterlogged due to high watertables (GWG 1996).

The overall estimated annual damage due to salinity in the MDB is substantial: $130 million in agricultural costs, $100 million in infrastructure costs, and $40 in environmental costs. The costs to agriculture impacts in various ways, not just in terms of lost production, but also reduced land values, detrimental aesthetic impacts, and costs of remedial action where these are feasible. If nothing is done, losses of the order of 30 per cent will prevail within 30 years. It is estimated that this will result in the loss of 3,500 jobs by the year 2025 and, with the knock on effect, massive economic and social dislocation in the region (Anon. 1989). As at 1997, the economic benefit of ameliorating acidic, sodic and saline soils in the MIA has been estimated to be $135.7 million. Additionally, the local infrastructure cost for managing the salinity increase was estimated to be 2.2 million a year, increasing to $7.4 million per year by 2020.

As at year 2000, the net present value of the impact cost of dryland salinity to agriculture in the Murrumbidgee Irrigation Area (MIA) alone was estimated to be $32.5 million.

A range of measures continue to be undertaken to combat rising watertables and salinisation in the catchment especially in irrigation areas. Initiatives include stricter controls on rice production, more efficient irrigation of all crops, more efficient water use by urban residents, and significant tree planting. Since 1988, NSW, Vic and SA together with the Commonwealth Government have funded the construction of salt interception schemes (SIS) to reduce salinity in the Murray River. SIS are large scale groundwater pumping and drainage projects that intercept saline groundwater flows and dispose them generally by evaporation. In the Murray-Darling Basin, there are currently 18 operational SIS borefields and a handful of smaller schemes are under construction or investigation. Despite these measures by 2020 the probability of salinity in the Murray Darling river exceeding target threshold (of 800 EC, the drinking water threshold) will be about 50 per cent.

SIS are a significant component of the salinity management strategy in the Murray Darling Baisn. These schemes intercept saline groundwater before it reaches the main river system and maintain salinity levels agreed for the River Murray. The 18 current salt interception schemes have an estimated capital cost of $200milion

Salinity was not the only issue to impact on the economy. In the summer of 1991-92, when "the largest river bloom of blue-green algae recorded anywhere in the world emerged along the Darling River" (MDBMC 1994, 1993). This extended over 1,000 kilometres in the Murray-Darling, while other outbreaks occurred over the summer months at many locations in the Basin, such as Lake Cargelligo, the Carcoar Reservoir, and Lake Mokoan. A significant investment by Governments were undertaken to reduce the nutrient load on the river. Sewage treatment plans was the major cause of excess nutrients in the river and significant investment was made to upgrade the wastewater treatment plants in the basin to reduce the nutrient loads. Irrigation areas were identified as the second largest impact on the nutrient loads in the basin and further measures was provided to decrease the nutrient run off from farms

A key initiative of state governments was to construct fishways which allow fish to pass barriers within the rivers. Since 1985, 27 fishways have been built. In 1994 the NSW Government introduced the NSW Fisheries Management Act 1994 which may require a fishway to be built around any new in-stream barrier or as a result of a significant upgrade or were renewal works are undertaken on an existing structure. As the major

irrigation structures in the Murrumbidgee River are upgraded the estimated investment in the construction of fish passage in the order of $50 to $60 million over the next 20 to 30 years.

Whilst there may not be space in the revised manuscript to present all of these, a synthesised version and selected key data will be incorporated into the revised paper to strengthen the arguments presented.

7) Reviewer Comment: It would also be useful to the reader to see a simple timeline of when major policies implemented in relation to the quantitative data presented in Fig 4.

Author response: This is a good suggestion. Such a time line will be prepared and incorporated into the revised paper along with relevant text.

8) Reviewer Comment: The proposed framework for socio-hydrologic modeling is an exciting one. That systems may face great costs when they “swing” from state to state is relevant not only to taxpayers and politicians, but to those interested in protecting the overall productivity and health of the system. Given the interest of the authors in incorporating both quantitative (e.g. hydrologic) and qualitative (e.g. cultural norms) within the socio-hydrologic framework, it would be interesting to include a deeper discussion on how to measure the qualitative “costs”. In this case, there seems to be merit to weighing not only the ecological destruction over time, but also the loss of livelihood that farmers now face as the health of ecological systems take precedence and the pendulum swings out of the farmer’s favor. If it is to be a truly socio-hydrologic model, there should be some way in which the damages to the agricultural community (possible displacement, reduced income, anger/mistrust) should be incorporated, as they are equally real as the damages to the environment. More insight on how the proposed model would capture this type of system complexity would be very insightful.

Author response: The impact of the pro-environmental policies have been estimated in the Government’s Basin Plan in the form of plausible scenarios that might occur from the alternative water level reduction scenarios that was considered leading up to the implementation of the Basin Plan. The first represents a 20% water reduction. It is estimated that such a reduction will reduce rice production by 30-40%, thereby reducing but not eliminating existing rice and horticultural industries. However, the recovery of the river system in this scenario would be expected to be prolonged, owing to the lower water reduction from communities. Consequently, long term impacts on sustainability might be limited. Also, the investment in alternative technologies and industries as well as technical re-training initiatives caused by the $10 billion Government investment might not bear fruit as existing industries will have less economic incentive to raise the efficiency of current practices. Within a 40% water level reduction scenario, rice production will be significantly curtailed causing many extant rice production farms to cease operations. These farms might institutionalise the technical and infrastructure based transformations required to remain viable post water reductions, or change industries altogether. Of course, farms might be sold to larger firms, for whom efficiency practices and adequate training will more viably occur. The $12.9 billion Government injection into the Murrumbidgee communities would be expected to raise the ability of communities to recover from this significant water reduction, though at reasonable social costs from mobilising the labour resource. The environmental eco-systems will be expected to recover quicker in this scenario, than the first. A 60% water reduction scenario undoubtedly allows for the eco-system to recover most effectively. However, this significant reduction will pose great strain on social communities supported by existing industries. The reduction in water will render rice production almost impossible, causing the possible sale of irrigated water to other communities, or the transformation of grower activity from rice to other crops that use less water. In this scenario, the $12.9 billion Government investment might aid in re-training and raising efficiencies in existing production, but it is likely that associated service industries to rice growing and milling will suffer significantly in the short term, while labour resources economically re-skill and mobilise for injection into new industries. In the long run, however, this approach should trigger fundamental structural change that might serve to more

sustainably balance economic developmental needs of societies against the imperative of using natural resources sustainably. At present, the community impact in terms of health of the various local economic sectors, population, income, etc, are captured in an economic input-output model developed by one of the authors (State Water) (see Figure 2). As a start, in the socio-hydrology model, it is proposed to use this input-output model to explore and to develop simple empirical relationships between principal drivers and indicators that can trace the impacts of community well-being. These empirical relationships will be used in the initial socio-hydrology model to model changes to local communities. Whist the level of complexity is initially rudimentary, it will serve to prove the concepts behind socio-hydrology and its viability.

Technical Comments Reviewer Comment: Examples are first given for the term “infrastructure” on p7203 line 16, therefore there is no need to repeatedly include the same example (e.g. dams and weirs) every time the term is used again. (Further instances on p.7203, line 17; p.7206, line 17; p.7208, line 7; p.7210, lines 25-26; p. 7218, line 8). p. 7202, line 5: Write out the full term prior to using its abbreviation (i.e. New South Wales (NSW)) p. 7202, line 18: Missing word- “to” p. 7204, line 2: “these” dynamics-repeated throughout p. 7209, Title 3.2.2: Note that “Band-Aid” is a registered brand name for adhesive bandages Fig 2: The colors used in the figure and those included in the key do not match Fig 6 and 7: The photos used need citations.

Author response: The authors thank the reviewer for pointing out all the errors as listed above. All these will be corrected in the revised manuscript.

Reviewer Comment: p. 7206, lines 5-8: “pendulum swing”, although defined here, is later re-defined several times. (p. 7216, line 18 and 20-21).

Author response: The description of “pendulum swing” will be consolidated and given in the first instance in the revised manuscript.

Reviewer Comment: Fig 3: It would be helpful to see how the authors envision the pendulum swinging here (analogous to the visual used in Fig 5 or 6).

Author response: In Figure 3, during era 1 and 2, the development of agriculture infrastructure was consequently followed by an increase in agriculture production and population. The environment degraded, effectively depicting the pendulum swing towards agriculture production. In era 3, with higher levels of environmental infrastructure and investment, the deterioration in the environment slowed and in this period the rise in agriculture was mitigated. It is expected with the heavy investment in environment in era 4, it would see its remediation and rehabilitation. In this era, the pendulum is swinging clearly towards the environment. Whether the agriculture sector suffers depends on its ability to switch to highly profitable crops which use significantly less water (fruits and nuts). The population will continue to decline given the nature of the macro-economy. This discussion will be added to the revised manuscript.

Reviewer Comment: Fig 3: What exactly does “Emphasis Level” mean?

Author response: The term emphasis level was used in the absence of a scale in the vertical axis and was adopted to describe the degree of increase in the parameters described in Figure 3 (agriculture, population, infrastructure, and environment). This will be made clear in the revised manuscript.

Reviewer Comment: Fig 6 and 7: There seems to be much repetition between Fig 6 and 7. Could these be combined somehow?

Author response: Figure 6 is a conceptual framework of a socio-hydrology model applicable to the Murrumbidgee river basin that naturally arose from a historical analysis of what happened. Figure 7 is presented as the outcome of a further distillation from Figure 6, through generalizing the drivers and the resulting interactions and feedbacks in a manner that has wider applicability across climatic and socio-economic gradients (Ostrom, 2009). Figure 7 has similarities with Figure 1 in Ostrom, 2009 highlighting its generalised nature. In so far as Figure 7 was a distillation of Figure 6, there are similarities. Nevertheless the intent was to generalise Figure 6 for a wider application, Figure 7 being the outcome of that process.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 7197, 2013.