Socio-Hydrological System Analysis for Characterizing Adaptation to Water Scarcity in Complex Human-Water Systems: An Exploratory Application of Hydrological and Agent-Based Modeling

A Case study of Upper Russian River Watershed, CA, US.

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Abstract:
Russian River Watershed has been experiencing a looming freshwater crisis due to changes in the inter-basin diversions and pervasive drought. As of April 2021, both of the major reservoirs of the watershed are at their lowest levels and the annual rainfall hits less than 40% of the historic average. Agricultural activities play an important role in the local economy and substantially impact the natural hydrological cycle. Here, we propose exploratory socio-hydrological modeling to 1) inform water conservation plans in coping with drought, 2) test the aptitude of exploratory modeling in addressing complexity and deep uncertainty in coupled human-water systems, 3) facilitate community involvement in co-creation of knowledge, and 4) contribute to the resilience of the community. The overarching research question is how exploratory socio-hydrological modeling could potentially inform water conservation planning and co-creation of knowledge in the study area. Specifically, we develop a coupled hydrological and agent-based model to characterize the dynamic of water and society in the Potter Valley Irrigation District. Our proposed methods include a diverse range of methods and skills from hydrological and socio-political sciences, complex adaptive systems, and environmental policy. The proposed research will be conducted in collaboration with the Russian River Keeper Non-Governmental Organization to ensure modelers have adequate insights from multiple stakeholders and to facilitate the inclusion of the community in different parts of the model development and analysis process. The student partner will conduct data collection, model development and actively maintain the communication with the community partner.

1. Introduction:

Human modifications have resulted in rapid changes in hydrological systems across scales and have produced major shifts in the dominant hydrological properties and challenging predictions and complicating effective water resources management and planning[1]. Additionally, major shifts in climatic extremes frequencies and magnitudes brought more complexities in the efforts to navigate coupled human-water systems [2]–[5]. This calls for developing novel approaches for water resources management in which the interaction of water and society is inevitable [1], [6]–[8]. A wide range of approaches have been used to quantify and model these alterations of hydrological processes, including system dynamic methods [9]–[13], Agent-Based Modeling (ABM) [14]–[18], and dynamical modeling [19], [20].

The Russian River Watershed has been playing a vital role in the development and livelihood of Northern California. The watershed has been facing pervasive challenges in restoring its socio-environmental sustainability and characterizing the vulnerability trade-offs in drought and flood mitigation in addition to adaptation to observed changes in available water and operation of historical inter-basin diversions [21]–[23]. Human modifications in the watershed have created a complex human-water system for which the classical stationary models seem inefficient to project system-level tipping points, patterns of co-evolution, state of the system, and unintended policy implementation consequences [24].

Here, we propose exploratory socio-hydrological modeling to 1) inform water conservation plans in coping with drought, 2) test the aptitude of exploratory modeling in addressing complexity and deep uncertainty in coupled human-water systems, 3) facilitate community involvement in co-creation of knowledge, and 4) contribute to the resilience of the Upper Russian River community. Specifically, the overarching objective of the proposed research is to investigate the dynamics of agricultural water demand in response to drought conditions (or generally water scarcity) in the Potter Valley Irrigation District (PVID) located at the upstream of Lake Mendocino which is the main water source in the Upper Russian River watershed as it has been experiencing drought[1] in recent years [22], [23].

This research aims to answer three major questions: 1) What are the controlling processes in farmer's adaptation to drought and how changes in available water could impact farmer's behavior and decision-making processes? 2) How characterization of the role of human behavior could inform the design of efficient conservation policies? and 3) How exploratory modeling is able to facilitate the co-creation of knowledge in complex adaptive systems?

2. Research approach:

We build upon the fact that hydrological and social systems are interdependent, co-evolve over time and have the potential to produce emergent dynamics that cannot be understood if humans, the built environment, and hydrology are examined separately. The field of socio-hydrology has recently emerged to focus on the interactions and feedbacks between water resources and the social systems that depend on them [25], [26]. At the heart of socio-hydrology is the notion that

[1] https://bit.ly/3d36D16

human behavior and social processes are endogenous parts of the water cycle. That is, as hydrological processes are managed for the benefit of humans, social aspects such as behavioral norms also change the effects of which are then fed back to influence hydrological processes [27], [28].

To model agricultural water use and surface water dynamics, we will couple a semi-distributed top-down hydrological model [28]–[30] and an ABM [31]to further study the impacts of water conservation policies (e.g., changing crop patterns and water-saving technologies) through different scenarios. This coupled model will enable us to characterize the complexity of co-evolving human-hydrological systems by dynamically updating the bio-physical system variables based on feedback from human behavior and interaction with the hydrological system [17], [18], [32].

Additionally, Based on the Social Construction of Technology (SCOT) approach [33], socio-hydrological models are not neutral tools without any impacts due to particular choices, knowledge, preference, and "naturalized discourses" are embedded in these models. These (mostly unconscious) could result in the promotion of certain policies or practices that subsequently affect socioeconomic conditions [34]. To better account for the challenges posed by complexity and deep uncertainty and also to facilitate the stakeholder engagement in the co-creation of knowledge, we will implement the proposed modeling following an exploratory framework [35], [36] . Figure 1 shows the relationship between socio-hydrological models and society.

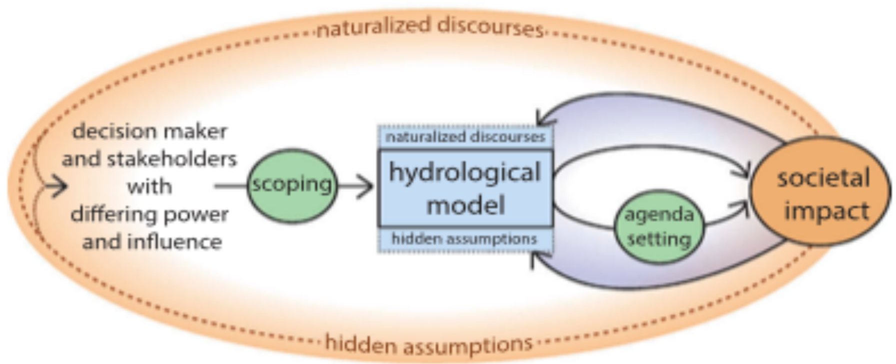

Figure 1. The relationship between socio-hydrological models and society based on Social Construction of Technology (SCOT) [34].

Implementation of exploratory modeling will enhance model formulation by making valid conclusions not necessarily from individually correct models of complex systems, but from an ensemble of different framings of these systems, for example with various interactions between elements and different agent rules and ultimately help in coping with systematic uncertainty. Moreover, exploratory modeling will facilitate the engagement of stakeholders in the co-creation of knowledge through including stakeholder input into the iterative process of modeling and combining computational and human capabilities interactively [37]–[41]. Figure 2 illustrates different forms of stakeholder participation and the ways that exploratory modeling could help from co-creation of knowledge to co-design a shared problem, co-produce sensible results for the problem, and co-disseminate robust sensible inferences. We will be committed to including a wide range of multiple stakeholders in the community to ensure we would be able to develop our models based on the principles of Justice, Equity, Diversity, and Inclusion (JEDI).

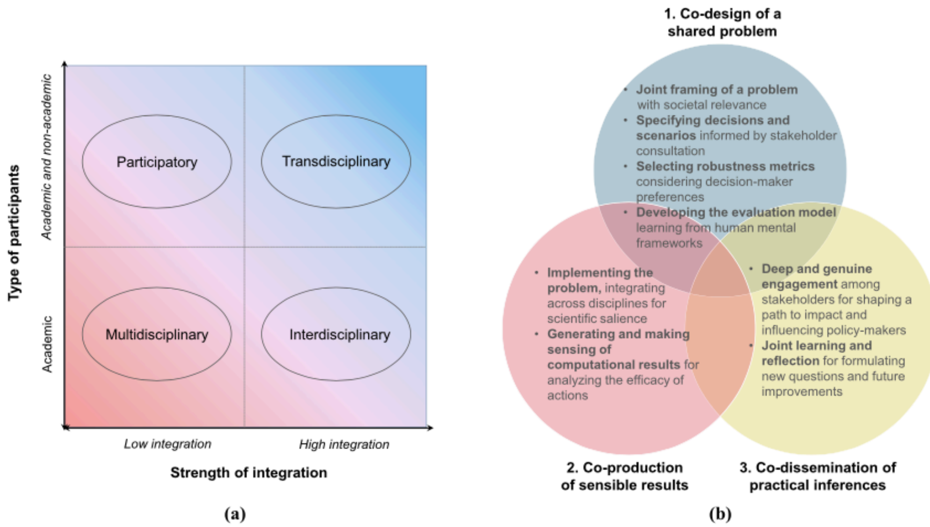

Figure 2. The co-creation of knowledge with stakeholders. (a) shows different forms of stakeholder participation based on [35] *; b) shows the three ways for the co-creation of knowledge in exploratory modeling* [36].

3. Expected Outcomes:

Upon successful completion, the proposed research will contribute to three main outcomes: 1) decision makers, stakeholders, and researchers will be able to deploy the open access coupled semi-distributed hydrological and agent-based model to conduct socio-hydrological analysis and inform water conservation planning and design. The developed model will benefit both the decision makers and the local community to enhance their water supply and demand management, 2) open access database of socio-economic data in the Potter Valley Irrigation district will be developed based on data gathered through desk study, field visit, and focus group interview, and 3) inclusion of stakeholders opinions, preferences, values, and decision making progress to understand the dynamics of agricultural water use in adaptation to a drought that potential will improve the livelihood of the local community and long-term resilience of the study area.

4. Significance:

Upper Russian River Watershed has been facing a looming water supply and demand crisis exacerbated by changes in climatic conditions and infrastructure operations. This has led both the decision makers and water users to revisit their water management strategies and proactively look for robust solutions. We suggest a socio-hydrological analysis for the PVID, enabled by an integrated systems model that combines the simulation of the Russian River's natural and human-modified environment with the active involvement of human agents determining water allocation and use decisions. Our proposed research analysis will point to severe, potentially destabilizing, declines in the Russian River's freshwater security. Without proper intervening conservation plans, over 700 vineyards, domestic suppliers, farmers, and other entities with water rights for the Russian River will face a drastic decline in their water rights and substantially hit the economy of the watershed. To gain a holistic on its water future, the Russian River community must proactively seek to enact an ambitious portfolio of interventions.

5. References

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RUSSIAN RIVERKEEPER

April 8, 2021

Beshad Mohajer, PhD. Student
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Dear Mr. Mohajer,

I am writing today to express our interest to work collaboratively with you on your proposed research project focused on modeling interconnections of hydrology and human activities in the upper Russian River Watershed in California. Russian Riverkeeper and other watershed stakeholders are keenly interested in any insight into human activities and the relationship to water management and are happy to commit our time to support this project due to its high value to our community.

As you are aware this year we are facing the most severe water shortage in the upper Russian River in the last 100 years resulting in impacts to the environment and exposing inequities in the allocation and cost of water. Our shifting hydrologic trends and static water demands are increasingly out of synch as human activities have not shifted to respond to changes in our water balance. This has resulted in environmental harm, lower water supply reliability and growing inequities in our community.

The Earth Systems Science for the Anthropocene program core values are a great fit for our watershed community in Northern California. The focus on Justice Equity Diversity and Inclusion, use of multi-disciplinary approach and real-world solutions should lead to high value outcomes. Developing a paired social and hydrologic model will help us understand how to respond to shifts in our water balance by identifying how we can positively shift human activities.

I have spoken with our staff this week and they are all eager to support this project as needed and understand how valuable this will be to our watershed goals to achieve more sustainable water management.

We appreciate your work to secure funding for your project and are ready to support you and your project and look forward to working with you if you are successful.

Sincerely,

Don McEnhill
Executive Director

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