

Article

Socio-Hydrology: A New Understanding to Unite or a New Science to Divide?

Kaveh Madani ^{1,2,*}  and Majid Shafiee-Jood ³ 

¹ Department of Political Science and the MacMillan Center for International and Area Studies, Yale University, New Haven, CT 06511, USA

² Department of Physical Geography, Stockholm University, SE-106 91 Stockholm, Sweden

³ Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA; shafiee2@illinois.edu

* Correspondence: kaveh.madani@yale.edu; Tel.: +1-(203)-436-8913

Received: 3 June 2020; Accepted: 3 July 2020; Published: 8 July 2020



Abstract: The socio-hydrology community has been very successful in promoting the need for taking the human factor into account in the mainstream hydrology literature since 2012. However, the interest in studying and modeling human-water systems is not new and pre-existed the post-2012 socio-hydrology. So, it is critical to ask what socio-hydrology has been able to offer that would have been unachievable using the existing methods, tools, and analysis frameworks. Thus far, the socio-hydrology studies show a strong overlap with what has already been in the literature, especially in the water resources systems and coupled human and natural systems (CHANS) areas. Nevertheless, the work in these areas has been generally dismissed by the socio-hydrology literature. This paper overviews some of the general concerns about originality, practicality, and contributions of socio-hydrology. It is argued that while in theory, a common sense about the need for considering humans as an integral component of water resources systems models can strengthen our coupled human-water systems research, the current approaches and trends in socio-hydrology can make this interest area less inclusive and interdisciplinary.

Keywords: socio-hydrology; hydro-sociology; human-water systems; human-nature systems; water resources systems; social-ecological systems; CHANS; SES; socio-hydrologic modeling; integrated water resources management; IWRM; water resources management; hydrology

1. Introduction

The increasing interest in more explicit representation of human behavior and decisions in hydrologic models is undeniably a positive change that must be welcomed and promoted. The water resources community must appreciate the courage of those hydrologists who have been questioning the reliability and practical relevance of our sophisticated mathematical models in which the human dimension of water resource systems is overlooked. However, the interest in coupled human-water systems is certainly not new. For decades, people in natural/social science and engineering have been exploring human-water systems.

The need to push the envelope and expand the boundaries of our models has resulted in the emergence of interdisciplinary methods, interest areas, and even fields of study. The recent decade might be a turning point in the history of human-water systems studies as we have observed a tremendous increase in the interest of researchers and funding agencies in incorporating complexity and the human dimension into our water resources models.

In pursuit of their interest in better understanding human-water systems, Murugesu Sivapalan, Hubert Savenije, and Günter Blöschl “welcomed” their peers in “traditional hydrology” to “a new

science” called socio-hydrology in an invited commentary in 2012 [1]. Blaming “traditional hydrology” for ignoring the human factor for too long, the authors proposed socio-hydrology as “a new science that is aimed at understanding the dynamics and co-evolution of coupled human-water systems”. Demetris Koutsoyiannis [2], a reviewer of this invited commentary, who published his review comments online, criticized the authors for discounting the attention to the human factor in classical hydrology, downgrading the significance of Integrated Water Resources Management (IWRM), and dismissing the human-water systems analysis studies. Koutsoyiannis was not convinced that proposing a “new science” was necessary and found the authors’ claims “immodest”. The supposedly novel idea of socio-hydrology was also harshly criticized by Sivakumar [3], who believed that socio-hydrology was “not a new science, but a recycled and re-worded hydro-sociology” that had been originally proposed by Falkenmark [4] to study human-water interactions. Since 2012, similar critiques have been also expressed in different publications (e.g., [5]) and at informal and formal water gatherings (e.g., the annual meetings of World Environmental and Water Resources Congress) about the approach, novelty, claims, and contributions of socio-hydrology.

Despite the cold welcome, proposers of socio-hydrology have been certainly successful in creating a new space of interest and engaging an international group of researchers. To date, the invited commentary of Sivapalan et al. [1] has been cited more than 400 times (Web of Science (WoS); more than 600 times on Google Scholar). Although some of the significant critiques of socio-hydrology have not been directly addressed by its leaders and followers, so far, about 180 socio-hydrology papers have been published that have been cited nearly 4000 times in total according to the WoS (Figure 1). A considerable number of early career researchers have joined the community of researchers that identify themselves as socio-hydrologists. The socio-hydrologists have a working group with the Penta Rhei initiative of the International Association for Hydrological Science (IAHS), run summer schools and training workshops, publish special issues in different journals, and have been successful in receiving funding from major research agencies in Europe and North America for doing socio-hydrology research. The proposers of socio-hydrology have also received major international awards and recognitions for their “new science”.

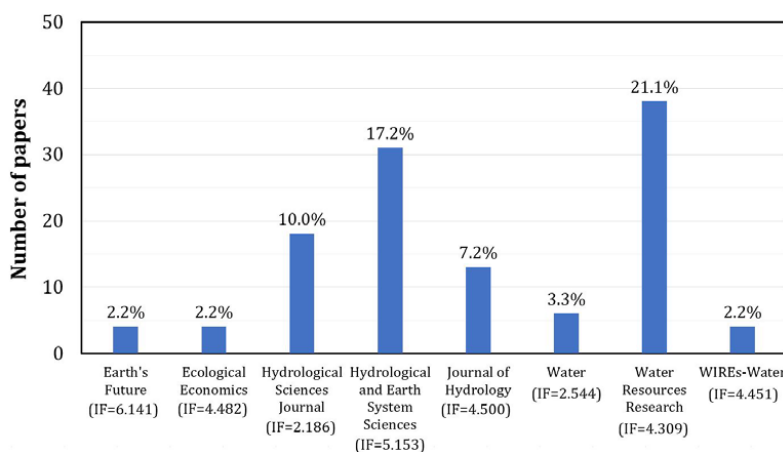


Figure 1. Number and percentage of socio-hydrology papers published in different journals. IF values show the impact factors of the journals in 2019 according to the Clarivate Analytics’ Journal Citation Report. Only journals that have published at least four papers are shown. In our literature search, we first searched for the keywords “socio-hydrology”, “socio-hydrology”, “socio hydrology”, “socio-hydrologic”, “socio hydrologic”, “socio-hydrologic”, “socio-hydrological”, “socio-hydrological”, and “socio hydrological” in the WoS database, resulting in 278 peer-reviewed journal papers. After reviewing these papers, we discarded those which did not focus on topics that are directly related to socio-hydrology. Our final database includes 180 papers, cited 3756 times overall based on WoS citation report, with 593 contributing authors.

As researchers who are interested in understanding and managing coupled, dynamic, complex human-water systems problems, we celebrate this growing interest in studying human-water systems problems. As colleagues, who have had the chance of interacting with socio-hydrologists in various meetings and discussions, we also acknowledge that the socio-hydrology community leaders have been effective in creating a useful momentum and an invaluable opportunity to expand the traditional research and education horizon in hydrology. Yet, as the outsiders of the group, who have been enthusiastically following their products, we struggle to comprehend what this “new science” is, what it is trying to do that is different from previous works in this space, how it is going to do it, and what it has accomplished to date.

Given the norms and cultures of our field, we have been hesitant to write this paper in anticipation of any misinterpretation or unintentional offense. Nevertheless, we feel that the ongoing development trends in socio-hydrology as well as dismissing the outstanding concerns and critiques of human-water systems experts can create a counterproductive divide between the relevant research communities, wasting valuable economic resources and human talents. Thus, we feel ethically and scientifically responsible to ask some questions about socio-hydrology at this stage of the coupled human-water systems field’s history when many young students and researchers are joining the socio-hydrology club in their pursuit of new methods, insights, and scientific inquiries.

Our intention is not to write a critique or start a debate. Instead, in this paper, we simply ask some questions that over the years have kept us wondering why socio-hydrology must be regarded as a “new science” or even a new field. As outsiders, some of our questions and comments are perhaps rooted in our ignorance and poor understanding of socio-hydrology. Nevertheless, we think that answering these questions in future socio-hydrology publications can address some of the main concerns of the many researchers who have been working or going to work on coupled human-water systems problems. We believe that the increasing interest in the human dimension of water resources problems has the potential to unite and strengthen our large, but currently fragmented communities, once we better understand each other, improve our communication skills, and sharpen our messages. So, we hope that our colleagues find these sincere concerns and questions constructive in shaping the future of socio-hydrology and training new generations of socio-hydrologists.

2. Socio-Hydrology: Originality, Practicality, and Contributions

2.1. Is Socio-Hydrology a New Science?

Socio-hydrology was introduced by its proposers as a “new science” and “a discovery-based fundamental science, whose practice is informed through observing, understanding, and predicting socio-hydrologic phenomena” [1]. The authors insisted that their proposed “interdisciplinary” science of people and water “must” strive to be quantitative “with ambition to make predictions of water cycle dynamics”. They compared socio-hydrology with eco-hydrology, arguing that eco-hydrology is similar to socio-hydrology in coupling water with another system, while the former studies “the co-evolution and self-organization of vegetation in the landscape in relation to water availability” and the latter would focus on “the co-evolution and self-organization of people in the landscape with respect to water availability”. In this comparison, however, they referred to eco-hydrology as a “field” and to socio-hydrology as a “science”.

Before getting into what socio-hydrology has achieved, let us focus on the ambitious claim of creating a “new science”. The socio-hydrology proposers’ argument that many hydrologists overlook the interdependence and interrelated dynamics of water and humans in their models is valid and reaffirms what many experts in the water resources field have been talking about for decades. But does the lack of attention to the human dimension by a group of hydrologists justify the need for creating a new science? If many hydrologists are missing a significant component in their models, do we need to revisit hydrology or create a new science?

Like any other field, the water resources field is full of limitations, and over time, we detect new restrictions and develop new interests, expectations, and questions. Accordingly, we revise our approaches, methods, models, and even buzzwords. The review of hyphenated hydrology by McCurley and Jawitz [6] is a good proof that our new questions can even form sub-disciplines and evolve our understanding and expectations from our disciplines. As a result, hydrology in the 21st century is very different from hydrology in the 12th century. If recognizing each new need justifies creating a new science, hydrologists must have created numerous branches of “science” by now.

The precedent of inventing a new science based on the recognition of existing limitations can be counterproductive and weaken the hydrology community by generating tendency and competition for creating new spaces (for example, the suggestions to create socio-meteorology, socio-climatology [7] and socio-hydrogeology [8] have been motivated by the suggestion to create the “new science” of socio-hydrology). Instead, our discipline and community must be open and prepared to evolve in response to our new needs. Even when the new need is felt, the process of proposing a new interest area, developing new research questions, and identifying a research gap must be scientific. How can we suggest a new science without scientifically proving that what we offer is different from what is available?

When proposing socio-hydrology, Sivapalan et al. [1] did not make any reference to: (1) hydro-sociology that had been around since the 1970's [3,6]; (2) coupled human-water systems studies by the system dynamics and water resources systems communities in the last five decades; (3) the popular coupled human-environment systems (also known as coupled human and natural systems (CHANS)) and socio-ecological system (SES) research areas; (4) the major human-water studies by social scientists and economists; as well as (5) other studies that had specifically referred to “socio-hydrology” earlier. For example, Smakhtin et al. [9] had suggested that considering riparian communities as an integral part of the riverine ecosystem could lead to new fields of work such as “socio-hydrology” or “socio-ecology”. Kock [10] had developed “agent-based models of socio-hydrological systems for exploring the institutional dynamics of water resources conflict”. He had based his “socio-hydrologic” approach on Mohorjy's [11] idea of integrating the hydrologic and socio-economic aspects of water resources planning and defined socio-hydrologic systems as systems in which “social, economic and hydrologic subsystems are causally linked”.

Overlooking the existing literature might have been the result of the authors' unfamiliarity with the human-water systems space. Yet, the trend has continued in later publications. Although the later publications of the socio-hydrology community have cited a very limited number of water-human systems studies, the past and ongoing human-water systems research has been largely dismissed by the socio-hydrology literature. Apparently, the peer review system has failed to provide constructive feedback to socio-hydrologists, refer them to the similar work done by others, ask for better explanation of why and how socio-hydrology is different, and remind the socio-hydrologists that what's new to them, might not be new in science, and if they insist that there is a need for a new science, this need must be justified through scientific evidence and gap analysis that is based on a comprehensive review of the existing literature.

Socio-hydrology can be a new interest area or sub-field or even a new field once it clarifies what it is searching for, can clearly communicate how it is different from the existing fields, and through a number of solid analyses, proves the practicality of its goals and the value of the insights it can offer. However, creating a “new science” based on simple inquiries in an invited commentary seems extremely ambitious and perhaps very unscientific!

2.2. What Is New about Socio-Hydrology?

A review of 180 socio-hydrology papers suggests that these papers have been mainly written by three networks (Figure 2), led by three hydrologists/civil (water/environmental) engineers, i.e., Sivapalan, Blöschl, and Di Baldassarre. While the proposers of socio-hydrology had insisted that socio-hydrology must be quantitative [1], a significant portion of socio-hydrology papers is

dedicated to opinion papers and commentaries that provide verbal and often ambitious discussions on why socio-hydrology is essential, what it is going offer, or what it must do without solid proof. Other non-quantitative papers include reviews of the socio-hydrology literature and their accomplishments. Most of these papers have been written by hydrologists with an occasional leadership or co-authorship of social scientists. Quantitative socio-hydrology papers have grown in number over the years and include system dynamics modeling and analyzing time-series and survey data.

As a quantitative science, socio-hydrology intended to make advancements in three areas [1]: (1) historical socio-hydrology: learning from the past; (2) comparative socio-hydrology: compare and contrast different human-water systems; and (3) process socio-hydrology: understanding existing human-water systems to “predict possible trajectories in the future”. So far, most of the socio-hydrology publications with quantitative elements that deal with real cases belong to the first two areas. In these studies, historical correlations and/or survey data are used to derive a hypothesis that can explain the past dynamics of the studied human-water systems. These studies are valuable but the different insights they offer by being branded as socio-hydrology studies remain unclear. In the reviews of their past work, socio-hydrologists (e.g., [12,13]) refer to their developed mathematical models for human-water systems as system dynamics models. Yet, their modeling papers do not make a proper connection to the water resources system dynamics literature. Higher mathematical sophistication does not necessarily provide additional insights. Nonetheless, given the interest of socio-hydrologists in quantitative science, one must note that most of the system dynamics models developed by the non-socio-hydrologists are mathematically much more sophisticated than the socio-hydrology system dynamics models. Assuming that the past studies have been ignored simply because of unfamiliarity with the human-water resources system dynamics literature, one still can ask: what has socio-hydrology added to these modeling studies that system dynamics could have not offered?

The same question applies to the papers written by social scientists (e.g., [14–16]) that do not have a strong hydrologic component but have some quantitative elements. In these studies, water has simply been the study domain for the social scientists. So, it is not clear what makes these socio-hydrology papers any different from the many studies of humans in water systems in the past. Even for developing her conceptual human-water system model, Leong [14] borrows the conceptual system dynamics model of Newell and Wasson [17], which preceded the 2012 socio-hydrology paper. What the science of socio-hydrology has added to these social science studies or what insight these studies have offered that could have not been gained by the existing methods that are not branded as socio-hydrologic tools remains unclear.

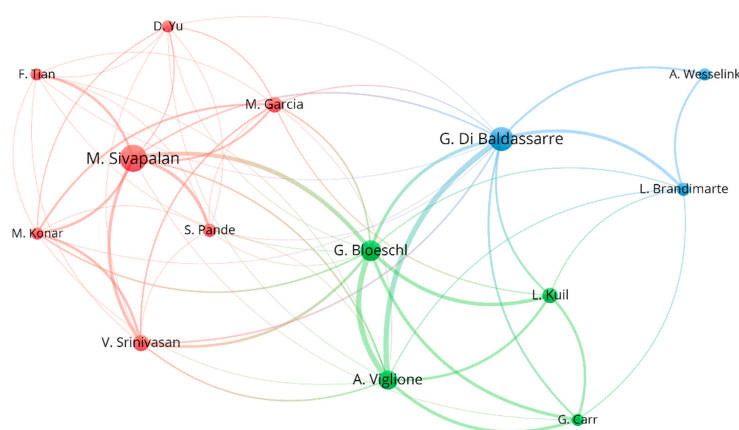


Figure 2. Co-authorship network based on the selected 180 papers. Only authors with at least 6 socio-hydrology papers are shown. Size of nodes corresponds to the number of papers written by an author. Thickness of a link between two authors corresponds to the number of papers they have co-authored. The network was plotted with VOSviewer [18,19] using bibliographic records extracted from WoS.

The idea of studying the evolution of complex, coupled human-water systems is not new. Over the last two decades, many scholars have used system dynamics as a framework to study and explain the evolution of coupled human-water systems, causal relationships, non-linear feedbacks, paradoxical behavior, counter-intuitive dynamics, and the unintended consequences of structural or non-structural interventions (e.g., see the review by Mirchi et al. [20]). The idea of internalizing the human component (not treating it as an exogenous element), suggested by Sivapalan et al. [1] is not new either. Before their paper, many people had developed coupled human-water system dynamics models for explaining the underlying mechanisms of these systems and making future projections to guide policy (e.g., [21–38]).

The idea of predicting the future through socio-hydrology as was originally suggested by Sivapalan et al. [1] seems to be in contrast to the socio-hydrologists' claim that socio-hydrology is not interested in scenario-based approaches as well as their expressed interest in advising policy. Complex human-water systems have some essential characteristics, including uncertainty, bounded rationality, indeterminate causality, limited predictability, evolutionary change, and non-stationarity [39]. So, predicting or forecasting the long-term evolution of coupled human-water systems is impossible. Nevertheless, projecting the future of systems involving human and nature is a common approach (note the difference between *prediction* and *projection* [40]). Any projection of the future evolution of human-nature systems, involves scenarios or if-then statements. Even when different scenarios are not evaluated, the inherent assumption is that business-as-usual is the underlying scenario. In addition, the essential characteristics of these systems are what cause surprises, unintended consequences, and “black swan events” [41]. Expanding the boundaries of our models can help us better capture feedbacks and detect undesirable patterns, especially when studying the past. Nonetheless, the future evolution of human-water systems will involve many surprises, unintended consequences, and black swans that cannot be detected and avoided with the help of socio-hydrology.

In response to the critiques on the capacity of socio-hydrology to predict social behavior and politics (e.g., [42]), socio-hydrologists claimed that “predictions in socio-hydrology do not aim at predicting time series” [43]. Instead, they aim at predicting phenomena emerging in human-water systems “in a quantitative and generalizable way”. This could be in contrast with the earlier emphasis on branding socio-hydrology as a “quantitative” science.

In Srinivasan et al. [44], the socio-hydrologists criticize the existing “prediction” paradigms and call for a “fundamental change” in our understanding of “prediction”. In this opinion paper, the authors “argued” that socio-hydrology can replace the traditional “predictions” that are “mere sets of scenarios that present snapshots of the world at some future date” with “projection of alternative, plausible and co-evolving trajectories of the socio-hydrological system” that can provide insights into causal relationships and help identify a desirable operating space. This authors' argument and suggestion, in this case, are not new either. As proof, let us look at a relevant section of an example paper in the coupled human-water systems literature in 2009 that has used system dynamics as the analysis framework [24]:

“System dynamics which provides a unique framework for integrating the disparate physical and social systems important to water resource management is formulated on the premise that the structure of a system, the network of cause and effect relations between system elements, governs the overall system's behavior. [45]

The systems approach is a discipline for seeing the structures that underlie complex domains. System dynamics is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots, and for seeing processes rather than objects [21]. The major concept of the system dynamics simulation approach is feedback which is used as the basis for structuring description of complex systems and their economic, social, political, and environmental implications. [46]

The typical purpose of a system dynamics study is to realize how and why the dynamics of concern are generated and to look for managerial policies that can improve the situation”. [47]

In another section of the paper, the authors write that:

“In system dynamics studies the emphasis is on understanding trends and behaviors rather than values and numbers”.

This suggests that neither the idea of coupled human-water systems modeling, nor the idea of projecting trends and behavior rather than snapshot prediction is novel. They existed in the water resources systems literature before the 2012 proposal of socio-hydrology. So, it is justified to ask what different questions socio-hydrology is asking, what alternative study approaches it is proposing, and why the vast literature on this subject was dismissed before proposing a “new science” in 2012 [1] or calling for a “fundamental change” in 2017 [44].

The desire to develop generic models of human-water systems to “predict” future patterns has shaped some of the endeavors in socio-hydrology in which the researchers have tried to identify and introduce what they refer to as “classes of emergent phenomena” [13]. These “phenomena” have been defined as “actual outcomes, paradoxical dynamics, or unintended consequences that arise from water management” in the analyzed human-water systems. While the effort is valuable, one might wonder why the socio-hydrologists have dismissed the efforts of other water resource researchers in studying, developing, and explaining generic structures, causal dynamics, and evolution, and even projecting and explaining the evolving structures of human-water systems based on real-world systems or hypothetical examples using methods such as system dynamics and game theory (e.g., [39,48–60]).

Many, if not all, of the syndromes, prototypes, phenomena, or sub-phenomena that the socio-hydrologists have proposed, detected, modeled, or expressed interest in, are already in the literature under similar or other names. For example, the safe development/government paradox [61–63], “levee effect” and “reservoir effect” [13], all result from the “shifting the burden” archetype in complex systems [51,64] (Figure 3). This archetype explains the unintended consequence of rectifying the obvious problem symptoms by simple solutions (e.g., raising a levee or building a reservoir) while overlooking the primary causes with the potential of causing addiction to the symptomatic remedies as the problem worsens (raising levees further or building more reservoirs).

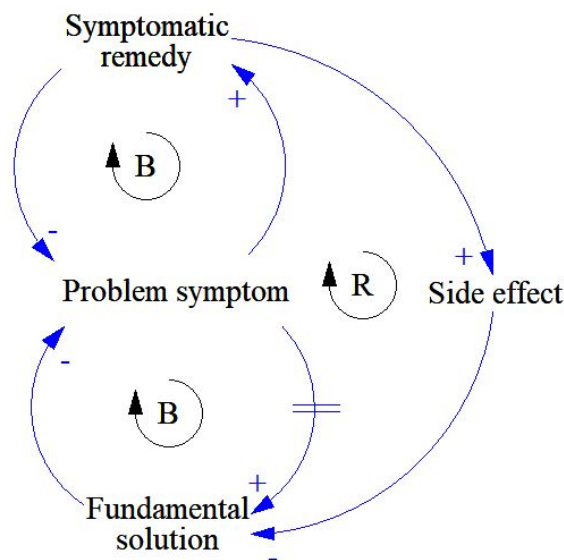


Figure 3. The Causal Loop Diagram (CLD) of the “shifting the burden” systems archetype. In this particular setting, addressing the problem symptom using a quick fix rather than a fundamental measure will cause increasing dependence on symptomatic fixes. “B” refers to a balancing loop and R refers to a reinforcing loop. Double bars reflect lag time.

Rebound effect (Jevons’ paradox [65]), vicious supply-demand cycles [66], and irrigation efficiency paradox [67,68], are all produced by the “fix that backfires” archetype in complex systems [20,51,56,64,69]

(Figure 4). This archetype explains how quick-fix and short-sighted solutions (increasing irrigation efficiency, inventing a stronger pump, building a desalination plant or water supply reservoir, digging or deepening wells, and inter-basin water transfer) that cure the problem symptoms (e.g., water shortage) can worsen the situation in the long-run through unintended/side effects (e.g., increased water consumption or demand).

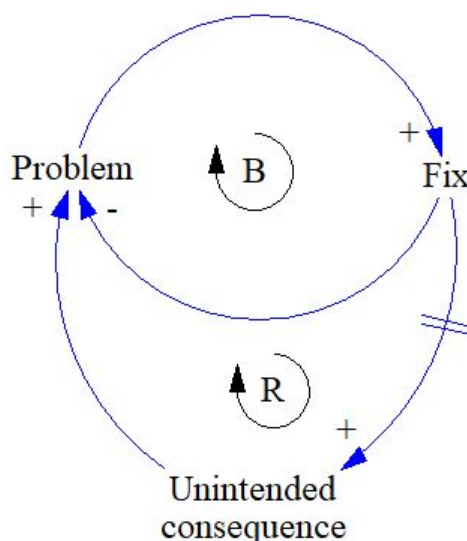


Figure 4. The Causal Loop Diagram (CLD) of the “fixes that fail” or “fixes that backfire” system archetype. In this particular setting, the implemented fix alleviates the problem in the short-run but results in unintended consequences in the long-run that can make the situation worse and necessitate additional fixes. “B” refers to a balancing loop and R refers to a reinforcing loop. Double bars reflect lag time.

Reintroducing what exists in the literature without referring to it is not supposed to be a scientific contribution. Finding that overall water consumption/demand can increase as the result of increasing water supply might be new to some hydrologists, who are used to modeling water demand as an exogenous variable, but this finding is definitely not new in the water resources literature.

A range of other concepts that have been mentioned or used in the socio-hydrology like risk attitude, loss aversion, memory, trust, heuristics and cognitive biases to model and explain trends in human-water systems are not new to the water resources literature either and have been used by people in water resources systems, economics, and social sciences in the past (e.g., [70–82]). Concepts such as path dependency, adaptation pathways, and facilitated stakeholder participation that were discussed in Srinivasan et al. [44] are also among the well-known concepts in the water resources systems literature (e.g., [83–92]).

By comparing the selected 180 socio-hydrology papers to what has been already in the scientific literature, it is hard to find what new insights and approaches have been offered by the “new science” of socio-hydrology. Seidl and Barthel’s [5] concerns about socio-hydrology’s lack of protocols for interdisciplinary research and failure to acknowledge “much previous work on integrated models undertaken by hydrologists and social scientists” in addition to comments of other scholars on the dismissed works in the water-human systems space remain outstanding.

We emphasize that many of the publications that have identified themselves as socio-hydrologic research are significant and provide very useful insights. The scientific findings and suggestions of papers such as [14,15,93–109] are significant and potentially helpful for policymaking. Though, given that their questions, methods of study, and analysis frameworks are similar to what already existed in the literature, it is not clear why it was necessary to identify them as socio-hydrologic research. It is important to note that while socio-hydrology as a “science” might not have methodologically helped the research of these authors in a unique way, their work in this space might have been inspired

by the activities of the socio-hydrology community. Indeed, the socio-hydrology community has effectively increased the number of hydrologists who care about the human dimension in their research, especially in the case of early career scientists. This is a positive development and must be appreciated.

2.3. *Where Are the Boundaries of Socio-Hydrology?*

The proposers of socio-hydrology have had the ambition of proposing a science that is unique and can do novel things. Though, it seems that over time, perhaps after receiving feedback from their peers and becoming familiar with part of the existing human-water systems literature, their expectations and goals have evolved. For example, projecting qualitative behavior is now being promoted while admitting that modeling behavior is not a trivial task [43]. In 2012, however, the goal was to use quantitative science to predict the evolution of human-water systems. This change in communicating the objectives and expectations is, of course, a good sign, and in agreement with what many water resources scholars have said in the past, i.e., trends, patterns, governing problem structures, and pathways to get to the ideal space generally matter more than numbers and snapshots in complex human-water systems studies. Yet, the coordinates of socio-hydrology in the scientific space remain hard to map as they seem to have been defined by the socio-hydrology leaders in reference to imaginary or perceived limits and capacities of other fields or interest areas.

In their original paper, Sivapalan et al. [1], refer to integrated water resources management (IWRM) as a “science”. They subsequently define the socio-hydrology’s point of departure from IWRM by arguing that IWRM is “unrealistic, especially for long-term predictions, as it does not account for the dynamics of the interactions between water and people”. The authors introduce IWRM as a method which “often uses scenario-based approaches” to explore the human-water interactions. They end up promoting socio-hydrology as a “fundamental science” that can underpin IWRM. But, how accurate are these statements?

The “new science” of socio-hydrology was given an identity by being compared with the “science of IWRM” while IWRM is not a science! IWRM is simply an ambitious “process” (not product) and a recommended cross-sectoral policy-making approach [110] for holistic management of water instead of fragmented and sectoral water management. Similar to other ambitious targets and processes that are set through international negotiations by high-level politicians (e.g., Agenda 21, Sustainable Development Goals (SDGs), and Paris Agreement) IWRM has not fully implemented for many practical reasons [111–114]. The understanding of policymakers, researchers, stakeholders, and the general public of the IWRM concept has been evolving and will continue to evolve as we detect more problems and face new practical challenges. Just like sustainability, IWRM is a moving and unachievable, but useful target that we chase [115]. Enforcing IWRM principles requires insights from natural/social scientists, engineers, stakeholders, policymakers, practitioners, and the general public. Socio-hydrologists can also provide useful insights but socio-hydrology on its own will not make IWRM practical.

Ceola et al. [43] recognize the need for a systems approach to study human-water systems. Nevertheless, socio-hydrologists seem to stay reluctant to acknowledge the contributions of the water resources systems community in the coupled human-water systems study space as discussed earlier. Instead, they try to draw an arbitrary line between socio-hydrology and water resources systems. Di Baldassarre et al. [13] claim that water resources systems is focused on “optimization” with the goal of combining “hydrology and economics” to “design and operate optimal infrastructure projects”. The authors put socio-hydrology in contrast with their understanding of water resources systems and state that unlike water resources systems, socio-hydrology is focused on “understanding why certain water management outcomes arise rather than proposing actual management solutions”.

Classification of water resources systems as a normative approach that is only limited to optimization and combines hydrology and economics must be due to unfamiliarity of the socio-hydrologists as well as the reviewers of their papers with the water resources systems research space. Water resources systems analysis involves normative and positive

approaches, develops simulation and optimization models, and uses quantitative and qualitative approaches [116–119]. Water resources systems studies do not always have economics as a component (e.g., [85,120–136]) and are not always focused on designing and running water infrastructure (e.g., [31,82,130,137–148]). Additionally, the water resources systems studies do not always limit themselves to proposing solutions as Di Baldassarre et al. [13] argue. There are many studies in the water resources systems literature that look at “why” certain behavior or evolution path has emerged or might emerge in coupled human-water systems (e.g., [49,52,53,57,59,76,145,149–158]).

Di Baldassarre et al. [13] also distinguish socio-hydrology from CHANS and complex systems science by stating that the former has an explicit focus on water and the hydrologic cycle. If this is the case, one might wonder if socio-hydrology is just a sub-area of CHANS. If so, it is not clear why the existence of CHANS was never recognized by the original proposers of socio-hydrology. What can socio-hydrology offer that CHANS cannot? In an era of increasing interest in the nexus of water with food, energy, environment, etc. what does justify limiting the dynamics of the natural systems to water and the hydrologic cycle?

We certainly know that the natural systems around us are not limited to water and we, as humans, do not only interact with the hydrologic system [159]. So, limiting the scope of the natural component of the “new science” to the hydrologic cycle and not acknowledging that socio-hydrology is a limited subset of CHANS needs a strong justification if the socio-hydrology community insists on keeping the boundaries of socio-hydrology as stated in Di Baldassarre et al. [13]. Even CHANS, with a much larger scope and age, does not recognize itself as a science. Hence, referring to socio-hydrology with a much smaller focus than CHANS as a “new science” might not be fair. The ideas that socio-hydrology is promoting are not new in the CHANS literature either and existed before 2012. As a proof, let us have a look at an abstract of a 2007 review paper in the CHANS literature [160] that suggests that the socio-hydrologists’ idea of coupling social and natural systems to reveal complex patterns and new insights into nonlinear dynamics with thresholds, reciprocal feedback loops, time delays, surprises, etc. are not novel:

“Integrated studies of coupled human and natural systems reveal new and complex patterns and processes not evident when studied by social or natural scientists separately. Synthesis of six case studies from around the world shows that couplings between human and natural systems vary across space, time, and organizational units. They also exhibit nonlinear dynamics with thresholds, reciprocal feedback loops, time lags, resilience, heterogeneity, and surprises. Furthermore, past couplings have legacy effects on present conditions and future possibilities”.

While the socio-hydrologists have tried to claim a new territory, the available evidence so far does not suggest that their approach, inquiries, and goals are unique and different. Consequently, mapping the boundaries of the socio-hydrology “science” and finding its overlaps with and points of departure from the existing fields, disciplines and interest areas are nearly impossible.

2.4. Is Socio-Hydrology Practical?

Based on what was discussed so far, there is no strong evidence that socio-hydrology has been successful as a “discovery-based fundamental science” in accommodating the “dynamics we never had to deal with” as claimed by Sivapalan et al. [1]. Deriving causal relationships based on statistical correlations is not necessarily novel and has its own limitations [161]. Improving the mathematical sophistication of socio-hydrology models might help capture some significant dynamics in both human and water components that are currently missing from socio-hydrologic analyses [161]. Improving the behavior resolution of the socio-hydrologic models through replacing differential equations with game theory and agent-based models to better capture the heterogeneity across humans and their interactions networks with careful consideration trade-offs of disaggregation [162] is another possible area of improvement in socio-hydrology. Yet, the unique role of socio-hydrology in providing insights into water-human systems problems remains unclear. Some of the socio-hydrologic modeling papers cited

in Section 2.2 have relatively sophisticated mathematical components. However, the developed systems models are comparable to the models that had existed in the water resources systems, water resources economics, and the CHANS literature. So, it is not quite clear how these studies have benefitted from socio-hydrology.

Developing models and generic mechanisms to replicate the historical observations is possible with proxy variables (e.g., memory, culture, emotion, trust, satisfaction, and utility). Nevertheless, extrapolation with the models that replicate historical trends in complex systems has major caveats. Such models and mechanisms are mostly incapable of predicting the future evolution of human-water systems which are associated with uncertainty, bounded rationality, indeterminate causality, limited predictability, evolutionary change, and non-stationarity. What has happened in the past in complex human-nature systems will not necessarily repeat in the future. So even if socio-hydrology is only interested in future trajectories and trends, its ability to project the future is very limited.

Given that water is only one, and from the policy-making standpoint often a small, component of complex human-nature systems [159], limiting the study boundaries to water can create additional sources of unreliability for socio-hydrology models in future projections. When the other components of natural systems are not included in the model but exist in reality, the modeler must inevitably rely on exogenous variables or scenarios. Nonetheless, models that exclude other natural resource components cannot make reliable projections about the future patterns and evolutions, increasing our inability to detect unintended consequences and the actual interrelated dynamics of the human-nature systems around us. To address this issue, other components of the natural systems can be added to human-water systems models. But in that case, CHANS becomes the analysis domain and socio-hydrology gets redundant.

Fully internalizing the exogenous human and water components is also impractical, even when the goal is modeling the past events and evolutions. For example, modeling the Syrian conflict solely based on the interactions of water and people (only endogenous variables) might suggest that the Syrian crisis was caused by a drought, which is a misleading conclusion. While drought has certainly been effective as a trigger or catalyst of the crisis, one must not overlook major variables such as the Syrian politics, ideological conflicts, political economy, foreign interventions, and the accumulation of problems in multiple sectors over the years as the result of bad governance, poor economy, unemployment, etc. Developing a reliable socio-hydrologic model that can meaningfully replicate the Syrian crisis is either impossible or requires considering a significant number exogenous socio-economic and climatic variables, making the idea of internalizing all exogenous variables impractical.

Socio-hydrologists have shown a strong desire in advising policy [13,43] but no interest in scenario analysis and “proposing management solutions”. They have also indicated that their projections of the future will not include time-series [43]. At the end of the day, policymakers are in desperate need of solutions and need to make decisions based on scenarios in uncertain environments. Also, in most cases, they require quantitative data, especially if they are operating in the water sector. All decision analysis studies and future projections inherently include exogenous variables as internalizing all exogenous variables is just impossible. No matter how complex, the modeler must choose some arbitrary boundaries for the complex systems models and make some variables exogenous. So, it is not clear how much socio-hydrologists can support the decision-making process if they are not interested in scenario-analysis, do not like to propose solutions, and insist on avoiding exogenous variables. Nevertheless, if they like using scenarios to project the future trajectories and “stress test” the human-water systems as suggested by Srinivasan et al. [44], their literature must avoid actively implying that exogenous scenario-analysis is an improper practice that is popular among the non-socio-hydrologists.

So far, the socio-hydrology literature has set a lot of ambitious targets. Yet, there is little evidence that what socio-hydrology has offered is original. Without a clear understanding of the boundaries of socio-hydrology and its unique analysis methods/tools, judging about the practicality of the declared

goals is not easy. Nevertheless, socio-hydrology seems to be more practical in studying the past rather than predicting the future, unless it evolves its targets and waives some of the unnecessary restrictions it has imposed on itself such as remaining a quantitative, advising policymakers without proposing solutions, avoiding scenarios or exogenous variables, and not going beyond water systems and hydrologic cycles.

2.5. Is Socio-Hydrology Converging to Water Resources Systems or Coupled Human and Natural Systems?

Assuming that the socio-hydrologists have been fully unaware of the existing literature, one can conclude that their efforts have resulted in reproducing and recognizing what existed. Unless clear new paths are defined and alternative methods and approaches are developed by them in the near future, the convergence of socio-hydrology to the existing domains such as water resources systems and coupled human-environment systems might be inevitable.

The socio-hydrology literature includes numerous papers that focus on what must be ideally done. Speaking of what is missing in hydrology and what needs to be done is good but we often get too busy talking about our ideals that “we forget that we also need means and realistic pathways to the end goal” [163]. To reach their targets, the socio-hydrologists have recognized the need for a systems approach [43] and have developed mathematical methods using this approach. Nevertheless, the tools offered by the quantitative socio-hydrology literature already exist in the water resources systems and CHANS literature. The insights gained by the socio-hydrologists through different exercises were already available in the literature (as discussed above) or/and could have been achieved for the case studies of interest using the methods that existed in the water resources systems and CHANS literature.

Some of the papers that have been written and branded as socio-hydrology papers could have also been published without making a reference to socio-hydrology. An example of this case is Ishtiaque et al. [164]. This paper which focuses on flood management in coastal Bangladesh and has been published in the *Ecology and Society* journal (one of the reputable journals in CHANS/SES) shares two authors with Yu et al. [95] and Sung et al. [98] which have been published in the special issue of “Socio-hydrology: Spatial and Temporal Dynamics of Coupled Human-Water Systems” in *Water Resources Research* with 32 publications. The Ishtiaque et al.’s paper identifies itself as an SES study and although it uses socio-hydrology as a keyword, it does not use this term even once in the whole paper. Two alternative conclusions can be made here. First, that the SES and CHANS study frameworks are more comprehensive and mature than socio-hydrology frameworks. So, making a reference to socio-hydrology or limiting the scope of the work to socio-hydrology was unnecessary. Second, although flood management was at the center of the studied case, limiting the natural system to water would have made the analysis unreliable and the authors had to use the SES study frameworks to be able to include other natural components in their SES problem. Both of these conclusions undermine the value of socio-hydrology when compared with CHANS.

It is noteworthy that just like hydrology or any other field, the water resources systems field has evolved over the last seven decades [117,118,165–170]. The increasing understanding of the limitations of the past models, improved computational power, and data availability, as well as the recognition of the real-world complexities have forced the water resources systems community to revisit and broaden their scope and improve their modeling approaches. Among such improvements, one must note the increasing interest in better representation of humans and stakeholders’ opinion in the models using complex systems theories, system dynamics modeling, game theory, multi-criteria assessment, agent-based modeling, and different methods of human behavior analysis in social sciences, operations research, and economics. Indeed, the water resources systems community has also shown interest in and has been working for some time on coupled human-water systems as evidenced by the many references cited earlier. So, it is natural for socio-hydrology and water resources systems to converge under the umbrella of coupled human-water systems.

Over time, the water resources systems modelers have also broadened the scope of their models beyond water systems and added other components such as food, energy, climate,

and ecology (e.g., [144,171–182]). So, their research is organically transitioning into the CHANS space. Socio-hydrology will fail in understanding and explaining human-water systems if it limits its scope to the hydrologic cycle. Getting into food, energy, and natural systems is inevitable for the socio-hydrologists, in an increasingly complex world, especially if they want to help decision makers solve and navigate through contemporary problems involving humans and water. Expanding the boundaries of the natural side of socio-hydrology beyond water implies converging into CHANS as it has occurred in the case of water resources systems analysis.

2.6. Is Socio-Hydrology Reinventing the Wheel?

Sivakumar [3] labeled socio-hydrology as a “recycled and re-worded hydro-sociology”. McCurley and Jawitz [6] also argued that socio-hydrology was prominent at the beginning of “modern hydrology” (1989) but later decayed and remerged. McCurley and Jawitz believed that the studies of coevolution of water and humans are not novel and existed for decades but the interest in socio-hydrology has considerably increased in the last decade.

Dismissing the existing literature by the socio-hydrologists has led to the reintroduction of existing concepts under new terms, sometimes as new discoveries and socio-hydrology-specific jargons. As explained in Section 2.2, for example, a concept such as “shifting the burden” (Figure 3) already exists in the system dynamics, complex systems, and water resources literature that can explain the generic structure and evolution of coupled human-water systems with certain characteristics. This general structure can illustrate the unintended consequences of implementing certain policy or engineering solutions (e.g., building a reservoir or raising a levee) in a certain setting. While the general structure is the same, the components of the problem can change (e.g., from a levee to a reservoir) without an impact on the overall behavior of the coupled systems. So, it is unclear why new jargons such as “levee effect”, “reservoir effect”, etc. must be developed and promoted. In the same setting (Figure 3), implementing a certain intervention such as offering an insurance policy, providing water subsidies, granting loans or cheap farmlands, inter-basin water transfers, digging deeper wells, and building a desalination plant can have the same impact. Is socio-hydrology going to develop new jargons like “insurance effect”, “subsidies effect”, “loan effect”, “cheap land effect”, “water transfer effect”, etc., for each specific example?

These terms can encourage attention to a specific component of the water system (e.g., levee and reservoir) rather than the generic structure of the coupled human-water system. This is in contrast with the declared interest in identifying generalizable human-water systems evolution patterns, something that has been also done by other researchers in the past (see Section 2.2). Inventing new terms and concepts that already exist under different names makes communication with researchers of other fields harder. This is not an effective strategy for marriage between disciplines. As an example, economists, social/natural scientists, engineers, and water resources systems scholars have frequently used the famous prisoner’s dilemma setting (game structure) to explain the tragedy of the commons. A shared aquifer is perhaps the most popular example in the water resources literature to explain the tragedy of commons. Rather than creating a new game (e.g., “farmers’ dilemma”), prisoner’s dilemma has been used in the water resources literature to explain this setting that has a specific dominant structure (see [53,54], for example). The strategy, in this case, has been to use groundwater sharing as an accessible example for the water resources community to seek attention to the institutional setting which drives a certain trajectory in evolution of the coupled human-water system, rather than giving an unnecessary weight to the type of water resources component (i.e., groundwater). Once the structure is introduced, people can be directed to similar settings in which groundwater is replaced with a shared wetland [59], an irrigation system [52,183], a water transfer system [57,184], a trans-boundary river [185], a water quality control system [186], or the atmosphere [187–189] while the general insights and trends will remain unchanged. This approach could facilitate communication with people in other disciplines which might not be familiar with specific water resources settings, our disciplinary jargons, or the hydrologic cycle but understand prisoner’s dilemma.

Similarly, socio-hydrology can benefit from using the well-known generic structures in complex systems to explain trajectories in water-human systems problems without a need to invent new terms and concepts. Levees, reservoirs, irrigation efficiency, etc. can be used as examples in our classrooms and conferences to make the complex systems concepts more accessible for the people in hydrology without compromising the capacity of socio-hydrologists to communicate with people in other disciplines, if developing an interdisciplinary domain is a goal. Socio-hydrologists are encouraged to take Seidl and Barthel's [5] feedback on their approach to interdisciplinarity more seriously:

"Socio-hydrology is still dominated by hydrologists, who have adopted a perceived hegemonic attitude toward inter-disciplinary collaboration".

The socio-hydrology community is dominated by hydrologists. If the socio-hydrology's objective is to break the existing boundaries through a systems approach that leads to a holistic understanding of complex human-water systems, hydrologists must be open to actively learning from and working with other disciplines and do not need to pull every exciting concept toward their own domain. Rephrasing the concepts from other fields might not be the most constructive step toward scientific interdisciplinarity.

The socio-hydrology literature has shown a strong tendency to borrow fashionable phrases and exciting concepts from other fields (e.g., co-evolution, tipping points, self-organization, Anthropocene, black swan, ludic fallacy, unintended consequences). Using "popular terms and fashionable phraseology" socio-hydrology [2] and the fame of the socio-hydrology proposers have made the socio-hydrology papers highly cited and popular. Invention of socio-hydrology has also sparked the idea of developing socio-hydrogeology, socio-climatology, socio-meteorology. Yet, the popularity of socio-hydrology has mainly emerged in networks that are less familiar with the water resources systems and CHANS literature. Socio-hydrology remains to be dominated by hydrologists who are less "traditional" than the mainstream hydrologists but more "traditional" than the water experts who have been working in the human-water systems space for decades. We noted many papers in the literature that use socio-hydrology as a keyword or in their title but do not make a proper connection to socio-hydrology "concepts" or literature throughout their articles. Seidl and Barthel [5] also noted that 26% of the socio-hydrology papers they reviewed mention the term socio-hydrology in their title, abstracts, and keywords but "do not refer to the concept of socio-hydrology presented by Sivapalan et al. [1]". Seidl and Barthel expressed their "surprise", claiming that when they contacted the authors of several of those papers, they confirmed that they were not aware of the socio-hydrology concepts.

While the desire for adopting fashionable concepts from other disciplines is high among the socio-hydrologists, the inappropriate use of such concepts significantly hurt the scientific rigor of some socio-hydrology publications. The interest of the original proposers of socio-hydrology [1] in predicting black swan events (also questioned by Koutsoyiannis [2] in his review report), reflects their misunderstanding of the black swan theory [41] which asserts that black swans might be predictable retrospectively, not prospectively. As another example, Di Baldassarre et al. [104] explained the known mechanism of increase in water demand as the result of increasing water supply (e.g., [24,35,38,69]) as the Jevons' paradox (rebound effect). However, Jevons' paradox in economics is about the increased efficiency in use of a resource (an intervention on the demand side), not an intervention on the supply side. In other words, the total resource volume remains constant and the rebound is caused due to increase in the rate of resource consumption. But, in the featured examples of Di Baldassarre et al. [104], changes in the supply side, i.e., increasing the volume of resource (through building a new reservoir) had led to an increase in demand (by enabling "agricultural, industrial or urban expansion") that ended up offsetting the increase in supply. In their examples, the intervention is on the supply side (reservoirs) as opposed to the Jevons' paradox which involves an intervention on the demand side (e.g., increasing resource use efficiency through technology advancements). While the governing structure of the two problems and the overall behavior in the variables of interest (e.g., supply-demand gap) might be the same, the interventions that cause this behavior can be different. That is why using generic

coupled human-water systems archetypes for this type of problems has been proposed [20,51,56]. The “fixes that fail” archetype (Figure 4) can explain the behaviors of both problems (Jevons’ paradox and viscous supply-demand cycles) as discussed earlier (see Section 2.2).

Borrowing concepts and terms from other disciplines can be illuminating and valuable as long as they are used correctly and are not rephrased unnecessarily. Relabeling and rewording the syntaxes and terminologies of other fields might create short-term popularity. Though, in the long run, it can increase our distance from scholars in other fields rather than breaking the boundaries and barriers to facilitate interdisciplinary and trans-disciplinary interactions. We already have too many terminologies in different disciplines that are worded differently but mean the same thing.

3. Efficiency of Our Peer-Review Systems

We raised some concerns about the claims that have been made by socio-hydrology literature. These concerns are about the general interest area of socio-hydrology and not specific to certain publications. Some of these concerns are not new but have remained unaddressed since the day the “new science” was proposed in 2012 [1]. The socio-hydrology community could have avoided most of these concerns through essential scientific efforts on a proactive basis (e.g., by a comprehensive review of the existing literature). However, these basic concerns could have also been addressed reactively and in response to peer review comments. If we attribute the systematic overlooking of the water resources systems, system dynamics, and CHANS research in the socio-hydrology publications to the unfamiliarity of socio-hydrologists with the existing literature, then we must be seriously concerned about the major flaws and deficiencies of our peer review system. Evidently, the peer review system has systematically failed in providing constructive feedback to our colleagues in socio-hydrology.

As discussed in Section 1, the questions asked in this paper are not supposed to undermine socio-hydrology. We consider the increasing interest in socio-hydrology as a positive development, whilst remaining surprised that these issues have not been raised in the peer review of 180 socio-hydrology publications by some of the best water resources journals that are supposed to have a fundamental role in setting the science agenda and recognizing the value of novel insights [190]. This calls for revisiting our peer review system and asking how an effective review system can be set up when a “new science” is proposed. Who is qualified to review papers that belong to a “new” space? How must we set up a reliable review system that promotes innovation and interdisciplinarity but does not compromise our scientific research procedures and standards?

Another issue that has contributed to the existing deficiencies in the socio-hydrology literature is our culture in academia. We do not want to challenge, shame, and disrespect our colleagues. So, we have strong reservations about putting our thoughts, comments, and feedback in writing in fear of offending our colleagues. When our colleagues are more senior and famous, our concerns grow further. The two of us also had serious reservations about writing this article. However, this culture must change. We have to be more helpful to each other and not be afraid of providing constructive feedback to our colleagues if we care about them and really believe in the power of science and interdisciplinary approaches. The concerns we listed here are not new and we have heard our colleagues talking about them for years but did not share them formally. When our formal peer review systems fail, we have a stronger responsibility to protect the integrity of science and help our colleagues flourish and succeed.

While the flaws of our peer review system require great attention, we should not forget that as academics, we still have an ethical responsibility to ensure that to the best of our knowledge what we propose as a “new” contribution does not already exist. It is very hard to imagine that the socio-hydrology community has remained unaware of the ongoing and past research in other areas such as system dynamics with a strong overlap with their work, especially when they refer to their early products as system dynamics models, use CLDs, and frequently use the popular terms such as unintended consequences, complexity, feedbacks, evolution, etc.

4. Conclusions and Final Remarks

Undoubtedly, the seminal paper of Sivapalan et al. [1] and their subsequent leadership has created an increasing interest in social systems in the hydrologic science community. The socio-hydrologists' success is evidenced by the number of published socio-hydrology papers since 2012, as well as the number of researchers who identify themselves as socio-hydrologists or use the socio-hydrology term in their publications. Yet, socio-hydrology seems to have become mostly popular among the mainstream hydrologists with limited familiarity with the past work in the human-water systems space, not to those who have worked in this space for decades. The socio-hydrologists' interest in holistic understanding of human-water systems, which necessitates systems approaches, together with their desire to advise policy creates a natural overlap between socio-hydrology and research in water resources systems, SES and CHANS areas. Nevertheless, socio-hydrologists insist that their work is different from the works of other groups without providing sufficient scientific evidence.

Socio-hydrology was originally proposed as a “new science” but so far it has not been more than an interest area or a sub-field of hydrology. While the socio-hydrology literature shows a great tendency to borrow fashionable syntaxes and popular concepts from the literature of other fields, socio-hydrologists have systematically overlooked the past and ongoing work in the coupled human-water systems space and this has led to reproduction of some existing concepts under new names.

Some concerns about the practicality of socio-hydrology goals, the types of unique tools/methods it uses, the new questions it asks, and its boundaries and points of departure from existing domains have been around and remained unaddressed since 2012. Thus, it is not clear to us why socio-hydrology insists on creating arbitrary boundaries with water resources systems and CHANS. The overviewed deficiencies in the socio-hydrology literature reflect the existing shortfalls of our peer review system that require serious attention, especially in the era of increasing interest in developing new interdisciplinary fields in response to our research needs.

Generally, the ex-ante creation of a new science or even a new field is not scientific and sets the counterproductive precedent of creating new sciences based on personal judgement rather than scientific proof. Establishing a new field must be done through a scientific procedure that recognizes the new needs, carefully examines what is available, identifies the gap, proposes meaningful and new questions, and suggests solid evidence for the possibility of answering such questions using new, old, or revised approaches and methods. Certainly, this procedure was not followed by socio-hydrology and as a result, after eight years, we still have a hard time figuring out what socio-hydrology means and what it is trying to do that is novel. This can be attributed to our ignorance, but we believe that this confusion has been contagious and common for a lot of non-socio-hydrologists.

In our opinion, the valuable contribution of the socio-hydrologists is not their “new science”, models, ambitious statements, and exciting agenda, but their perseverance and dedication to reminding the mainstream hydrologists about the need for taking the human factor into account. For the reasons discussed in the paper, a good number of socio-hydrology papers would have been nearly unpublishable in their current forms in traditional water resources management or water resources systems journals. The same is true if these papers had been reviewed by those familiar with the larger water resources systems, system dynamics, and CHANS literature. Nevertheless, the appearance of these papers in the most reputable hydrology/water resources journals and the dedicated efforts of the socio-hydrology leaders to promote their “new science” at major gatherings of the field have resulted in: (1) an increasing recognition of the need for incorporating the human element into traditional hydrologic models; (2) an increasing interest, especially among the early-career researchers to study and model coupled human-water systems; and (3) a big surge in the production of coupled human-water systems literature (mainly based on systems dynamics methods) that provide potentially useful insights for policymaking. Thanks to the efforts of the socio-hydrology leaders, the coupled human-water systems community now has a bigger and more enthusiastic task force. This success must be celebrated and promoted as it can strengthen the current efforts of those who have been working on coupled human-water systems for a long time.

Meanwhile, to avoid wasting economic resources and human talents, the socio-hydrology leaders have a great responsibility to ensure that their community is aware of and recognizes the major contributions of the water resources systems and CHANS communities to studying coupled human-water systems. The presented boundaries and coordinates of the socio-hydrology “science” seem to be suffering from a misunderstanding of what other communities (e.g., water resources systems) are doing. Socio-hydrologists have an ethical responsibility to review what other groups have done and clearly indicate their point of departure, if such departure is necessary at all.

Hjorth and Madani [191] warned that within the water resources profession, our mental frames [192], beliefs, expectations, and judgements could converge over time as we continue to read the same journals and go to the same conferences. Repetitions make our frames stronger and empower them in our brains. To conserve our mental frames, we have a tendency to preoccupy ourselves with issues that are closer to our comfort zones. We disregard the observations that do not fit into our frames as we know well that “a frame modification would imply adjustment, insecurity, and even confusion, possibly not just for the individual but for an entire community” [191]. This issue could be among the reasons that the socio-hydrology, water resources systems, and CHANS communities have not successfully interacted with each other in a complementary fashion. Instead, each group has remained defensive of its own framing of problems and its own unique solutions to it. As proponents of the systems approach in decision making in the real world, we have failed to adopt such an approach in our own world, i.e., academia, where most of the real-world complexities do not exist and the stakes are supposedly much lower. Instead, as academics with strong interest overlaps, we have competed to create and lead our own territories, dismissing what others have done. It is true and very unfortunate that “we work hard, but separately, to solve interlinked problems” [191].

New challenges require changed priorities and new thinking. We need to update our common sense and come to grips with our mistaken beliefs [115]. Common sense can unite us but creating new science might divide us. Thus, if we want a unified effort, we must function within a common-sense framework [191] instead of developing and protecting our own science. The lack of common understanding makes scientists compete to interpret problems [115], propose new terms, “correct” evaluation methods [193] and disciplinary jargons [194], and prescribe solutions based on their own preferences and knowledge of their own domain instead of focusing on problem solving. If the subject is more important, more people will try to compete and pull it toward their domain where they feel most empowered by their own capabilities and perspectives [195]. Creating a common sense for hydrologists that humans must be an integral element of water models can unite the water resources community. However, insisting on creating a “new science” of socio-hydrology while undermining the existing work in the human-water systems space might be a frustrating precedent that can lead to further fragmentation of the already siloed scientists.

Lastly, despite the possible misinterpretations of our intention, we decided to write this paper as outsiders who remain interested but confused about the developments and contributions of socio-hydrology. The ability to give constructive and critical feedback, without causing resentment, is a superpower that we might not possess. Nevertheless, we remain hopeful that these comments encourage our colleagues in socio-hydrology to sharpen their messages, more comprehensively consider the existing literature, and, if appropriate, join their forces and merge their work with other scholars who are working on human-nature and human-water systems problems as unity can certainly make us more powerful.

Author Contributions: K.M. and M.S.-J. did the analysis and literature review through extensive discussions. M.S.-J. did the literature search in the WoS database and produced the figures. K.M. wrote the manuscript with input from M.S.-J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We thank the Guest Editor, Slobodan Simonovic, for the invitation to write this paper. We are also thankful to the anonymous reviewers for their constructive feedback.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sivapalan, M.; Savenije, H.H.G.; Blöschl, G. Socio-hydrology: A new science of people and water. *Hydrol. Process.* **2012**, *26*, 1270–1276. [CrossRef]
2. Koutsoyiannis, D. *Review Report of “Socio-Hydrology: A New Science of People and Water”*; National Technical University of Athens: Athens, Greece, 2011. Available online: <http://www.itia.ntua.gr/en/docinfo/1991/> (accessed on 20 May 2020).
3. Sivakumar, B. Socio-hydrology: Not a new science, but a recycled and re-worded hydrosociology. *Hydrol. Process.* **2012**, *26*, 3788–3790. [CrossRef]
4. Falkenmark, M. Main problems of water use and transfer of technology. *Geojournal* **1979**, *3*, 435–443. [CrossRef]
5. Seidl, R.; Barthel, R. Linking scientific disciplines: Hydrology and social sciences. *J. Hydrol.* **2017**, *550*, 441–452. [CrossRef]
6. McCurley, K.L.; Jawitz, J.W. Hyphenated hydrology: Interdisciplinary evolution of water resource science. *Water Resour. Res.* **2017**, *53*, 2972–2982. [CrossRef]
7. Keys, P.W.; Wang-Erlandsson, L. On the social dynamics of moisture recycling. *Earth Syst. Dyn.* **2018**, *9*, 829–847. [CrossRef]
8. Hynds, P.; Regan, S.; Andrade, L.; Mooney, S.; O’Malley, K.; DiPelino, S.; O’Dwyer, J. Muddy Waters: Refining the Way Forward for the “Sustainability Science” of Socio-Hydrogeology. *Water* **2018**, *10*, 1111. [CrossRef]
9. Smakhtin, V.U.; Shilpakar, R.L.; Hughes, D.A. Hydrology-based assessment of environmental flows: An example from Nepal. *Hydrol. Sci. J.* **2006**, *51*, 207–222. [CrossRef]
10. Kock, B. Agent-Based Models of Socio-Hydrological Systems for Exploring the Institutional Dynamics of Water Resources Conflict. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 2008.
11. Mohorjy, A.M. Multidisciplinary planning and managing of water reuse. *JAWRA J. Am. Water Resour. Assoc.* **1989**, *25*, 433–442. [CrossRef]
12. Pande, S.; Sivapalan, M. Progress in socio-hydrology: A meta-analysis of challenges and opportunities. *WIREs Water* **2016**, *4*, e1193. [CrossRef]
13. Di Baldassarre, G.; Sivapalan, M.; Rusca, M.; Cudennec, C.; Garcia, M.; Kreibich, H.; Konar, M.; Mondino, E.; Mård, J.; Pande, S.; et al. Sociohydrology: Scientific challenges in addressing the sustainable development goals. *Water Resour. Res.* **2019**, *55*, 6327–6355. [CrossRef]
14. Leong, C. The role of narratives in sociohydrological models of flood behaviors. *Water Resour. Res.* **2018**, *54*, 3100–3121. [CrossRef]
15. Sanderson, M.R.; Bergtold, J.S.; Heier Stamm, J.L.; Caldas, M.M.; Ramsey, S.M. Bringing the “social” into sociohydrology: Conservation policy support in the Central Great Plains of Kansas, USA. *Water Resour. Res.* **2017**, *53*, 6725–6743. [CrossRef]
16. Haefner, M.; Jackson-Smith, D.; Flint, C.G. Social position influencing the water perception gap between local leaders and constituents in a socio-hydrological system. *Water Resour. Res.* **2018**, *54*, 663–679. [CrossRef]
17. Newell, B.; Wasson, R. Social system vs solar system: Why policy makers need history. In *Conflict and Cooperation Related to International Water Resources: Historical Perspectives*; Castelein, S., Otte, A., Eds.; UNESCO: Paris, France, 2002; p. 22.
18. Van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
19. Van Eck, N.J.; Waltman, L. Visualizing Bibliometric networks. In *Measuring Scholarly Impact*; Springer International Publishing: Cham, Switzerland, 2014; pp. 285–320, ISBN 9783319103778.
20. Mirchi, A.; Madani, K.; Watkins, D.; Ahmad, S. Synthesis of system dynamics tools for holistic conceptualization of water resources problems. *Water Resour. Manag.* **2012**, *26*, 2421–2442. [CrossRef]
21. Simonovic, S.P.; Fahmy, H. A new modeling approach for water resources policy analysis. *Water Resour. Res.* **1999**, *35*, 295–304. [CrossRef]
22. Guo, H.C.; Liu, L.; Huang, G.H.; Fuller, G.A.; Zou, R.; Yin, Y.Y. A system dynamics approach for regional environmental planning and management: A study for the Lake Erhai Basin. *J. Environ. Manag.* **2001**, *61*, 93–111. [CrossRef]
23. Madani, K. Water Transfer and watershed development: A system dynamics approach. In Proceedings of the World Environmental and Water Resources Congress, Tampa, FL, USA, 15–19 May 2007; pp. 1–15.

24. Madani, K.; Mariño, M.A. System dynamics analysis for managing Iran's Zayandeh-Rud river basin. *Water Resour. Manag.* **2009**, *23*, 2163–2187. [\[CrossRef\]](#)
25. Ahmad, S.; Prashar, D. Evaluating municipal water conservation policies using a dynamic simulation model. *Water Resour. Manag.* **2010**, *24*, 3371–3395. [\[CrossRef\]](#)
26. Shahbazbegian, M.; Bagheri, A. Rethinking assessment of drought impacts: A systemic approach towards sustainability. *Sustain. Sci.* **2010**, *5*, 223–236. [\[CrossRef\]](#)
27. Bagheri, A.; Darijani, M.; Asgary, A.; Morid, S. Crisis in urban water systems during the reconstruction period: A system dynamics analysis of alternative policies after the 2003 earthquake in Bam-Iran. *Water Resour. Manag.* **2010**, *24*, 2567–2596. [\[CrossRef\]](#)
28. Madani, K. *Towards Sustainable Watershed Management: Using System Dynamics for Integrated Water Resources Planning*; VDM Verlag Dr. Müller: Saarbrücken, Germany, 2010.
29. Davies, E.G.R.; Simonovic, S.P. Global water resources modeling with an integrated model of the social-economic-environmental system. *Adv. Water Resour.* **2011**, *34*, 684–700. [\[CrossRef\]](#)
30. Zarghami, M.; Akbariyeh, S. System dynamics modeling for complex urban water systems: Application to the city of Tabriz, Iran. *Resour. Conserv. Recycl.* **2012**, *60*, 99–106. [\[CrossRef\]](#)
31. Simonovic, S.P. World water dynamics: Global modeling of water resources. *J. Environ. Manage.* **2002**, *66*, 249–267. [\[CrossRef\]](#)
32. Xu, Z.X.; Takeuchi, K.; Ishidaira, H.; Zhang, X.W. Sustainability analysis for Yellow River water resources using the system dynamics approach. *Water Resour. Manag.* **2002**, *16*, 239–261. [\[CrossRef\]](#)
33. Martínez Fernández, J.; Selma, M.A.E. The dynamics of water scarcity on irrigated landscapes: Mazarrón and Aguilas in south-eastern Spain. *Syst. Dyn. Rev.* **2004**, *20*, 117–137. [\[CrossRef\]](#)
34. Simonovic, S.P.; Rajasekaram, V. Integrated analyses of Canada's water resources: A system dynamics approach. *Can. Water Resour. J.* **2004**, *29*, 223–250. [\[CrossRef\]](#)
35. Madani Larijani, K. *Watershed Management and Sustainability—A System Dynamics Approach (Case Study: Zayandeh-Rud River Basin, Iran)*; Lund University: Lund, Sweden, 2005.
36. Bagheri, A. *Sustainable Development: Implementation in Urban Water Systems*; Lund University: Lund, Sweden, 2006.
37. Leal Neto, A.D.C.; Legey, L.F.L.; González-Araya, M.C.; Jablonski, S. A system dynamics model for the environmental management of the Sepetiba Bay Watershed, Brazil. *Environ. Manage.* **2006**, *38*, 879–888. [\[CrossRef\]](#)
38. Bagheri, A.; Hjorth, P. A framework for process indicators to monitor for sustainable development: Practice to an urban water system. *Environ. Dev. Sustain.* **2007**, *9*, 143–161. [\[CrossRef\]](#)
39. Hjorth, P.; Bagheri, A. Navigating towards sustainable development: A system dynamics approach. *Futures* **2006**, *38*, 74–92. [\[CrossRef\]](#)
40. MacCracken, M. Prediction versus projection—Forecast versus possibility. *WeatherZine* **2001**, *26*, 3–4.
41. Taleb, N.N. *The Black Swan: The Impact of Highly Improbable*, 1st ed.; Random House: New York, NY, USA, 2007.
42. Loucks, D.P. Debates-perspectives on socio-hydrology: Simulating hydrologic-human interactions. *Water Resour. Res.* **2015**, *51*, 4789–4794. [\[CrossRef\]](#)
43. Ceola, S.; Montanari, A.; Krueger, T.; Dyer, F.; Kreibich, H.; Westerberg, I.; Carr, G.; Cudennec, C.; Elshorbagy, A.; Savenije, H.; et al. Adaptation of water resources systems to changing society and environment: A statement by the International Association of Hydrological Sciences. *Hydrol. Sci. J.* **2016**, *61*, 2803–2817. [\[CrossRef\]](#)
44. Srinivasan, V.; Sanderson, M.; Garcia, M.; Konar, M.; Blöschl, G.; Sivapalan, M. Prediction in a socio-hydrological world. *Hydrol. Sci. J.* **2017**, *62*, 338–345. [\[CrossRef\]](#)
45. Sterman, J. *Systems Thinking and Modeling for a Complex World*; McGraw Hill: Boston, MA, USA, 2000, ISBN 0-07-231135-5.
46. Bender, M.J.; Simonovic, S.P. A systems approach for collaborative decision support in water resources planning. In Proceedings of the 1996 International Symposium on Technology and Society Technical Expertise and Public Decisions, Princeton, NJ, USA, 21–22 June 1996; pp. 357–363. [\[CrossRef\]](#)
47. Saysel, A.K.; Barlas, Y.; Yenigün, O. Environmental sustainability in an agricultural development project: A system dynamics approach. *J. Environ. Manage.* **2002**, *64*, 247–260. [\[CrossRef\]](#)
48. Bagheri, A.; Hjorth, P. Planning for sustainable development: A paradigm shift towards a process-based approach. *Sustain. Dev.* **2007**, *15*, 83–96. [\[CrossRef\]](#)

49. Hui, R.; Lund, J.R.; Madani, K. Game theory and risk-based leveed river system planning with noncooperation. *Water Resour. Res.* **2016**, *52*, 119–134. [\[CrossRef\]](#)
50. Gohari, A.; Mirchi, A.; Madani, K. System dynamics evaluation of climate change adaptation strategies for water resources management in Central Iran. *Water Resour. Manag.* **2017**, *31*, 1413–1434. [\[CrossRef\]](#)
51. Bahaddin, B.; Mirchi, A.; Watkins, D.; Ahmad, S.; Rich, E.; Madani, K. System Archetypes in Water Resource Management. In Proceedings of the World Environmental and Water Resources Congress 2018, Minneapolis, MN, USA, 3–7 June 2018; pp. 130–140.
52. Ristić, B.; Madani, K. A game theory warning to blind drivers playing chicken with public goods. *Water Resour. Res.* **2019**, *55*, 2000–2013. [\[CrossRef\]](#)
53. Madani, K. Game theory and water resources. *J. Hydrol.* **2010**, *381*, 225–238. [\[CrossRef\]](#)
54. Madani, K.; Hipel, K.W. Non-cooperative stability definitions for strategic analysis of generic water resources conflicts. *Water Resour. Manag.* **2011**, *25*, 1949–1977. [\[CrossRef\]](#)
55. Mirchi, A. System Dynamics Modeling As a Quantitative- Qualitative Framework for Sustainable Water Resources Management: Insights for Water Quality Policy in the Great Lakes Region. Doctoral Thesis, Michigan Technological University, Houghton, MI, USA, 2013.
56. Mirchi, A.; Watkins, D.W.; Madani, K. Water resources system archetypes: Towards a holistic understanding of persistent water resources problems. In Proceedings of the AGU Fall Meeting, San Francisco, CA, USA, 5–9 December 2011; p. H11F-1142.
57. Madani, K.; Lund, J.R. California's Sacramento-San Joaquin delta conflict: From cooperation to chicken. *J. Water Resour. Plan. Manag.* **2012**, *138*, 90–99. [\[CrossRef\]](#)
58. Mirchi, A.; Watkins, D. A systems approach to holistic total maximum daily load policy: Case of Lake Allegan, Michigan. *J. Water Resour. Plan. Manag.* **2013**, *139*, 544–553. [\[CrossRef\]](#)
59. Madani, K.; Zarezadeh, M. The significance of game structure evolution for deriving game-theoretic policy insights. In Proceedings of the 2014 IEEE International Conference on Systems, Man, and Cybernetics (SMC), San Diego, CA, USA, 5–8 October 2014; pp. 2715–2720. [\[CrossRef\]](#)
60. Mirchi, A.; Watkins, D.W.; Huckins, C.J.; Madani, K.; Hjorth, P. Water resources management in a homogenizing world: Averting the Growth and Underinvestment trajectory. *Water Resour. Res.* **2014**, *50*, 7515–7526. [\[CrossRef\]](#)
61. White, G.F. *Human Adjustments to Floods: A Geographical Approach to the Flood Problem in the United States*; The University of Chicago–Department of Geography: Chicago, IL, USA, 1945.
62. Burton, I.; Kates, R.W.; White, G.F. *The Human Ecology of Extreme Geophysical Events*; FMHI Publications: Tampa, FL, USA, 1968. Available online: https://scholarcommons.usf.edu/fmhi_pub/78/ (accessed on 7 July 2020).
63. Burby, R.J. Hurricane Katrina and the paradoxes of government disaster policy: Bringing about wise governmental decisions for hazardous Areas. *Ann. Am. Acad. Pol. Soc. Sci.* **2006**, *604*, 171–191. [\[CrossRef\]](#)
64. Senge, P.M. *The Fifth Discipline: The Art and Practice of the Learning Organization*; Doubleday/Currency: New York, NY, USA, 1990.
65. Alcott, B. Jevons' paradox. *Ecol. Econ.* **2005**, *54*, 9–21. [\[CrossRef\]](#)
66. Kallis, G. Coevolution in water resource development. The vicious cycle of water supply and demand in Athens, Greece. *Ecol. Econ.* **2010**, *69*, 796–809. [\[CrossRef\]](#)
67. Ward, F.A.; Pulido-Velazquez, M. Water conservation in irrigation can increase water use. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 18215–18220. [\[CrossRef\]](#)
68. Grafton, R.Q.; Williams, J.; Perry, C.J.; Molle, F.; Ringler, C.; Steduto, P.; Udall, B.; Wheeler, S.A.; Wang, Y.; Garrick, D.; et al. The paradox of irrigation efficiency. *Science* **2018**, *361*, 748–750. [\[CrossRef\]](#)
69. Gohari, A.; Eslamian, S.; Mirchi, A.; Abedi-Koupaei, J.; Massah Bavani, A.; Madani, K. Water transfer as a solution to water shortage: A fix that can Backfire. *J. Hydrol.* **2013**, *491*, 23–39. [\[CrossRef\]](#)
70. Sage, A.; White, E. On the value dependent role of the identification processing and evaluation of information in risk/benefit analysis. In *Risk/Benefit Analysis in Water Resources Planning and Management*; Haimes, Y.Y., Ed.; Springer: Boston, MA, USA, 1981; pp. 245–262.
71. Howitt, R.E.; Msangi, S.; Reynaud, A.; Knapp, K.C. Estimating intertemporal preferences for natural resource allocation. *Am. J. Agric. Econ.* **2005**, *87*, 969–983. [\[CrossRef\]](#)
72. Li, M.; Xu, W.; Rosegrant, M.W. Irrigation, risk aversion, and water right priority under water supply uncertainty. *Water Resour. Res.* **2017**, *53*, 7885–7903. [\[CrossRef\]](#) [\[PubMed\]](#)

73. Whateley, S.; Palmer, R.N.; Brown, C. Seasonal Hydroclimatic Forecasts as Innovations and the Challenges of Adoption by Water Managers. *J. Water Resour. Plan. Manag.* **2015**, *141*, 04014071. [\[CrossRef\]](#)
74. OBeidi, A.; Hipel, K. Strategic and dilemma analyses of a water export conflict. *INFOR Inf. Syst. Oper. Res.* **2005**, *43*, 247–270. [\[CrossRef\]](#)
75. Kuruppu, N.; Liverman, D. Mental preparation for climate adaptation: The role of cognition and culture in enhancing adaptive capacity of water management in Kiribati. *Glob. Environ. Change* **2011**, *21*, 657–669. [\[CrossRef\]](#)
76. Madani, K.; Dinar, A. Non-cooperative institutions for sustainable common pool resource management: Application to groundwater. *Ecol. Econ.* **2012**, *74*, 34–45. [\[CrossRef\]](#)
77. Hall, J.; Borgomeo, E. Risk-based principles for defining and managing water security. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **2013**, *371*. [\[CrossRef\]](#)
78. Madani, K.; Hooshyar, M. A game theory-reinforcement learning (GT-RL) method to develop optimal operation policies for multi-operator reservoir systems. *J. Hydrol.* **2014**, *519*, 732–742. [\[CrossRef\]](#)
79. Gallagher, J. Learning about an infrequent event: Evidence from flood insurance take-up in the United States. *Am. Econ. J. Appl. Econ.* **2014**, *6*, 206–233. [\[CrossRef\]](#)
80. Berglund, E.Z. Using agent-based modeling for water resources planning and management. *J. Water Resour. Plan. Manag.* **2015**, *141*, 1–17. [\[CrossRef\]](#)
81. DeCaro, D.A.; Arnold, C.A.; Frimpong Boamah, E.; Garmestani, A.S. Understanding and applying principles of social cognition and decision making in adaptive environmental governance. *Ecol. Soc.* **2017**, *22*, 33. [\[CrossRef\]](#) [\[PubMed\]](#)
82. Du, E.; Cai, X.; Brozović, N.; Minsker, B. Evaluating the impacts of farmers' behaviors on a hypothetical agricultural water market based on double auction. *Water Resour. Res.* **2017**, *53*, 4053–4072. [\[CrossRef\]](#)
83. Palmer, R.N.; Werick, W.J.; MacEwan, A.; Woods, A.W. Modeling water resources opportunities, challenges and trade-offs: The use of shared vision modeling for negotiation and conflict resolution. In Proceedings of the WRPMD'99, Tempe, AZ, USA, 6–9 June 1999; pp. 1–13. [\[CrossRef\]](#)
84. Cohen, S.; Neilsen, D.; Smith, S.; Neale, T.; Taylor, B.; Barton, M.; Merritt, W.; Alila, Y.; Shepherd, P.; McNeill, R.; et al. Learning with local help: Expanding the dialogue on climate change and water management in the Okanagan Region, British Columbia, Canada. *Clim. Change* **2006**, *75*, 331–358. [\[CrossRef\]](#)
85. Langsdale, S.; Beall, A.; Carmichael, J.; Cohen, S.; Forster, C. An exploration of water resources futures under climate change using system dynamics modeling. *Integr. Assess.* **2007**, *7*, 51–79.
86. Heinmiller, T. Path dependency and collective action in common pool governance. *Int. J. Commons* **2009**, *3*, 131. [\[CrossRef\]](#)
87. Harris, E. The impact of institutional path dependence on water market efficiency in Victoria, Australia. *Water Resour. Manag.* **2011**, *25*, 4069–4080. [\[CrossRef\]](#)
88. Libecap, G.D. Institutional path dependence in climate adaptation: Coman's "some unsettled problems of irrigation". *Am. Econ. Rev.* **2011**, *101*, 64–80. [\[CrossRef\]](#)
89. Carr, G.; Loucks, D.; Blöschl, G. An analysis of public participation in the Lake Ontario—St. Lawrence river study. In *Water Co-Management*; Grover, V.I., Krantzberg, G., Eds.; CRC Press: Boca Raton, FL, USA, 2013; pp. 48–77.
90. Haasnoot, M.; Kwakkel, J.H.; Walker, W.E.; ter Maat, J. Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Glob. Environ. Change* **2013**, *23*, 485–498. [\[CrossRef\]](#)
91. Langsdale, S.; Beall, A.; Bourget, E.; Hagen, E.; Kudlas, S.; Palmer, R.; Tate, D.; Werick, W. Collaborative modeling for decision support in water resources: Principles and best practices. *J. Am. Water Resour. Assoc.* **2013**, *49*, 629–638. [\[CrossRef\]](#)
92. Marshall, G.R.; Alexandra, J. Institutional path dependence and environmental water recovery in Australia's Murray-Darling Basin. *Water Altern.* **2016**, *9*, 679–703.
93. Elshafei, Y.; Tonts, M.; Sivapalan, M.; Hipsey, M.R. Sensitivity of emergent sociohydrologic dynamics to internal system properties and external sociopolitical factors: Implications for water management. *Water Resour. Res.* **2016**, *52*, 4944–4966. [\[CrossRef\]](#)
94. Van Emmerik, T.H.M.; Li, Z.; Sivapalan, M.; Pande, S.; Kandasamy, J.; Savenije, H.H.G.; Chanan, A.; Vigneswaran, S. Socio-hydrologic modeling to understand and mediate the competition for water between agriculture development and environmental health: Murrumbidgee River Basin, Australia. *Hydrol. Earth Syst. Sci. Discuss.* **2014**, *11*, 3387–3435. [\[CrossRef\]](#)

95. Garcia, M.; Portney, K.; Islam, S. A question driven socio-hydrological modeling process. *Hydrol. Earth Syst. Sci.* **2016**, *20*, 73–92. [CrossRef]
96. Yu, D.J.; Sangwan, N.; Sung, K.; Chen, X.; Merwade, V. Incorporating institutions and collective action into a sociohydrological model of flood resilience. *Water Resour. Res.* **2017**, *53*, 1336–1353. [CrossRef]
97. Gunda, T.; Turner, B.L.; Tidwell, V.C. The influential role of sociocultural feedbacks on community-managed irrigation system behaviors during times of water stress. *Water Resour. Res.* **2018**, *54*, 2697–2714. [CrossRef]
98. Kuil, L.; Evans, T.; McCord, P.F.; Salinas, J.L.; Blöschl, G. Exploring the influence of smallholders' perceptions regarding water availability on crop choice and water allocation through socio-hydrological modeling. *Water Resour. Res.* **2018**, *54*, 2580–2604. [CrossRef]
99. Sung, K.; Jeong, H.; Sangwan, N.; Yu, D.J. Effects of flood control strategies on flood resilience under sociohydrological disturbances. *Water Resour. Res.* **2018**, *54*, 2661–2680. [CrossRef]
100. Xu, L.; Gober, P.; Wheeler, H.S.; Kajikawa, Y. Reframing socio-hydrological research to include a social science perspective. *J. Hydrol.* **2018**, *563*, 76–83. [CrossRef]
101. O'Keeffe, J.; Moulds, S.; Bergin, E.; Brozović, N.; Mijic, A.; Buytaert, W. Including farmer irrigation behavior in a sociohydrological modeling framework with application in North India. *Water Resour. Res.* **2018**, *54*, 4849–4866. [CrossRef]
102. O'Keeffe, J.; Moulds, S.; Scheidegger, J.M.; Jackson, C.R.; Nair, T.; Mijic, A. Isolating the impacts of anthropogenic water use within the hydrological regime of north India. *Earth Surf. Process. Landf.* **2020**, *45*, 1217–1228. [CrossRef]
103. Srinivasan, V.; Lambin, E.F.; Gorelick, S.M.; Thompson, B.H.; Rozelle, S. The nature and causes of the global water crisis: Syndromes from a meta-analysis of coupled human-water studies. *Water Resour. Res.* **2012**, *48*, 1–16. [CrossRef]
104. Di Baldassarre, G.; Viglione, A.; Carr, G.; Kuil, L.; Salinas, J.L.; Blöschl, G. Socio-hydrology: Conceptualising human-flood interactions. *Hydrol. Earth Syst. Sci.* **2013**, *17*, 3295–3303. [CrossRef]
105. Di Baldassarre, G.; Wanders, N.; AghaKouchak, A.; Kuil, L.; Rangelcroft, S.; Veldkamp, T.I.E.; Garcia, M.; van Oel, P.R.; Breinl, K.; Van Loon, A.F. Water shortages worsened by reservoir effects. *Nat. Sustain.* **2018**, *1*, 617–622. [CrossRef]
106. Di Baldassarre, G.; Martinez, F.; Kalantari, Z.; Viglione, A. Drought and flood in the Anthropocene: Feedback mechanisms in reservoir operation. *Earth Syst. Dyn.* **2017**, *8*, 225–233. [CrossRef]
107. Gober, P.; Wheeler, H.S. Socio-hydrology and the science—Policy interface: A case study of the Saskatchewan river basin. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 1413–1422. [CrossRef]
108. Elshafei, Y.; Sivapalan, M.; Tonts, M.; Hipsey, M.R. A prototype framework for models of socio-hydrology: Identification of key feedback loops and parameterisation approach. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 2141–2166. [CrossRef]
109. Elshafei, Y.; Coletti, J.Z.; Sivapalan, M.; Hipsey, M.R. A model of the socio-hydrologic dynamics in a semiarid catchment: Isolating feedbacks in the coupled human-hydrology system. *Water Resour. Res.* **2015**, *51*, 6442–6471. [CrossRef]
110. Global Water Partnership. What Is IWRM? Available online: <https://www.gwp.org/en/GWP-CEE/about/why/what-is-iwrm/> (accessed on 30 May 2020).
111. Biswas, A.K. Integrated water resources management: A reassessment. *Water Int.* **2004**, *29*, 248–256. [CrossRef]
112. Biswas, A.K. Integrated water resources management: Is it working? *Int. J. Water Resour. Dev.* **2008**, *24*, 5–22. [CrossRef]
113. Molle, F. Nirvana concepts, narratives and policy models: Insights from the water sector. *Water Altern.* **2008**, *1*, 131–156.
114. Medema, W.; McIntosh, B.S.; Jeffrey, P.J. From premise to practice: A critical assessment of integrated Water resources management and adaptive management approaches in the water sector. *Ecol. Soc.* **2008**, *13*, 29. [CrossRef]
115. Hjorth, P.; Madani, K. Sustainability monitoring and assessment: New challenges require new thinking. *J. Water Resour. Plan. Manag.* **2014**, *140*, 133–135. [CrossRef]
116. Simonovic, S.P. *Managing Water Resources: Methods and Tools for a Systems Approach*; Routledge: London, UK, 2009; ISBN 9781844075546.

117. Mirchi, A.; Watkins, D.J.; Madani, K. Modeling for watershed planning, management, and decision making. In *Watersheds: Management, Restoration and Environmental Impact*; Nova Science Pub Inc.: London, UK, 2010; ISBN 9781616686673.
118. Loucks, D.P.; van Beek, E. *Water Resources Systems Planning and Management: An Introduction to Methods, Models and Applications*; UNESCO: Paris, France, 2005.
119. Loucks, D.P.; Stedinger, J.R.; Haith, D.A. *Water Resource Systems Planning and Analysis*, 1st ed.; Prentice Hall: Upper Saddle River, NJ, USA, 1981.
120. Nayak, M.A.; Herman, J.D.; Steinschneider, S. Balancing flood risk and water supply in California: Policy search integrating short-term forecast ensembles with conjunctive use. *Water Resour. Res.* **2018**, *54*, 7557–7576. [[CrossRef](#)]
121. Aljefri, Y.M.; Fang, L.; Hipel, K.W.; Madani, K. Strategic analyses of the hydropolitical conflicts surrounding the grand Ethiopian renaissance dam. *Group Decis. Negot.* **2019**, *28*, 305–340. [[CrossRef](#)]
122. Seifi, A.; Hipel, K.W. Interior-point method for reservoir operation with stochastic inflows. *J. Water Resour. Plan. Manag.* **2001**, *127*, 48–57. [[CrossRef](#)]
123. Wang, L.; Fang, L.; Hipel, K.W. Mathematical programming approaches for modeling water rights allocation. *J. Water Resour. Plan. Manag.* **2007**, *133*, 50–59. [[CrossRef](#)]
124. Rheinheimer, D.E.; Null, S.E.; Lund, J.R. Optimizing selective withdrawal from reservoirs to manage downstream temperatures with climate warming. *J. Water Resour. Plan. Manag.* **2015**, *141*, 1–9. [[CrossRef](#)]
125. Ahmad, S.; Simonovic, S.P. System dynamics modeling of reservoir operations for flood management. *J. Comput. Civ. Eng.* **2000**, *14*, 190–198. [[CrossRef](#)]
126. Akter, T.; Simonovic, S.P. Aggregation of fuzzy views of a large number of stakeholders for multi-objective flood management decision-making. *J. Environ. Manage.* **2005**, *77*, 133–143. [[CrossRef](#)]
127. Jiang, H.; Simonovic, S.P.; Yu, Z.; Wang, W. A system dynamics simulation approach for environmentally friendly operation of a reservoir system. *J. Hydrol.* **2020**, *587*, 124971. [[CrossRef](#)]
128. King, L.M.; Simonovic, S.P.; Hartford, D.N.D. Using system dynamics simulation for assessment of hydropower system safety. *Water Resour. Res.* **2017**, *53*, 7148–7174. [[CrossRef](#)]
129. Mautner, M.R.L.; Foglia, L.; Herrera, G.S.; Galán, R.; Herman, J.D. Urban growth and groundwater sustainability: Evaluating spatially distributed recharge alternatives in the Mexico City Metropolitan Area. *J. Hydrol.* **2020**, *586*, 124909. [[CrossRef](#)]
130. Simonovic, S.P.; Ahmad, S. Computer-based model for flood evacuation emergency planning. *Nat. Hazards* **2005**, *34*, 25–51. [[CrossRef](#)]
131. Chang, N.B.; Chen, H.W.; Ning, S.K. Identification of river water quality using the fuzzy synthetic evaluation approach. *J. Environ. Manage.* **2001**, *63*, 293–305. [[CrossRef](#)] [[PubMed](#)]
132. Sharma, A.; Hipel, K.W.; Schweizer, V. Strategic insights into the cauvery river dispute in India. *Sustainability* **2020**, *12*, 1286. [[CrossRef](#)]
133. Afshar, A.; Najafi, E. Consequence management of chemical intrusion in water distribution networks under inexact scenarios. *J. Hydroinform.* **2014**, *16*, 178–188. [[CrossRef](#)]
134. Hipel, K.W.; Ben-Haim, Y. Decision making in an uncertain world: Information-gap modeling in water resources management. *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev.* **1999**, *29*, 506–517. [[CrossRef](#)]
135. Gohari, A.; Bozorgi, A.; Madani, K.; Elledge, J.; Berndtsson, R. Adaptation of surface water supply to climate change in central Iran. *J. Water Clim. Change* **2014**, *5*, 391–407. [[CrossRef](#)]
136. Oliveira, R.; Loucks, D.P. Operating rules for multireservoir systems. *Water Resour. Res.* **1997**, *33*, 839–852. [[CrossRef](#)]
137. Winz, I.; Brierley, G.; Trowsdale, S. The use of system dynamics simulation in water resources management. *Water Resour. Manag.* **2009**, *23*, 1301–1323. [[CrossRef](#)]
138. Moridi, A. A bankruptcy method for pollution load reallocation in river systems. *J. Hydroinf.* **2019**, *21*, 45–55. [[CrossRef](#)]
139. Philpot, S.; Hipel, K.; Johnson, P. Strategic analysis of a water rights conflict in the south western United States. *J. Environ. Manage.* **2016**, *180*, 247–256. [[CrossRef](#)] [[PubMed](#)]
140. Sheikhmohammady, M.; Madani, K. A Descriptive model to analyze Asymmetric multilateral negotiations. In Proceedings of the Universities Council on Water Resources (UCOWR) Conference, Durham, NC, USA, 22–24 July 2008.

141. Read, L.; Madani, K.; Inanloo, B. Optimality versus stability in water resource allocation. *J. Environ. Manag.* **2014**, *133*, 343–354. [[CrossRef](#)] [[PubMed](#)]
142. Rouhi Rad, M.; Haacker, E.M.K.; Sharda, V.; Nozari, S.; Xiang, Z.; Araya, A.; Uddameri, V.; Suter, J.F.; Gowda, P. MOD\$AT: A hydro-economic modeling framework for aquifer management in irrigated agricultural regions. *Agric. Water Manag.* **2020**, *238*, 106194. [[CrossRef](#)]
143. Zeff, H.; Kaczan, D.; Characklis, G.W.; Jeuland, M.; Murray, B.; Locklier, K. Potential implications of groundwater trading and reformed water rights in Diamond Valley, Nevada. *J. Water Resour. Plan. Manag.* **2019**, *145*, 1–19. [[CrossRef](#)]
144. Housh, M.; Cai, X.; Ng, T.L.; McIsaac, G.F.; Ouyang, Y.; Khanna, M.; Sivapalan, M.; Jain, A.K.; Eckhoff, S.; Gasteyer, S.; et al. System of systems model for analysis of biofuel development. *J. Infrastruct. Syst.* **2015**, *21*, 04014050. [[CrossRef](#)]
145. Müller, M.F.; Müller-Itten, M.C.; Gorelick, S.M. How Jordan and Saudi Arabia are avoiding a tragedy of the commons over shared groundwater. *Water Resour. Res.* **2017**, *53*, 5451–5468. [[CrossRef](#)]
146. Madani, K.; Zarezadeh, M.; Morid, S. A new framework for resolving conflicts over transboundary rivers using bankruptcy methods. *Hydrol. Earth Syst. Sci.* **2014**, *18*, 3055–3068. [[CrossRef](#)]
147. Hassanzadeh, E.; Strickert, G.; Morales-Marin, L.; Noble, B.; Baulch, H.; Shupena-Soulodre, E.; Lindenschmidt, K.E. A framework for engaging stakeholders in water quality modeling and management: Application to the Qu'Appelle river basin, Canada. *J. Environ. Manag.* **2019**, *231*, 1117–1126. [[CrossRef](#)]
148. Simonovic, S.P.; Verma, R. A new methodology for water resources multicriteria decision making under uncertainty. *Phys. Chem. Earth* **2008**, *33*, 322–329. [[CrossRef](#)]
149. Parsapour-Moghaddam, P.; Abed-Elmdoust, A.; Kerachian, R. A Heuristic evolutionary game theoretic methodology for conjunctive use of surface and groundwater resources. *Water Resour. Manag.* **2015**, *29*, 3905–3918. [[CrossRef](#)]
150. Giuliani, M.; Castelletti, A.; Amigoni, F.; Cai, X. Multiagent systems and distributed constraint reasoning for regulatory mechanism design in water management. *J. Water Resour. Plan. Manag.* **2015**, *141*, 1–12. [[CrossRef](#)]
151. Hu, Y.; Quinn, C.J.; Cai, X.; Garfinkle, N.W. Combining human and machine intelligence to derive agents' behavioral rules for groundwater irrigation. *Adv. Water Resour.* **2017**, *109*, 29–40. [[CrossRef](#)]
152. Noël, P.H.; Cai, X. On the role of individuals in models of coupled human and natural systems: Lessons from a case study in the Republican River Basin. *Environ. Model. Softw.* **2017**, *92*, 1–16. [[CrossRef](#)]
153. Zekri, S.; Madani, K.; Bazargan-Lari, M.R.; Kotagama, H.; Kalbus, E. Feasibility of adopting smart water meters in aquifer management: An integrated hydro-economic analysis. *Agric. Water Manag.* **2017**, *181*, 85–93. [[CrossRef](#)]
154. Giuliani, M.; Herman, J.D. Modeling the behavior of water reservoir operators via eigenbehavior analysis. *Adv. Water Resour.* **2018**, *122*, 228–237. [[CrossRef](#)]
155. Loáiciga, H.A. Analytic game—Theoretic approach to ground-water extraction. *J. Hydrol.* **2004**, *297*, 22–33. [[CrossRef](#)]
156. Madani, K.; Dinar, A. Exogenous regulatory institutions for sustainable common pool resource management: Application to groundwater. *Water Resour. Econ.* **2013**, *2*, 57–76. [[CrossRef](#)]
157. Kanta, L.; Zechman, E. Complex adaptive systems framework to assess supply-side and demand-side management for urban water resources. *J. Water Resour. Plan. Manag.* **2014**, *140*, 75–85. [[CrossRef](#)]
158. Akhbari, M.; Grigg, N.S. Water management trade-offs between agriculture and the environment: A multiobjective approach and application. *J. Irrig. Drain. Eng.* **2014**, *140*, 1–11. [[CrossRef](#)]
159. Madani, K. The value of extreme events: What doesn't exterminate your water system makes it more resilient. *J. Hydrol.* **2019**, *575*, 269–272. [[CrossRef](#)]
160. Liu, J.; Dietz, T.; Carpenter, S.R.; Alberti, M.; Folke, C.; Moran, E.; Pell, A.N.; Deadman, P.; Kratz, T.; Lubchenco, J.; et al. Complexity of coupled human and natural systems. *Science* **2007**, *317*, 1513–1516. [[CrossRef](#)] [[PubMed](#)]
161. Müller, M.F.; Levy, M.C. Complementary vantage points: Integrating hydrology and economics for sociohydrologic knowledge generation. *Water Resour. Res.* **2019**, *55*, 2549–2571. [[CrossRef](#)]
162. Rahmandad, H.; Sterman, J. Heterogeneity and network structure in the dynamics of diffusion: Comparing agent-based and differential equation models. *Manag. Sci.* **2008**, *54*, 998–1014. [[CrossRef](#)]

163. Madani, K. Iran Statement, Statements by Heads of State and Government, High Level Segment Statements of COP23/CMP13/CMA1.2. In Proceedings of the 23rd Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), Bonn, Germany, 16 November 2017. Available online: http://unfccc.int/files/meetings/bonn_nov_2017/statements/application/pdf/iran_cop23cmp13cma1-2_hls.pdf (accessed on 7 July 2020).
164. Ishtiaque, A.; Sangwan, N.; Yu, D.J. Robust-yet-fragile nature of partly engineered social-ecological systems: A case study of coastal Bangladesh. *Ecol. Soc.* **2017**, *22*. [CrossRef]
165. Rosenberg, D.E.; Madani, K. Water resources systems analysis: A bright past and a challenging but promising future. *J. Water Resour. Plan. Manag.* **2014**, *140*, 407–409. [CrossRef]
166. Brown, C.M.; Lund, J.R.; Cai, X.; Reed, P.M.; Zagana, E.A.; Ostfeld, A.; Hall, J.; Characklis, G.W.; Yu, W.; Brekke, L. The future of water resources systems analysis: Toward a scientific framework for sustainable water management. *Water Resour. Res.* **2015**, *51*, 6110–6124. [CrossRef]
167. Vogel, R.M.; Lall, U.; Cai, X.; Rajagopalan, B.; Weiskel, P.K.; Hooper, R.P.; Matalas, N.C. Hydrology: The interdisciplinary science of water. *Water Resour. Res.* **2015**, *51*, 4409–4430. [CrossRef]
168. Kasprzyk, J.R.; Smith, R.M.; Stillwell, A.S.; Madani, K.; Ford, D.; McKinney, D.; Sorooshian, S. Defining the role of water resources systems analysis in a changing future. *J. Water Resour. Plan. Manag.* **2018**, *144*, 01818003. [CrossRef]
169. Loucks, D.P. From analyses to implementation and innovation. *Water* **2020**, *12*, 974. [CrossRef]
170. Hornberger, G.M.; Perrone, D. *Water Resources: Science and Society*; Johns Hopkins University Press: Baltimore, MD, USA, 2019.
171. Ringler, C.; Cai, X. Valuing fisheries and wetlands using integrated economic-hydrologic modeling—Mekong river basin. *J. Water Resour. Plan. Manag.* **2006**, *132*, 480–487. [CrossRef]
172. Yang, Y.C.E.; Cai, X. Reservoir reoperation for fish ecosystem restoration using daily inflows—Case study of Lake Shelbyville. *J. Water Resour. Plan. Manag.* **2011**, *137*, 470–480. [CrossRef]
173. Escriva-Bou, A.; Lund, J.R.; Pulido-Velazquez, M.; Hui, R.; Medellín-Azuara, J. Developing a water-energy-GHG emissions modeling framework: Insights from an application to California’s water system. *Environ. Model. Softw.* **2018**, *109*, 54–65. [CrossRef]
174. Liu, B.; Lund, J.R.; Liao, S.; Jin, X.; Liu, L.; Cheng, C. Optimal power peak shaving using hydropower to complement wind and solar power uncertainty. *Energy Convers. Manag.* **2020**, *209*, 112628. [CrossRef]
175. Shen, J.; Cheng, C.; Cheng, X.; Lund, J.R. Coordinated operations of large-scale UHVDC hydropower and conventional hydro energies about regional power grid. *Energy* **2016**, *95*, 433–446. [CrossRef]
176. Xu, Z.; Yang, Z.; Cai, X.; Yin, X.; Cai, Y. Modeling framework for reservoir capacity planning accounting for fish migration. *J. Water Resour. Plan. Manag.* **2020**, *146*, 04020006. [CrossRef]
177. Shafiee-Jood, M.; Housh, M.; Cai, X. Hierarchical decision-modeling framework to meet environmental objectives in biofuel development. *J. Water Resour. Plan. Manag.* **2018**, *144*, 04018030. [CrossRef]
178. Housh, M.; Yaeger, M.A.; Cai, X.; McIsaac, G.F.; Khanna, M.; Sivapalan, M.; Ouyang, Y.; Al-Qadi, I.; Jain, A.K. Managing multiple mandates: A system of systems model to analyze strategies for producing cellulosic ethanol and reducing riverine nitrate loads in the upper Mississippi river basin. *Environ. Sci. Technol.* **2015**, *49*, 11932–11940. [CrossRef]
179. Cai, X.; Wallington, K.; Shafiee-Jood, M.; Marston, L. Understanding and managing the food-energy-water nexus—Opportunities for water resources research. *Adv. Water Resour.* **2018**, *111*, 259–273. [CrossRef]
180. Su, Y.; Kern, J.D.; Denaro, S.; Hill, J.; Reed, P.; Sun, Y.; Cohen, J.; Characklis, G.W. An open source model for quantifying risks in bulk electric power systems from spatially and temporally correlated hydrometeorological processes. *Environ. Model. Softw.* **2020**, *126*, 104667. [CrossRef]
181. Escriva-Bou, A.; Lund, J.R.; Pulido-Velazquez, M. Optimal residential water conservation strategies considering related energy in California. *Water Resour. Res.* **2015**, *51*, 4482–4498. [CrossRef]
182. Escriva-Bou, A.; Lund, J.R.; Pulido-Velazquez, M. Saving energy from urban water demand management. *Water Resour. Res.* **2018**, *54*, 4265–4276. [CrossRef]
183. Wade, R. The management of irrigation systems: How to evoke trust and avoid prisoner’s dilemma. *World Dev.* **1988**, *16*, 489–500. [CrossRef]
184. Ferdon, H.R. Game Theory Analysis of Intra-District Water Transfers; Case Study of the Berrenda Mesa Water District. Master’s Thesis, California State Polytechnic University, San Luis Obispo, CA, USA, 2016.

185. Ert, E.; Cohen-Amin, S.; Dinar, A. The effect of issue linkage on cooperation in bilateral conflicts: An experimental analysis. *J. Behav. Exp. Econ.* **2019**, *79*, 134–142. [[CrossRef](#)]
186. Tayloer, A.C. A Planning Model for a Water Quality Management Agency. *Manag. Sci.* **1973**, *20*, 675–685. [[CrossRef](#)]
187. Pittel, K.; Rübhelke, D.T.G. Transitions in the negotiations on climate change: From prisoner's dilemma to chicken and beyond. *Int. Environ. Agreem. Polit. Law Econ.* **2012**, *12*, 23–39. [[CrossRef](#)]
188. Soroos, M.S. Global Change, environmental security, and the prisoner's dilemma. *J. Peace Res.* **1994**, *31*, 317–332. [[CrossRef](#)]
189. Madani, K. Modeling international climate change negotiations more responsibly: Can highly simplified game theory models provide reliable policy insights? *Ecol. Econ.* **2013**, *90*, 68–76. [[CrossRef](#)]
190. Quinn, N.; Blöschl, G.; Bárdossy, A.; Castellarin, A.; Clark, M.; Cudennec, C.; Koutsoyiannis, D.; Lall, U.; Lichner, L.; Parajka, J.; et al. Invigorating hydrological research through journal publications. *Water Resour. Res.* **2020**, *56*, 257–260. [[CrossRef](#)]
191. Hjorth, P.; Madani, K. Systems Analysis to Promote Frames and Mental Models for Sustainable Water Management. In Proceedings of the 3rd World Sustainability Forum, Basel, Switzerland, 1–30 November 2013; p. f003. [[CrossRef](#)]
192. Ackoff, R.L. Strategies, systems, and organizations: An interview with Russell, L. Ackoff. *Strateg. Leadersh.* **1997**, *25*, 22–27. [[CrossRef](#)]
193. Madani, K.; Khatami, S. Water for energy: Inconsistent assessment standards and inability to judge properly. *Curr. Sustain. Energy Rep.* **2015**, *2*, 10–16. [[CrossRef](#)]
194. Lund, J.R. Integrating social and physical sciences in water management. *Water Resour. Res.* **2015**, *51*, 5905–5918. [[CrossRef](#)]
195. Kurtz, C.F.; Snowden, D.J. The new dynamics of strategy: Sense-making in a complex and complicated world. *IBM Syst. J.* **2003**, *42*, 462–483. [[CrossRef](#)]



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).